

**Technical Guidance Note
(Monitoring)**

M20

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

Environment Agency
Version 4
July 2018

Foreword

This document provides 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 14181¹, Stationary source emissions – quality assurance of automated measuring systems*, and a related standard, *BS EN 13284-2² Stationary source emissions - Determination of low range mass concentration of dust - Part 2: Automated measuring systems*.

For simplicity, this document will refer to *testing laboratories* to cover both commercial testing laboratories and industrial operators in-house monitoring arrangements since EN 14181 uses this term. It will also use the term CEMs (Continuous Emission Monitoring Systems) instead of AMS (Automated Measuring Systems).

M20 provides additional information on:

- The monitoring requirements for large combustion plant and waste incineration.
- Choosing Continuous Emission Monitors (CEMs) that meet the performance requirements of the Industrial Emissions Directive (IED).³
- Demonstration of suitability through MCERTS product certification.
- Determining whether CEMs meet the uncertainty allowances specified by the above EC Directive.
- 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.

There are five sections covering:

- General guidance on quality assurance.
- The suitability, selection and installation of CEMs.
- The calibration and validation of CEMs.
- On-going quality assurance of CEMs.
- Annual surveillance tests for CEMs.

Also included within this document is the associated Method Implementation Document (MID) for EN 14181. For anybody carrying out work under EN 14181 or EN 13284-2, we recommend that you read this information in conjunction with the standards.

The MID supplements EN 14181 and its provisions reflect the clause numbers in this standard, but it does not re-state all the provisions of the standard. It also covers the requirements for EN13284-2 which is an application of EN 14181 for particulate monitoring CEMs. This MID is used as a basis for accreditation to the requirements of EN 14181 under the MCERTS scheme for manual stack emissions monitoring.

Feedback

If you have any comments on this document, please contact our National Customer Contact Centre: enquiries@environment-agency.gov.uk

Record of Amendments

Version number	Date	Section	Amendment
Version 3	June 2015	-	First publication – A major re-write incorporating the previously published M20, EN 14181 MID and Quick Guides 3, 5, 6 and 14. There are also changes to reflect the amendments within EN 14181:2014.
Version 4	July 2018	1.2	Section amended to include organic solvents and titanium dioxide processes.
Version 4	July 2018	2.2.1	Clarification on the evaluation of linearity.
Version 4	July 2018	2.2.2	Clarification regarding the selection of suitable operating ranges to avoid capping of peak-measurement values.
Version 4	July 2018	3.5.2 and 3.5.15	Clarification on the number of measurements required when emissions are low.
Version 4	July 2018	3.5.13 (ii)	Clarification on the reasons for the removal of invalid data pairs.
Version 4	July 2018	3.5.17 and 6.3 (iv)	Removal of the option to omit QAL2s on oxygen and moisture CEMs, if other determinands are passing variability tests.
Version 4	July 2018	3.6	Removal of the need to conduct a QAL2 every 3 years for incineration processes.
Version 4	July 2018	3.9	Section included on calibrating flow measuring instruments.
Version 4	July 2018	References	Reference to BS EN 16911-2 included.
Version 4	July 2018	6.2.1 (viii)b	Alternative linearity range provided for processes that do not have short term ELVs.
Version 4	July 2018	6.5 (i)	Requirement added to understand the reason for CEMs passing the variability test with low R ² values.
Version 4	July 2018	6.6 and 8.5	Clarification of the composition of data sets for variability tests.
Version 4	July 2018	6.7 and 8.5	Note on the uncertainty of CO moved from section 2.3.2 to sections 6.7 and 8.5

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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

1.1 Monitoring requirements in the IED

Monitoring under the Industrial Emissions Directive (IED) 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 M2⁴.

1.2 Scope and structure of EN 14181

EN 14181 applies only to permanently installed CEMs used for compliance monitoring; particularly those at installations falling under Chapters III and IV of the IED for large combustion plant and waste incineration. It may also apply to certain installations producing or using organic solvents and titanium dioxide. It does not apply to portable CEMs, such as those used in SRMs, or CEMs used outside the scope of the IED. The requirements for such CEMs, or SRMs which use 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. The four parts of EN 14181 are:

(i) QAL 1

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 IED and EN 14181, CEMs must meet certain performance requirements evaluated under our Monitoring Certification Scheme (MCERTS)⁵.

(ii) QAL 2

This second level of quality assurance specifies procedures to ensure that the CEM has been correctly installed, calibrated using SRMs and verified.

After the CEMs have been installed you must have the means for carrying out tests for: linearity; zero drift and span drift checks; and provisions for leak-checking the entire sampling system (for extractive CEMs).

In addition, QAL3 records are required to demonstrate that the CEM is stable prior to testing (ordinarily at least three months of QAL3 records).

(iii) QAL 3

QAL3 requires the plant operator to regularly measure the drift and precision of the CEM. The use of CUSUM charts 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.

The QAL3 requirements also apply to peripheral measurements, 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.

(iv) AST

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 5 to 10 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.

1.3 Roles, responsibilities and delegation of responsibilities

1.3.1 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 EN ISO/IEC 17025⁶ 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• Test laboratories must 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.

Organisation	Roles and requirements
	<ul style="list-style-type: none"> • 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 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 • Recognising the competence of those carrying out functional testing

1.3.2 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. Process operators have overall responsibility for complying with EN 14181. 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 must be MCERTS certified for the determinands specified in the IED or applicable permit where continuous monitoring is required.
Certification ranges and measurement ranges	The CEM must 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 the 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	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. 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.

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, the lower the certified range, the better the performance of the CEM is likely to be. 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 $\pm 3 \text{ mg.m}^{-3}$. 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} . Generally, CEMs with lower certified ranges will perform satisfactorily at higher ranges.

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 shall be evaluated either before installation or immediately afterwards. Evaluation shall also take account of the most probable peak-measurement values such that the CEM can capture all peaks whilst maintaining the required uncertainty of the measurement at the ELV.

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 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 they 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. This also applies to installations on site. Incorrect range setting can lead to the capping of peak-measurement values which is unacceptable.

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 IED specifies 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 14956⁷ 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 Chapter III of the IED). 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 IED. This approach is now employed in EN 15267-3⁸.

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 NOx are described in sub-section 2.3.4.

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 IED 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 may still 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 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 IED, 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 IED is defined as *95% of the 48h mean 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.

Note 3: The ELVs may be higher or lower than those in the table, depending on the exact type of process, the requirements of the BAT conclusions for specific sectors, and whether any derogations are in place.

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 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-dryers, delivering the sampled gases to the analyser in cooled, dry form.
- Heated lines and permeation-dryer, delivering the sampled gases to the analyser in a dry form.
- Dilution systems, although these are rarely used in the UK.
- The stack-mounted probe coupled directly to a chiller-dryer or permeation dryer, which passes the cooled/dry sample gas, via an unheated line, to an analyser.
- There may be NO_x converters to convert NO₂ to NO in cases where the operator needs to monitor total NO_x 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, such that it no longer meets the required performance specifications.

Such allowable flexibility 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 or witnessed testing that the alternative components meet the required performance specifications and have been tested on analogous systems. For example: an MCERTS certified permeation dryer may replace an existing permeation dryer, however, a chiller-dryer would not be accepted unless its performance could be proved to be equivalent to the original, either through MCERTS testing or witness test data.
- Additional manifolds and heated valves used to allow more than one analyser to share a sampling system.

To summarise: - 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.

2.3.4 CEMs for NO_x

The IED specifies limits for NO_x as NO₂. However, many 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 installations which have ELVs for NO_x are described in Annex A of this document (section 6.5 of the EN 14181 MID).

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

The requirements of EN 14181 apply. In addition, 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 M1⁹ and the MID for EN 15259¹⁰ in order to determine the most representative location for the CEM, according to the homogeneity test described in EN 15259. It is critical that CEMs are located at a point where there is safe access and other provisions for the effective and continued operation of the CEM, and where a representative sample can be provided.

It is a requirement for a stack to have a homogeneity test before the QAL2 and AST tests, unless it is exempted from this test, i.e. when the sampling plane area is less than 1m² (or when the diameter of circular stacks is less than 1.13m). If the test laboratory is performing single-point sampling on a stack which has not had a homogeneity test, then there is a risk that the QAL2 or AST could provide a false result due to a lack of homogeneity.

The MID for EN 15259 describes a procedure to determine whether the sample will be representative. Test laboratories shall use the MID for EN 15259 when characterising the stack gas conditions and assessing the intended location of the CEM. 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. The requirements described in BS EN 13284-1¹¹ for sampling point locations and provisions for monitoring should also be taken into account, particularly when sampling particulates. Additionally, 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.

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 9001¹² or BS EN ISO 14001¹³. Operators are also recommended to refer to the requirements of BS ISO 10012¹⁴ 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.

3.4 The functional tests

3.4.1 Delegation of responsibilities

EN 14181 specifies within QAL2 and the Annual Surveillance Test (AST) that CEMs must have a set of annual functional tests. The functional tests may be performed by the operator, test laboratory, CEMs supplier, or another third-party. However, they should be recognised as competent by us. We recommend that test laboratories, process operators and CEMs service-providers all include documented provisions for the functional tests and appropriate quality assurance measures within their management systems.

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.

3.4.2 Performing the functional tests

Process operators, CEMs suppliers and test laboratories need to perform safety risk-assessments before starting the functional tests. Any required corrective actions need to be carried out before the 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 reasonably practicable.

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 the IED and the permit.

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. 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.
- That the CEMs have a linear response to increasing values of a determinand. This premise is generally correct for all types of CEMs, with the exception of some types of particulate CEMs. These may ordinarily have a linear response, however, the particulate measured may result in a non-linear response due to variations in particle size and shape. For the calibration of particulate CEMs, refer to EN13284 - 2 and the corresponding MID for EN 13284 - 2.
- The SRM is accurate and precise with an uncertainty no greater than half the maximum permissible uncertainty specified by the regulatory authority for continuous emission monitors.

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 SRM values is less than the maximum permissible uncertainty.

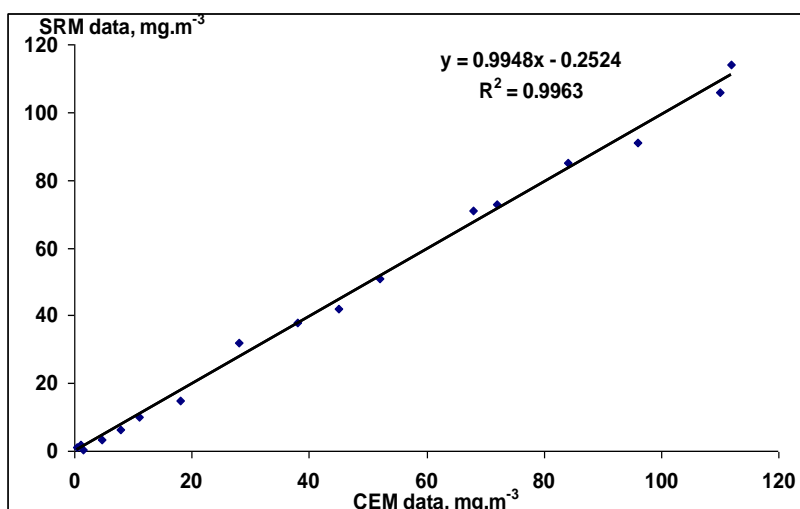
(i) A linear spread of data

Measurements can range from zero, or near zero, up to the ELV, and the difference between the highest and lowest SRM readings will be greater than the maximum permissible uncertainty.

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 ('Procedure a' in EN 14181, section 6.4.3).

Note: When displaying the results graphically the reference material should be plotted on the Y-axis, and the CEM data plotted on the X-axis.

Figure 2 – The principle of linear calibration using a SRM

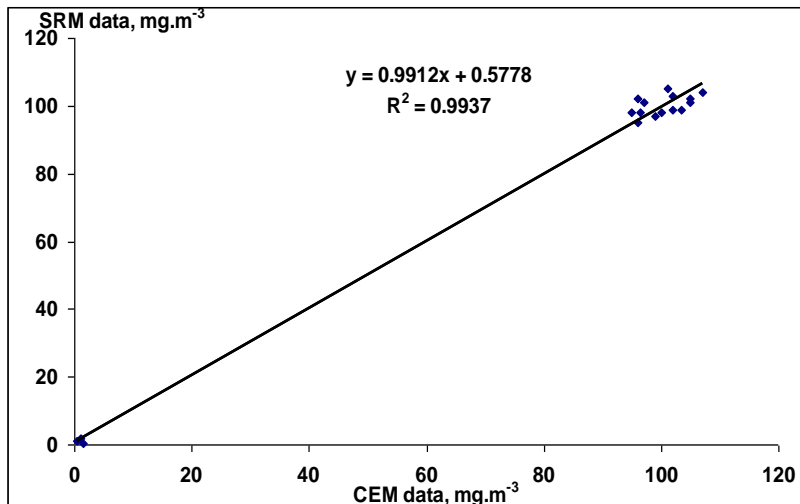


(ii) A high level cluster

Figure 3 shows a high level cluster. If the difference between the highest and lowest standardised SRM reading is smaller than the maximum permissible uncertainty and the lowest standardised SRM reading is greater than, or equal to, 15% of the daily ELV then the test laboratory can determine a calibration function using 'Procedure b', EN 14181, section 6.4.3.

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 reading which should then be included in the calculations.

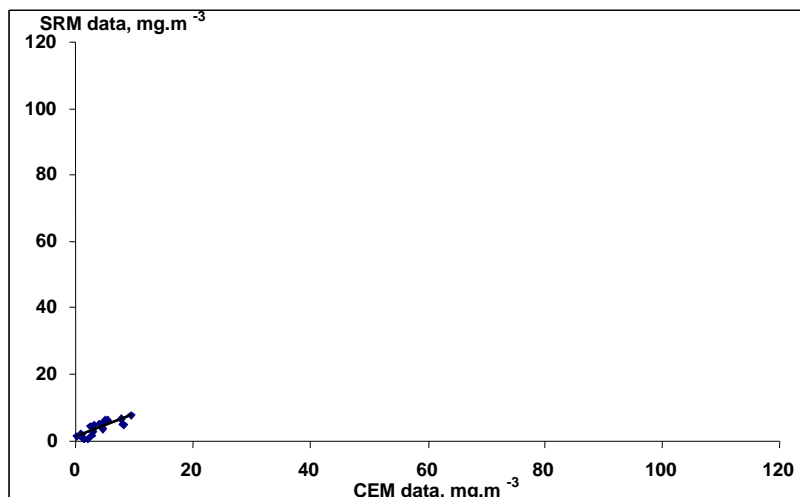
Figure 3 – A high level cluster



(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. Clusters are classed as low level when the difference between the highest and lowest standardised SRM reading is smaller than the maximum permissible uncertainty and the lowest standardised SRM reading is smaller than 15% of the daily ELV. The calibration function should be derived using 'Procedure c' in EN 14181, section 6.4.3.

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.

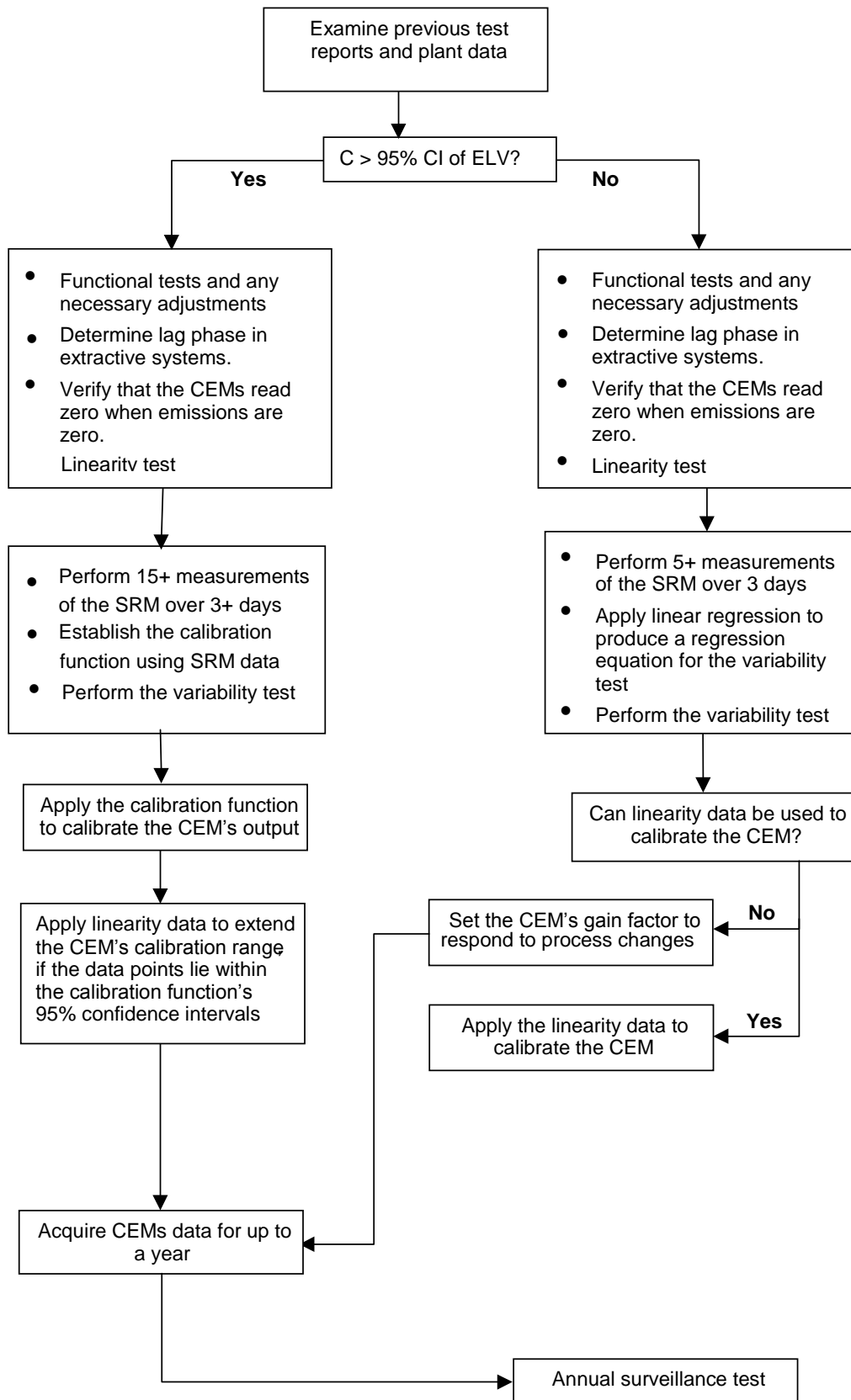
Figure 5 shows the monitoring strategy that can be applied when determining an appropriate approach to monitoring.

If the emissions are typically below the maximum permissible uncertainty, then an AST is permitted instead of a QAL2, however, the test laboratory or operator must first contact the site Regulatory Officer justifying the request for reduced sampling. For low emissions, reduced measurements with longer sampling times may be satisfactory, for example, the AST may consist of 5 measurements each with a sampling duration of 1.5 hours, thus providing a total sampling period of 7.5 hours.

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.

Further guidance on the spread of data is provided in Section 3.5.11.

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 EA Regulatory Officer.

3.5.3 Particulate monitors and low level clusters

In order to derive a reliable calibration function EN 14181 requires the following:

- A good spread of data, or medium to high-level clusters (including some values at or near zero for all cases).
- An acceptable level of accuracy and precision for the SRM or reference materials.
- A regression line which passes through zero, or near to zero (<5% of the daily ELV)

If the correlation co-efficient (R^2) of the regression line for the CEM and SRM data is 0.9 or more, then the calibration function will most likely be valid. However, there are two common conditions where it is not possible to apply the above requirements:

- Low-level clusters of data – This is very common for emissions of PM, especially when the industrial process is equipped with bag filters.
- When the R^2 value is under 0.9. This value is likely to fall when the cluster of emissions approaches zero.

Whenever there are low-level clusters of data, the uncertainty of the SRM will be proportionally greater with respect to the measured emissions. In such cases, there will be a greater degree of relative scatter of data points, which is reflected by a low R^2 value. In such cases, the test laboratory cannot produce a reliable calibration function using SRM data. In the case of particulate monitors, surrogates may be useful for zero, span and linearity tests, but the resultant data cannot be meaningfully related to concentrations of particulate. There are no surrogates available which can accurately mimic a CEM's response to specified concentrations of particulate matter, thus precluding the use of 'Procedure c'. Therefore, there are three options available to set up a particulate monitoring CEM for monitoring emissions if the SRM data are 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 are 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 are no data available to calibrate the CEM by the above methods, then the particulate monitor cannot be used as a quantitative monitor, however, it can serve as a qualitative indicator. Therefore, if the emissions are consistently low we recommend: that the SRM is used to verify that the emissions are low; that surrogates are then used to check the linearity, zero and span settings of the monitor, and lastly the monitor is set on its most sensitive range in order to alert the operator that the control devices for particulate may need attention if an increase in emissions is observed.

3.5.4 Regulation when particulate monitors cannot be calibrated

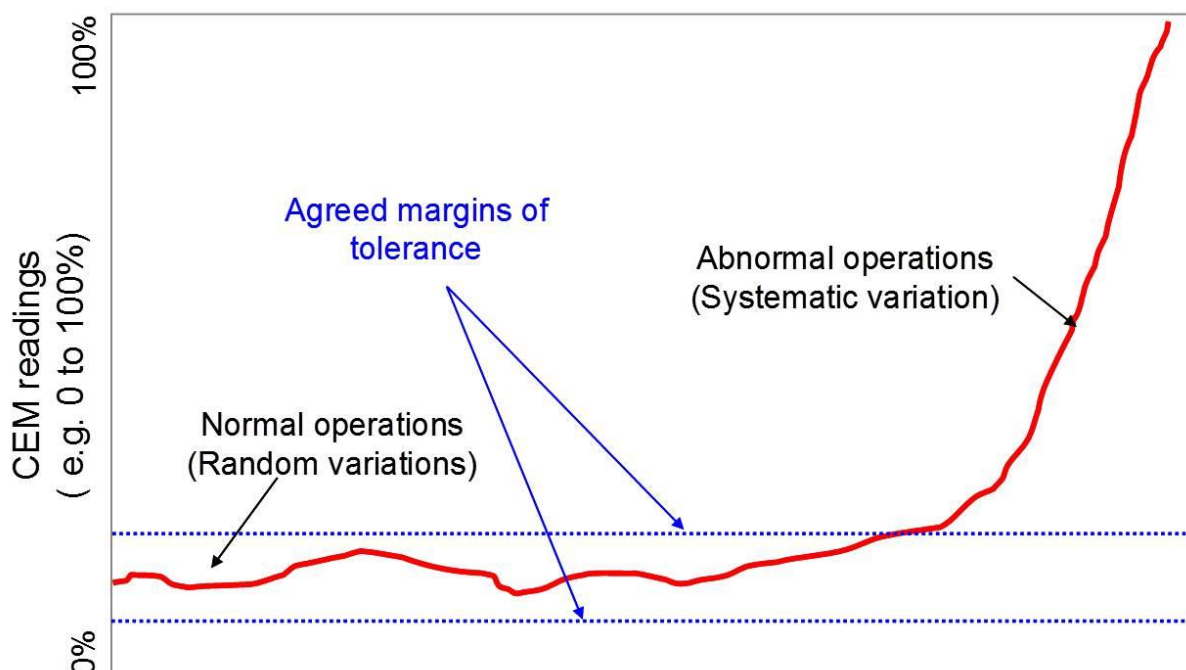
If a test report states that a particulate monitor cannot be calibrated due to very low emissions, then the output of the CEM will be qualitative. Whilst it may be possible to intuitively set the reading of the CEM to provide an output in mg.m^{-3} , such readings will be an approximation at best, with a strong likelihood of high levels of uncertainty. Unless it is possible to produce higher, representative emissions from the process, it is recommended

that such readings should be disregarded for regulatory purposes when compared to an ELV, even if there is an apparent breach of the ELV.

However, the output from the particulate monitor can demonstrate whether the process is under control or not. Such outputs should be regarded as an indicative trend that can demonstrate if there is a significant change in the process, resulting in an increase in emissions that requires immediate attention. Hence an operator must have operational procedures in place to respond appropriately to changes indicated by the monitor. Such a procedure could work by applying the following steps:

- A set of 5 repetitions of a SRM must show that the emissions are controlled and well below the ELV.
- The SRMs also show that the CEM responds, albeit with a high uncertainty, to low levels of particulate and therefore provides an indication of low emissions, if not accurate and precise measurements.
- The operator notes the representative output that the CEM produces when the emissions are low and well controlled. It is recommended that the output is in units other than mg.m^{-3} .
- The operator plots the emissions on a chart, such as the one shown in Figure 6, and includes upper and lower margins of tolerance to allow for random, but acceptable variations in the outputs of the CEM. These upper and low margins of allowable variations are agreed with us.
- If the output from the CEM changes and rises above the upper margin of error, then the operator takes immediate action to investigate the cause of the change in the output of the CEM, and then takes appropriate action to ensure that the readings return to within the margins of tolerance as quickly as practicable.
- When reporting emissions for annual emissions inventories, the operator may apply two approaches: (a) Using an average based on the results of periodic monitoring; (b) Reporting a result which states that the emissions are not more than a result based on the allowable uncertainty of the daily average ELV (or similar medium-term average ELV) expressed as a 95% confidence interval.

Figure 6 – Using control charts for indicative monitoring



3.5.5 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 the 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 either an external third party laboratory, or part of the operator's organisation. The applicable SRMs are defined in TGN M2.

We recommend 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% uncertainty 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.

3.5.6 Rules for CEMs measuring NO_x

When deriving calibration functions for NO_x the rules provided in Annex A of this document (section 6.5 of the EN 14181 MID) shall apply.

3.5.7 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.

3.5.8 Calibration using a SRM

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 IED (ideally, no more than half the uncertainties specified in the IED). 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 miscalibrate a CEM due to deficiencies within the SRM application, rather than any faults or a lack of accuracy and precision within the CEM itself.

3.5.9 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 14793¹⁵ 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 14792¹⁶ include such provisions for quality control and quality assurance.

3.5.10 The acquisition of data

When conducting the parallel measurements, EN 14181 requires the test laboratory to take the measured signals directly from the CEM (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.

3.5.11 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 at 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 IED sets 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, typically 18%, to determine when a process is under normal operation. If the boundary conditions for start-up, shutdown and normal operations are not clearly defined, then consult the site Regulatory Officer or a member of the Environment Agency's Site Based Regulation Monitoring and Assessment Team for guidance.

3.5.12 Averaging periods for SRMs

The averaging period for each SRM measurement should generally be equal to the averaging period of the short-term ELV; this ordinarily means 30 minutes for incineration plants, and 60 minutes for large combustion plants. Test laboratories should consider longer averaging periods if the emissions are low. Test laboratories may use averaging periods of less than 60 minutes for large combustion plants 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.

3.5.13 Number of data points and outliers

(i) Number of repetitions

QAL2 specifies at least 15 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 EN 14181 analysis assumes that the SRM measurement is perfect, the uncertainty in the SRM reading may be higher than the CEM reading 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.

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 be taken at the start and end of the monitoring period. Test laboratories shall state in their Site Specific Protocol the time intervals between the start times of each pair of successive measurements. Furthermore, test laboratories shall demonstrate that the interval between each pair of data provides representative samples, taking into account any process variations.

(ii) Outliers and invalid data

The emphasis is 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.

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.

Rejected, or invalid results, known as outliers, will negate the quality of any calibration or verification work. Therefore, test laboratories need to have a procedure for identifying outliers. However, there are many types of outlier test, all with benefits and disadvantages, and all with a degree of subjectivity. Therefore, it can be beneficial to standardise on the type of outlier test and its application. Based on experience with EN 14181, we have decided to standardise the approach for dealing with outliers and thus recommend the following procedure:

- Produce a plot using raw CEM data, and raw SRM data expressed under the same conditions as the CEMs.
- Plotting the data on a graph often reveals whether there are obvious outliers.
- Calculate the differences, D_i , between each pair of SRM and CEM values.
- Calculate the average of the differences, D_{ave} , and the standard deviation of the differences (s_D) of D_i .
- If D_i for any paired sample is greater or smaller than D_{ave} by more than two times the standard deviation ($2s_D$) then that paired sample is most likely an outlier and can be rejected. This procedure only needs to be carried out for one iteration, i.e. it does not need to be repeated once any outliers have been removed.

When test laboratories use instrumental SRMs to carry out a QAL2 exercise, it is a common practice to allow the SRM to run continuously for up to three days. In such cases, the test laboratory acquires well over the minimum fifteen repetitions, and may have at least two to three times as many pairs of data depending on the time interval between the start of each pair of data. The test laboratories must use all the pairs of data in the calculations for the calibration function and variability test, unless the laboratory can justify excluding any pairs of data. The following examples may justify excluding pairs of data:

- One or more of the pairs are outliers, as determined using the above test.
- Measurements for one or more of the pairs were taken when the monitoring was not representative.

An alternative approach would be to set a longer time interval between each data point; for example, if the averaging time was 30 minutes, separating the start of each data point by 2 hours in a 24 hour period would result in 12 pairs of data points during a QAL2 exercise. However, separating the start of each data point by 3 hours would result in 8 data points over 24 hours. When planning a monitoring exercise, it is important that the test laboratory determines how many data points it intends to take, and document this plan in the Site Specific Protocol.

If the test laboratory assesses a data set and considers that some of the data may be invalid then the test laboratory must note in the report the reasons for removing each data-pair (for example: changing process conditions, an error in the SRM or a failure of the SRM instrument).

3.5.14 Procedure a or b?

EN 14181 defines two situations based on the extent of the spread of readings, 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 Procedures 'a' and 'b' respectively.

In order to determine whether to use Procedure 'a' or 'b', the test laboratory uses the SRM data, and must first convert this data to values at standard conditions.

- Procedure a: This method is a standard linear regression. Even if the spread of data spans more than the maximum permissible uncertainty, at least one value near zero is required 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.
- Procedure b: 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 and include the result in the data set.

3.5.15 Procedure c for low-level clusters

When a low-level cluster occurs 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 method, known as 'Procedure 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 in section 3.5.1 (iii), then either the test laboratory or operator must 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, 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 allowable 95% confidence interval of the daily average ELV.
- Surrogate gases used for calibration, when applying 'Procedure 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 'Procedure c', need not be accredited. Further guidance on gases is given in Sections 3.8.2 and 4.2.1 (for QAL3).

3.5.16 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.

3.5.17 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 IED. 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 the CEMs.

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 usually required 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 found to be erroneous when compared to the reference monitoring and following the variability tests, then the SRM results for moisture shall 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.

3.5.18 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 system 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.

3.5.19 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 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 'Procedure 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 'Procedure b'. The variability test should always be considered as the definitive test.
- Establish the valid calibration range (which ideally should cover the ELV).
- Convert the data to calibrated and standardised values.
- Carry out the variability test.

Note: If the operator and/or we require a QAL2 and variability test for ammonia, and there is no designated ELV, then the test laboratory should 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.

3.5.20 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, or (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, the AST may then 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:

- 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 validity 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.

3.5.21 Cross-calibrating back-up CEMs

Where plants employ a standby CEM that is identical to the duty CEM, and both CEMs measure emissions from the same part of the process, then the calibration function from the duty CEM may be applied to the standby CEM. However, a check shall be made to ensure that the results from both CEMs do not differ by more than half the uncertainty allowance specified by the applicable directive.

Alternatively, 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. Measurements from the verified CEM are then used 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, the calibrated and verified CEM is used *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:

- When the CEM is installed.
- At least every five years, plus or minus 2 months. (Similarly, AST checks shall be carried out every 12 months, plus or minus 2 months).
- If a QAL3 evaluation or AST demonstrates a need for a QAL2.
- After a failure of the CEM that requires significant repairs affecting the calibration.
- After a significant upgrade or other significant change to the CEM affecting calibration
- 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.
- When the CEM exceeds the limits for operating outside the valid calibration range as defined in EN 14181, section 6.5

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.

If a CEM fails the validity 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 and validity acceptance tests, then no further action is needed.

3.7 Performing an AST instead of a QAL2

After the initial QAL2, we may allow ASTs during the following years instead of a full QAL2 if the following conditions have been met: (a) there has been no significant change to plant operation or fuel since the last AST and; (b) if at least 95% of the CEM measured values at standard conditions obtained since the last AST, and the SRM measured values obtained during the AST, are less than the maximum permissible uncertainties shown in Table 3.

Table 3 – Determinands and their allowable uncertainties

Determinand	Uncertainties
NOx	20%
SO ₂	20%
CO	10%
HCl	40%
Particulate	30%
TOC	30%

3.8 Significant changes to operating conditions and fuels

A QAL2 shall be performed within six months of a significant change to plant operation or fuel. An operational change is considered significant if it triggers the need for a permit variation and the change alters the emissions profile such that the calibration function is no longer valid.

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, or 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.

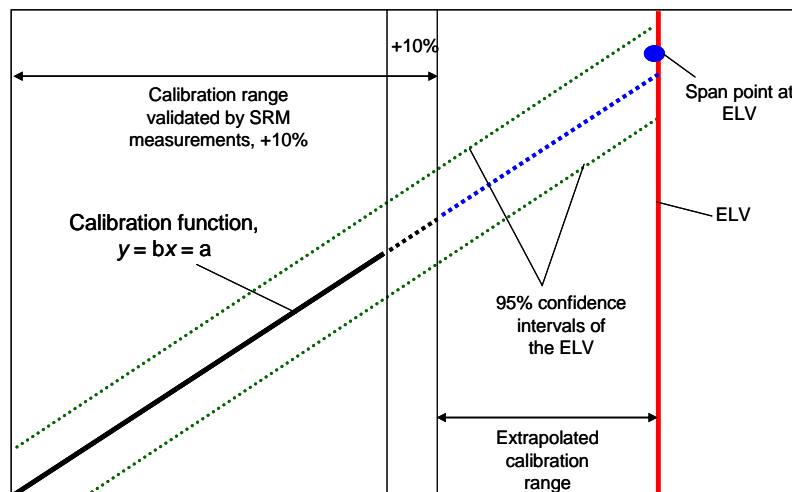
If there are significant changes to plant or fuel, the operator is required to demonstrate that the calibration function is still valid. A risk based approach can be adopted. If the operator is confident that the calibration function has not changed, then an AST can be performed to provide the evidence. If the AST shows that the calibration function is still valid, through a pass of the variability and validity acceptance tests, then a new QAL2 is not required. If it is known or strongly suspected that a change in calibration function has occurred due to changes in plant or fuel then the operator may choose to go straight to performing the QAL2.

3.8.1 Extending the calibration range

Extrapolation of the VCR (valid calibration range) to the daily ELV is explained in Annex A of this document (section 6.5 of the EN 14181 MID). However, there may be cases where a process operator would need to perform a QAL2 several times due to the unpredictable nature of emissions, in order to meet the requirements for a sufficient spread for a valid calibration range. If the operator can demonstrate the unpredictable nature of emissions, and if surrogates can be used to extend the valid calibration range to a degree of accuracy which is acceptable, then the VCR may be extended with our consent. In special situations such as these, the VCR may be extrapolated up to twice the daily ELV for gases and three times the ELV for particulates, provided that the highest reading with a surrogate does not differ from the extrapolated calibration function by more than half the 95% confidence interval of the ELV.

Note: The above arrangement currently applies to coal-fired power stations only.

Figure 7 – Extrapolating the valid calibration range, when process peaks are predictable



It is good practice for the test laboratory to check the level of agreement between the SRM and the CEM 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.

3.8.2 Requirements for test gases

Test laboratories must use traceable gas standards for QAL2 and AST testing; functional checks may be conducted using the operator's site gases. Traceable gas standards are prepared under EN ISO/IEC 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 EN ISO/IEC 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 EN ISO/IEC 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 nitrous oxide. EN ISO/IEC 17025 AGS does not have a specified stability period; 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, having been cross-compared with the AGS beforehand. EN ISO/IEC 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 with 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. EN ISO/IEC 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 EN ISO/IEC 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 4 – Requirements for test gases

Activity	Gas requirement	Subject to
QAL1 certification		EN 15267-3
Bench testing	AGS	EN ISO/IEC 17025
Field trial	AGS	EN ISO/IEC 17025
QAL2/AST (on-site validation)		EN 14181
Initial CEM set-up on site	WGMS ¹	ISO 6142 ² and EN ISO/IEC 17025
Functional checks	WGMS	ISO 6142 ² and EN ISO/IEC 17025
Linearity test for 'Procedure c'	AGS	EN ISO/IEC 17025
Site-gas quality check	AGS	EN ISO/IEC 17025
Test laboratory instruments	AGS	EN ISO/IEC 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 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 and written by JEP (Joint Environmental Programme).

3.8.3 Requirements for 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 the EN 14181 MID.

3.9 Calibrating flow measurement instruments

The methods used for the calibration of flow measurement instruments are based on BS EN 14181. The standard, BS EN 16911-2, *Stationary source emissions – Manual and automatic determination of velocity and volume flow rate in ducts, Part 2: Automated measuring systems*, follows the principles of BS EN 14181 closely. However, there are some minor differences to note. In EN ISO 16911-2 surrogate values are suggested for the ELV and the uncertainty limit specified as a 95% confidence interval. The method of calculating the maximum allowable standard deviation (Max sd) for the variability test also differs from BS EN 14181.

4 Ongoing quality assurance during operations (QAL3)

4.1 QAL3 – general

4.1.1 Principle

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.

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. Multiples of s_{AMS} are then used to set warning levels and alarm levels.

When calculating s_{AMS} , the method described in the examples in EN 14181 for determining s_{AMS} can be used. 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 incineration 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 differs from those used for CUSUM and Shewhart charts (see section 4.2.10).

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 they 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 for 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 short-term 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 effective auditing of the data.

4.2.3 Frequency of checks

If operators are using CUSUM charts, 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 1: 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.

Note 2: If the QAL3 results are approaching the action limits at the time of a CEMs service-visit, and there is a clear trend of drift, then the CEMs-supplier conducting the service visit may be requested to adjust the CEMs during the visit, rather than arrange for a separate visit soon afterwards.

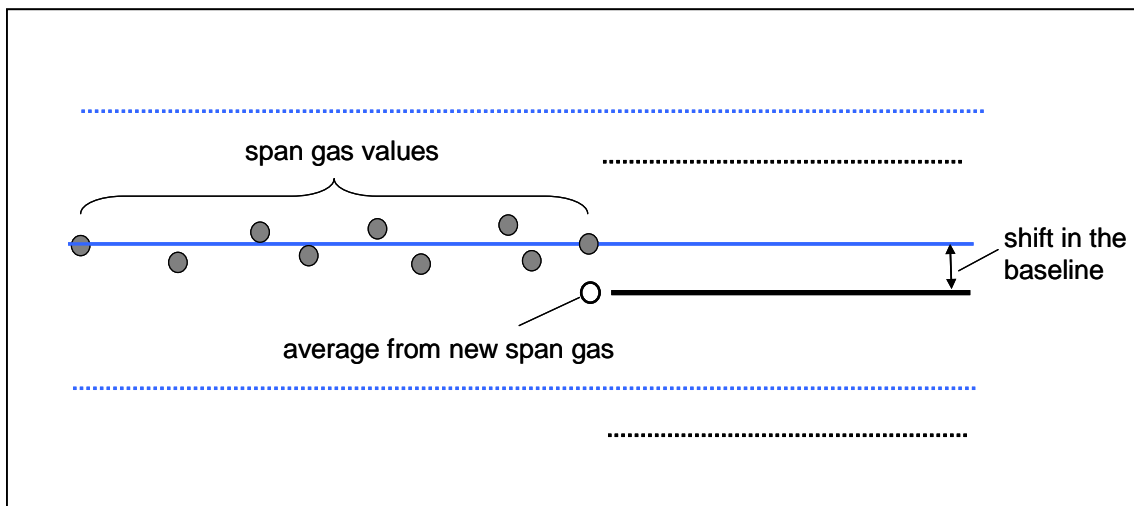
4.2.5 Replacing gas bottles or other surrogates

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 8).

Figure 8 – Shift in the baseline following a change of span-gas bottles



4.2.6 QAL3 checks and the IED

The IED 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 waste incineration plants during zero and span checks, providing that the operators still comply with the above and the requirements of the IED, as laid down in the permit.

4.2.7 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 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.

Annex C of EN 14181 provides examples of the 3 types of chart described below.

4.2.8 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, as shown in EN 14181, Annex C, section C.1.

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

When setting up the chart, n is the number of consecutive repetitions of the test carried out and 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.

4.2.9 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 (EN 14181 Annex C, section C.3.1) 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 are shown

by an abrupt change in curve shape. A gradual drift produces slight but continuous changes in the mean.

4.2.10 Exponentially Weighted Moving Average Charts (EWMA)

Exponentially Weighted Moving Average (EWMA) charts are an alternative to either Shewhart or CUSUM charts. An example is given in EN 14181, Annex C, section C.2.

In the EWMA chart, the control limit 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 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 $s_0 = s_{AMS}$, let $\lambda = 0,35$ and $K = 2,9445$, which produces an ARL of 11,7 (12) and a maximum ARL of 29.

It should be noted that only one upper control-limit and one lower control-limit are required.

4.3 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 are the same as for QAL2 (see section 3.4).

5.3 Parallel measurements with a SRM

When using instrumental methods for SRMs, the SRM monitoring-system may be operated continuously during the AST tests. Zero and span checks on monitoring systems used within SRMs shall be taken at the start and end of the monitoring period. Test laboratories shall state in their Site Specific Protocol the time intervals between the start times of each successive 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, except when applying TGN M22¹⁷ for FTIR. 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.

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 – Part 2: Automated measuring systems.
3. BS EN 16911-2. Stationary source emissions – Manual and automatic determination of velocity and volume flow rate in ducts. Part 2: Automated measuring systems.
4. Directive 2010/75/EU on Industrial Emissions
5. TGN M2. Monitoring of stack emissions to air. Environment Agency.
6. Performance Standards for Continuous Emission Monitoring Systems – The Environment Agency’s Monitoring Certification Scheme (MCERTS), www.mcerts.net
7. ISO/IEC 17025. General requirements for the competence of testing and calibration laboratories.
8. BS EN ISO 14956. Air quality — Evaluation of the suitability of a measurement procedure by comparison with a required measurement uncertainty.
9. 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.
10. TGN M1. Sampling requirements for monitoring stack emissions to air from industrial installations. Environment Agency.
11. 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
12. BS EN 13284-1. Stationary source emissions — Determination of low range mass concentration of dust — Part 1: Manual gravimetric method
13. BS EN ISO 9001. Quality management systems – Specification with guidance for use.
14. BS EN ISO 14001. Environmental management systems – Specification with guidance for use.
15. BS ISO 10012. Measurement management systems — Requirements for measurement processes and measuring equipment.
16. BS EN 14793. Demonstration of equivalence of an alternative method with a reference method.
17. BS EN 14792. Determination of mass concentration of NO_x: Reference method: chemiluminescence.
18. TGN M22. Measuring stack gas emissions using FTIR instruments. Environment Agency.

Annex A: Method Implementation Document (MID 14181)

(Normative)

EN 14181: Stationary source emissions
Quality assurance of automated measuring systems

1. Scope

EN 14181 shall be used on all installations where the permit specifies the application of EN 14181:

2. Normative references

- MCERTS – Manual stack-emission monitoring performance standard for organisations. Environment Agency.
- MCERTS – Personnel competency standard for manual stack-emission monitoring. Environment Agency.
- MCERTS performance standards for continuous emission monitoring systems
- Method Implementation Document for EN 15259
- Technical Guidance Note M1: Sampling requirements for monitoring stack emissions to air from industrial installations. Environment Agency.
- Technical Guidance Note M2: Monitoring of stack emissions to air. Environment Agency.
- Technical Guidance Note M20: Quality assurance of continuous emission monitoring systems. Environment Agency.

The latest versions of the above documents are available from www.mcerts.net. Test laboratories shall refer to the latest versions of the above documents.

3. Terms and definitions

3.1 Competent authority

In England the *competent authority* is the Environment Agency.

3.2 Emission limit value

The emission limit value (ELV) cited in EN 14181 is normally the daily average ELV. However, for some existing large combustion plants it is the 48-hour average. The ELV used for the statistical tests under QAL2 and the AST shall therefore be the daily average ELV, or the nearest equivalent ELV.

4. Symbols and abbreviations

No additional requirements to EN 14181.

5. Principle

This MID describes the procedures that test laboratories must follow when applying EN 14181, and to meet the requirements of the UKAS accreditation-scheme for EN 14181.

5.1 General

A *test laboratory* is a company or organisation that carries out the QAL2 and AST requirements as defined within EN 14181. It can be a commercial test laboratory or an industrial operator's in-house monitoring team. Test laboratories shall be accredited to EN ISO/IEC 17025 for the MCERTS performance standards for manual stack emission monitoring for the applicable SRMs, and EN 14181.

They shall have provisions for ensuring the minimum requirements for personal competency, which should be fully demonstrated and recorded.

EN 14181 requires operators to have a procedure for QAL3. We recommend that the test laboratory does not perform a QAL2 exercise unless an effective QAL3 procedure is in place at the regulated installations. For example, as a guideline, there should ideally be at least three months of QAL3 data demonstrating that the readings from the CEM are both stable and comply with the specifications for drift, as required for the QAL1 tests. If there is not an interval of at least three months, the test laboratory shall state the reasons for this in the test report.

Note: Whilst three months is considered to be the ideal minimum interval between commissioning and a QAL2, it is recognised that this is not always practical or possible.

5.2 Limitations

When conducting parallel measurements, the measured signals are either taken directly from the CEM, or from the installation's data acquisition and handling system (DAHS) (e.g. expressed as analogue or digital signal), provided that raw data are collected during the QAL2 and AST. If the data are taken from the operator's DAHS, then the test laboratory needs to ensure (as far as practicable) that the data from the DAHS is representative of the data taken from the CEM.

The QAL2 or AST tests shall state the scope of application of the tests, including the type of process.

5.3 Measurement site and installation

The test laboratory shall assess whether the following provisions are available and then report their findings in Section 2.3.2 of the report, for which there is a *pro-forma* in Appendix 2, noting any non-compliances. EN 14181 requires provisions for the effective management and maintenance of the CEM, in order to ensure the maintenance of the quality of data. Such provisions include at least the following:

- A safe and clean working environment with sufficient space and weather protections.
- Easy and safe access to the CEM.
- Adequate supplies of reference materials, tools and spare parts.
- Facilities to introduce the reference materials for gaseous-monitoring systems, both at the inlet of the sampling line (where present), and at the inlet of the CEM.
- Compliance with the requirements of TGN M1.
- The test laboratory shall state whether the site has had a homogeneity assessment to EN 15259, when and where this is reported. Test laboratories performing the homogeneity assessments shall comply with the requirements of the MID for EN 15259.

If the monitoring location has not had a homogeneity test to EN 15259, then it is strongly recommended that the test laboratory performs grid sampling until the homogeneity test has been completed.

If it is not possible to perform a homogeneity test, for example, due to reasons of health and safety, then the test laboratory shall note the reasons in the test report.

5.4 Testing laboratories performing SRM measurements

The same requirements as 5.1 above.

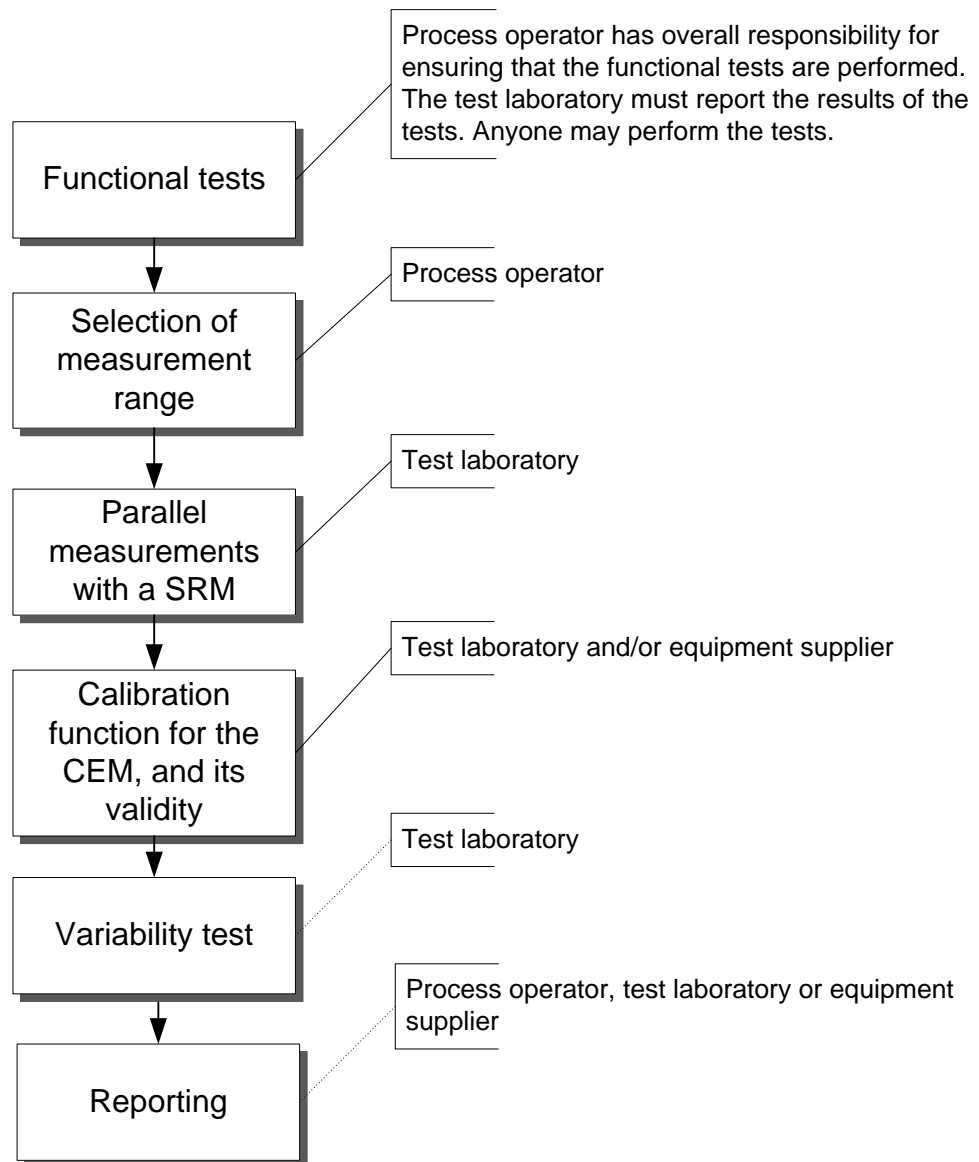
6. Calibration and validation of the CEM (QAL2)

6.1 General

Figure 1 shows the responsibilities of the various parties participating in the QAL2 and AST procedures. Overall control of the work can be the responsibility of the process operator, the test laboratory, or an independent third-party organisation (refer to TGN M20). The report-approver and staff working on QAL2 and AST exercises shall have the required training, competencies and experience. Only specifically authorised staff may approve QAL2 and AST reports.

The initial calibration function resulting from the first QAL2 test shall be entered. Thereafter, in individual cases, the continued use of the previous calibration function may be allowed if it can be proven by use of a specified statistical procedure that the new calibration function does not significantly differ from the previous one.

Figure 1 - Flow diagram showing responsibility for calibration and variability tests



6.2 Functional tests

The test laboratory shall inform the process operator in advance of the QAL2 or AST that the functional tests are a mandatory requirement within EN 14181, and that the functional tests must be performed before the parallel reference tests specified within the QAL2 and AST requirements of EN 14181. Additionally, the test laboratory needs to inform the process operator of the risks associated with not performing the functional tests which include regulatory enforcement action or possible failure of the QAL2 and AST.

The functional tests should be performed no more than one calendar month before the parallel reference measurements with SRMs. If the functional tests are performed earlier than this, then the test laboratory shall inform the operator that they should provide verifiable evidence to demonstrate that the results of the functional tests are still valid. This evidence should include at least performance tests, i.e. QAL 3 data, to demonstrate that the performance of the CEM has not changed between the functional tests and the parallel reference measurements. Such tests would include at least zero and span data for the entire

sampling system and analyser. The test laboratory must document this evidence on the QAL2 or AST report, as applicable.

If the functional tests are not performed, then the test laboratory shall include the reasons for this in the QAL2 or AST report.

Note 1: Even though a test laboratory has informed the operator that it is the operator's obligations under EN 14181, there may be cases where the above conditions are not met and are beyond the control of the test laboratory.

The test laboratory must report the results of the functional tests, in section five of the EN 14181 report, including all the information detailed in the report template. A *pro forma* form for this is provided in Appendix 1 of this MID.

Whilst anyone may perform the functional tests they must be recognised as competent by us. 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. Such training could be provided by the manufacturer or supplier of the CEMs.

Functional tests are required for oxygen-monitoring CEMs, and for moisture-monitoring CEMs if these are present. The criteria for the tests shall be based upon the requirements of the MCERTS performance standards.

Note 2: Performing the linearity and span test for moisture requires a moisture generator, which can create practical difficulties on site. Whilst we recommend that this test is performed and operators can require their suppliers to perform this test, both operators and test laboratories may apply a risk-based approach if they do not wish to perform the test. However, if the CEM fails the QAL2 variability test due to a failure of the moisture monitoring, then the linearity test for moisture will be required.

Note 3: Moisture-monitoring CEMs means those CEMs which typically measure one or more gaseous stack-gases on a hot and wet basis.

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.

6.2.1 Specific requirements for functional tests

Annex A of EN 14181 specifies the individual parts of the functional test to be performed during the QAL2 and AST for extractive and non-extractive CEMs. In addition, the specific requirements shown below shall also apply.

(i) General

The lead organisation for reporting the results of the functional tests shall be the MCERTS accredited test laboratory. This applies whether the test laboratory is performing the tests or not. The organisation conducting linearity tests must have access to approved surrogate reference materials for any particulate analysers.

All parts used for repairs must be covered by the instrument's QAL1 certificate, i.e. the parts must meet the same performance specifications as those used within the CEM during its QAL1 testing and approval.

(ii) Alignment and cleanliness

No additional requirements to EN 14181.

(iii) Sampling system

If the CEM is equipped with a NO_x converter, then the efficiency of the converter must be tested at intervals specified by the supplier of the converter.

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%. The test for converter efficiency should meet the requirements of EN 14792. It may be performed by any organisation with demonstrable competence. Our preference is that those performing the test should apply gas-phase titration.

(iv) Documentation and records

The operator is required to either have, or have access to, the documentation specified in Annex A, section A.4 of EN 14181. The organisation conducting the functional test shall assess whether the documentation is controlled, readily accessible and up to date. A complete audit is not required, but simply a compliance check to ensure that the documentation is in place.

(v) Serviceability

A list of recommended reference material(s), tools and spare parts must be supplied by the CEM manufacturer / supplier and cross-checked with availability on site or by supply agreement.

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

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

(vi) Leak test

No additional requirements to EN 14181. Note that the response time and leak test could be covered at the same time by injecting one gas (SO₂ or CO₂) directly into the probe.

(vii) Zero and span check

Refer to original QAL1 tests regarding ranges of reference materials. Data to be supplied by the manufacturer / supplier.

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

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

(viii) Linearity

No additional requirements. The data for zero readings are treated in the same way as other data points.

a. Procedure

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.

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. 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. If a suitable short-term ELV is not available then 2 x daily ELV may be used as an alternative.

c. Test gases

Test gases shall be traceable, where possible, to EN ISO/IEC 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.

d. Meaning of 'upper limit of linearity test range'

The linearity test concludes with the calculation of the residuals of the average concentrations, and a test of those residuals. Initially expressed in concentration units, the residuals shall be converted to relative units by dividing by the upper limit (Cu) of the range used during the linearity test. As the linearity is tested using concentrations of approximately 20%, 40% etc of the short-term ELV, then Cu shall be taken to mean the concentration at 100% of that range.

(ix) Interference

MCERTS certification of CEMs will show which interferents can have a measurable effect on the CEMs response to stack gases other than the target determinand. Therefore, if there is a failure of the QAL2 or AST tests, then the test laboratory shall refer to the MCERTS testing data, and determine whether any significant interferents are likely to be present in the stack which could result in a failure of the QAL2. If so, then the test laboratory shall determine the extent to which such interferents may introduce a bias into the measurements from the CEM.

Note 1: Test data on potential interferences should be available from the CEM manufacturer or supplier.

Note 2: In reality, the interference test will be very rarely required. We know of very few examples of this test being required.

(x) Zero and span drift (audit)

No additional requirements to EN 14181. 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.

(xi) Response time

The response time is specified in the MCERTS performance standards for CEMs.

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. 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.

(xii) Report

The functional test shall be supplied, assessed and validated prior 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.

6.3 Parallel measurements with an SRM

(i) Execution of the SRM tests

Only suitably qualified testing laboratories may perform the SRMs required for QAL2 and ASTs (see section 5.1). It must be noted that 15 tests is the minimum number specified in EN 14181, and that it is advisable to carry out a greater number in case any tests are deemed invalid. The tests should be performed over the time periods specified in EN 14181; for example, EN 14181 requires the QAL2 to take place over three full working days. If these days are consecutive, then this implies that five days would be needed for the QAL2 exercise; this includes a day for setting up the monitoring equipment, and a day for packing it away after the three days of monitoring (Figure 2).

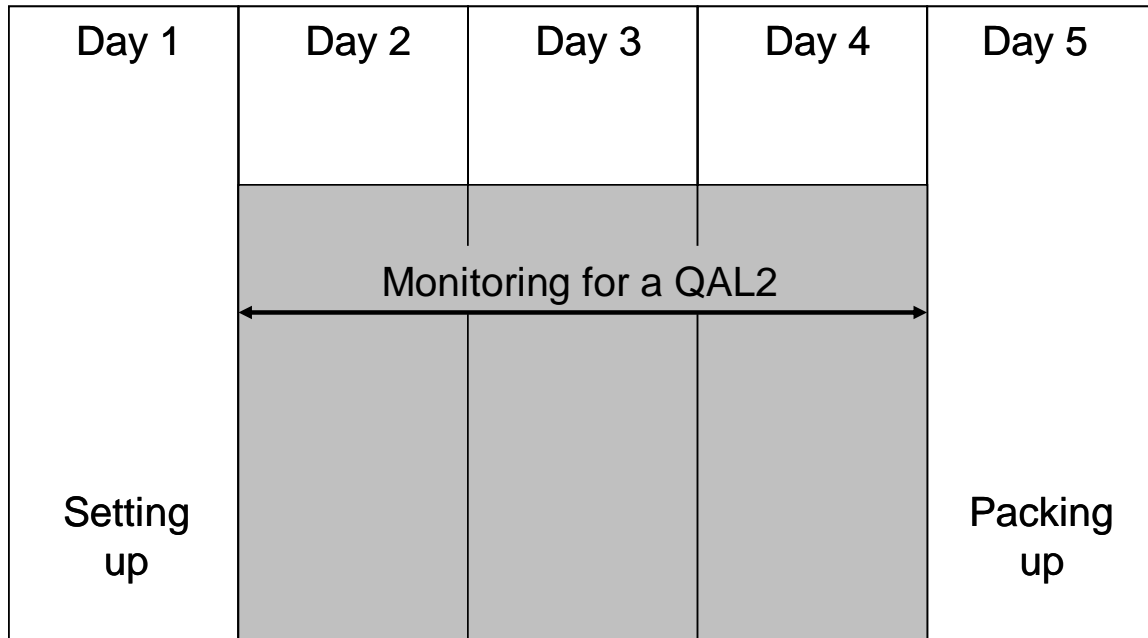
If the test laboratory performs the parallel reference tests over a total shorter duration, then the test laboratory shall provide evidence to show that measurements over a shorter, total duration are representative of the process. Additionally, the length of the sampling day should not compromise safety. Therefore, the length of the sampling day should balance the requirements for representative data against the requirements for safety.

Note 1: For example, if the process is stable, then shorter time-periods could be suitable. Alternatively, historical data, supported by statistical analyses, could be used to show that shorter time-periods are also representative

In terms of sampling strategy, the test laboratory shall meet the requirements of MID 15259, particularly with regard to ensuring that samples are spatially and temporally representative.

Note 2: This includes using the results of a homogeneity test to decide the sampling strategy for sampling gases.

Figure 2 – An example of a QAL2 programme, spread over five working days.



Ideally operators should select a time when the emissions are likely to be at the 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 be taken at the start and the end of the monitoring period. Test laboratories shall state in their Site Specific Protocol the time intervals between the start times of successive pairs 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 3: 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, it is essential to ensure that the measurements are still representative.

Monitoring systems used within SRMs must meet the performance standard of the relevant EN standard. Instruments, other than those classed as portable instruments, that are certified under MCERTS will meet these requirements. Certified systems must be certified to the appropriate determinands and ranges.

Note 4: There is an MCERTS scheme for portable analysers and one for transportable analysers / CEMs. The portables scheme is applicable to handheld, battery powered analysers that are used mainly for process control. Analysers that are used for calibration of CEMs under EN 14181 have been certified on the transportable analysers / CEMs scheme; this scheme has more challenging performance requirements than the portables scheme.

Note 5: TGN M20 provides further guidance on using instrumental methods and on the number of samples.

Note 6: It is recommended that the three days for the QAL2 SRM tests should be spaced apart, so that the data may be analysed after each day. This is especially the case for particulates.

(ii) 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 incineration plants, and 60 minutes for large combustion plants. Test laboratories should consider longer averaging periods if the emissions are low. Test laboratories may use averaging periods of less than 60 minutes for large combustion plants if the test laboratory can demonstrate no significant difference between 30 minute and 60 minute averaging periods. However, the averaging period must never fall below 30 minutes.

(iii) Outliers

Test laboratories must always consider whether outliers are present. The procedure described in M20 section 3.5.13 shall be used for this purpose. The use of alternative procedures must be justified and agreed in writing with us. Once the test laboratory has eliminated any outliers, then all the remaining data pairs shall be used. The test report shall give a clear indication of any data pairs removed by the outlier procedure.

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 to, 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.

(iv) Peripheral CEM instruments

a. Oxygen

- If the CEM fails the variability tests using the operator's oxygen measurements, then the SRM oxygen measurements may be used instead. If the CEM then passes the variability test the operator shall remedy the oxygen equipment or methods of determination, and verify its performance using SRM data and the QAL2 procedure. If a QAL2 procedure is required then default values of 10% for the 95% CI, and 21% oxygen concentration (v/v) for the ELV shall be used.
- If reference monitoring is performed for oxygen, at least 15 measurements shall be taken over the same measuring periods, as for the other determinands. It must be noted that 15 tests are a minimum and that it is advised to carry out a greater number in case any tests are deemed invalid.

b. Moisture

- If the CEM fails the variability tests using the operator's moisture measurements, then the SRM moisture measurements may be used instead. If the CEM then passes the variability test the operator shall remedy the moisture equipment or methods of determination, and verify its performance using SRM data and the QAL2 procedure. If a QAL2 procedure is required then default values of 30% for the 95% CI, and 30% moisture concentration (v/v) for the ELV shall be used.
- If reference monitoring is performed for moisture, at least 15 measurements should be taken over the same measuring periods as for the other determinands. It must be noted

that 15 tests are a minimum and that it is advised to carry out a greater number in case any tests are deemed invalid.

- EN 14181 allows the operator to use default values for moisture in certain circumstances. For example, in the case of wet abatement techniques with nearly constant water vapour concentration, the moisture concentration may be calculated using other operational data. However, the moisture values must still be validated.

(v) Sample lines and delays

When CEMs and SRMs use a combination of different techniques, different lengths of sampling system and different flow rates, then there will be a difference between the readings of the SRM and CEM at any given time due to the different lag times. Therefore, the test laboratory shall have a procedure to determine the lag times, and for matching the data from the CEMs and SRMs accordingly. For further details see M20, section 3.5.18

(vi) Spread of data over the calibration range

- At least one of the 15 selected data points must be at or near zero. If this condition is not fulfilled, then extra measurements are necessary to attain measurement data at or near zero, i.e. use of functional-test data. EN 14181 states that the test laboratory shall verify that the CEMs read zero when the emissions are zero.
- Near zero is defined as a value 5% or less of the daily average ELV.
- Ideally, zero values should be measured when the installation is not producing emissions. If this is not possible, then reference materials shall be used to determine the CEM's response to zero values of the determinand.
- When performing the calculations to determine whether to use Procedure 'a' or 'b', the test laboratory must not use a surrogate zero-value in these calculations, as this would automatically result in selecting 'Procedure a' every time.

(vii) Low level clusters

A low level cluster of data values is defined as a spread of data where the difference between the maximum and minimum standardised SRM readings is less than the maximum permissible uncertainty and the minimum standardised SRM reading is less than 15% the daily average ELV. Under such circumstances it is likely that the resultant SRM and CEM data does not provide a good line of best fit. For example, an R^2 value of less than 0.9 for gases indicates a poor fit. In such cases, a calibration function may be unreliable. Therefore, the test laboratory may use the SRM data to confirm that the CEM is responding to low emissions, and that the process is compliant with the ELV. Linearity data may be included when deriving the calibration function. However, test gases used for calibration purposes must be accredited as detailed in section 3.8.2 of M20.

Note 8: As a guideline, when there are low level clusters, the difference between the average of the CEM and SRM data should not be more than the 95% confidence interval of the daily average ELV.

Note 9: Test gases used solely for obtaining linearity data do not have to be accredited. If linearity data is to be used for calibration purposes (i.e. 'Procedure c') then test gases that are accredited shall be used.

Note 10: TGN M20 provides further guidance on dealing with low-level clusters of data.

(viii) CEM repairs or replacement and when a QAL2 test is required

If all or part of the CEM is repaired, or an identical type of CEM is substituted for the CEM which was initially installed and calibrated, then the calibration function determined during the most recent QAL2 shall continue to be used. QAL3 data shall be collected and inspected in the defined manner to determine whether or not a new QAL2 is needed.

(ix) Low levels of determinands when oxygen levels are high

High oxygen concentrations can result in apparent breaches of the ELV, as well as apparent failures of the QAL2 and AST exercises. For example, in a batch process, the oxygen concentrations can reach high levels at the end of a process. This problem is known to us and can occur even at very low concentrations, typically when the actual emissions have fallen significantly. In such cases, it is likely that the high-oxygen concentrations are representative of start-up or shut-down modes of operation, rather than normal operations. The ELVs in permits will apply to normal operations and exclude start-up and shut-down, unless otherwise stated.

Therefore, if test laboratories encounter this situation, then the following actions are recommended:

- Determine whether results with higher than normal oxygen concentrations can be disregarded as outliers. As a rule, an oxygen concentrations above 18% can be considered as abnormal.
- If the oxygen concentrations are high throughout the QAL2 or AST, then determine whether these concentrations are normal.
- If the calculations result in QAL2 or AST failures, then note this in the report together with a caveat explaining the reasons, i.e. higher than normal oxygen concentrations.
- Ask us for guidance on a case-by-case basis.

6.4 Data evaluation

The test laboratory shall take part in our Proficiency Testing Scheme for EN 14181, and maintain the level of proficiency required to meet the requirements of the scheme. Spreadsheets used for calculations in QAL2 and AST exercises shall be controlled documents within the test laboratory's quality system.

Refer to EN 14181 for examples of QAL2 tests for gaseous CEMs.

Refer to EN 13284-2 for examples of QAL2 tests for particulate CEMs.

6.4.1 Preparation of data

Ordinarily test laboratories shall prepare the data according to the requirements of EN 14181, and determine a calibration function using data at the conditions experienced by the CEM. Refer to EN 14181 for an example of a calculation.

6.4.2 Establishing the calibration function

The scale of the CEMs measurement range shall be scaled according to the ELV (e.g. 2x the short-term ELV in order to capture the expected peaks in emissions) and not the range measured during the QAL2. For example, if the ELV is 60 mg.m^{-3} for HCl and the range

measured during the QAL2 was varied from zero to 20 mg.m⁻³ expressed as a half-hourly average, then the CEM should ideally be set to measure of range of zero to 120 mg.m⁻³. Refer to EN 14181 for an example of a calculation.

6.5 The calibration function of the CEM and its validity

Refer to EN 14181 for an example calculation.

(i) Cases where the emissions are sufficiently high to apply Procedure 'a' or 'b'

In general, if the data is sufficiently linear to derive a valid calibration function, then:

- Based on the calibrated CEM data, the calibration range for gases may ordinarily be extended by 10%, or to 20% of the ELV whichever is greater; and 100% for particulates (if the particulate CEM is demonstrably linear).
- The calibration range may be extrapolated further for gases using reference materials. The calibration function is extrapolated to the daily ELV. This extrapolation is valid if the difference between a reading from a reference point (e.g. a span gas) at the ELV, and the extrapolated calibration line at the ELV, is not more than the uncertainty specified by the authorities. In special cases where extrapolation is required beyond the ELV, refer to section 3.8.1 of M20.

Note 1: A valid calibration should ideally have a correlation co-efficient of the regression line (R^2 value) of at least 0.9. However, it can be lower than this and still pass the variability test. It is not uncommon for results containing clusters of particulate data to produce an R^2 value of 0.5 and still pass the variability test. If the CEM does pass the variability test, but exhibits a low R^2 value then it is advisable to investigate the reason for this.

(ii) Cases where the emissions are not sufficiently high enough to derive a calibration function using SRM data

If the scatter of data points means that it is not possible to derive a valid calibration function, i.e. the difference in the maximum and minimum standardised SRM readings is less than the maximum permissible uncertainty and the minimum standardised SRM reading is less than 15% of the daily average ELV, then:

- The CEM may be calibrated using additional reference materials.
- The SRM data is used to verify that the emissions are well within the ELV and that the CEM is responding with an acceptable degree of accuracy and precision to low levels of emissions.

Note 2: The readings are acceptable if the average of the CEM and SRM results do not differ by more than the 95% confidence interval of the daily average ELV.

Note 3: Refer to TGN M20 for further guidance on dealing with low levels of emissions; this is described as 'Procedure c'.

Note 4: When using 'Procedure c', the valid calibration range is based on the highest CEM calibrated value obtained from the stack gases; not the surrogate gas at the ELV concentration.

(iii) Calibration functions for oxides of nitrogen (NO_x)

The three ways in which installations measure NO_x are:

- Measuring NO alone and then applying a conversion factor to account for NO₂ in the stack gases, i.e. inferring the NO₂ concentrations.
- Measuring NO and NO₂ separately and combining the measurements.
- Using a NOx converter to provide a single combined amount of NOx.

This can create challenges when performing a QAL2 or AST, especially if the standard reference method (SRM) uses a different technique to the CEMs. Furthermore, in the case of separate calibration functions for NO and NO₂, the NO can be oxidised in sampling lines, there can be different rates of oxidation in the SRM and CEM sampling lines, or not at all with *in situ* CEMs. This would mean that SRMs and CEMs both measuring NO and NO₂ separately are not always comparable.

Expressing NO as NO₂, on the other hand, and adding the two NO₂ concentrations, would eliminate this problem. Therefore, we recommend the following approaches when performing QAL2 and AST exercises.

If the operator may measure NO alone instead of total NOx, then the test laboratory may either measure NO alone, or total NOx. If the operator measures total NOx, then the test laboratory must also use a SRM which measures total NOx. NO and NOx may be measured independently, or together as total NOx. Table 1 summarises the approach to use.

Note: If the operator is permitted to measure NO alone, but chooses to measure total NOx, then SRMs shall also measure total NOx. 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 NOx through the use of a conversion factor.

For the treatment of NOx calibration functions during the AST see section 8.3 of this MID.

Table 1 – Generating calibration functions for NOx

CEMs	SRMs	Approach
NO	NO	Generate a calibration function for NO
NO	Total - NOx	Generate a calibration function for NO using the measurements for total-NOx, bearing in mind that the calibration function should implicitly include the proportion of NO ₂ in the stack gas.
NO+NO ₂	Total -NOx	Convert the NO+NO ₂ to total NOx. Generate calibration function
Total - NOx	NO+NO ₂	
NO+NO ₂	NO+NO ₂	

6.6 Calculation of variability

Note that the daily average ELV is applied.

The test should be based on the results of parallel measurements from the stack only. It shall not include data obtained by use of reference materials. Refer to EN 14181 for an example calculation.

6.7 Test of variability

Note that the daily average ELV is applied. In practice, an uncertainty of 10% for CO is very difficult to achieve, whilst the risks of applying a higher uncertainty of 20% are very low. Therefore, test laboratories may use a 95% confidence interval of 20% for CO. EN 14181, Annex I contains k_v values for three to 30+ pairs of data. Refer to EN 14181 for an example calculation.

6.8 QAL2 report

Both the QAL2 and AST report submitted to the operator and us shall comply with the minimum requirements shown in the template in Appendix 2. Reports produced by test laboratories shall therefore comply with specified headings, structure and order of items within the template. The reports shall be retained by the operator and test laboratory. It is not necessary to include all raw data (as opposed to averaged raw-data), although the raw data shall be made available to us and the operator upon request.

Note: The averaged raw-data means the short-term averages, e.g. half-hourly or hourly averages. In other words, all of the necessary data required to perform the calculations prescribed in EN 14181.

Furthermore:

- The operator and the test laboratory shall retain all raw data for a period of at least five years.
- Operators and test laboratories shall have quality assurance provisions to assure the traceability of data.
- Recommendations and statements shall be included in the QAL2 report.

Test laboratories should state any actions that the operator needs to perform. For example, some functional tests may have been omitted before the parallel reference tests; or the QAL3 procedure might be incomplete.

Test laboratories shall provide the operator (and us if requested) an indication of the results of the QAL2 or AST not later than one calendar month after the completion of the exercise, provided that the test laboratory has all the information required.

7. Ongoing quality assurance during operation (QAL3)

7.1 General

The QAL3 procedure is the responsibility of the operator. However, during QAL2 and AST exercises, the test laboratory shall check whether there is a QAL3 procedure in place, and whether there are data to show that the operator has implemented the QAL3 procedure. Then the test laboratory shall report their findings in the QAL2/AST report. The main points to note are that:

- The CEM must be able to indicate negative values.
- The operator shall decide which type of control chart or procedure is to be used.

- When using Shewhart charts, no adjustment of the zero and span figures should be made.

Note: 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 QAL1 specification for zero and span drift.

- If the CEM has been calibrated over an expanded range, (refer to sections 6.5 of this document and EN 14181), then the zero and span checks will be over this set range.

7.2 Calculation of the standard deviation

Refer to TGN M20, section 4.1.2 for guidance.

7.3 Documentation of control charts

No additional requirements; refer to TGN M20, section 4.3 for guidance.

8. Annual Surveillance Test (AST)

8.1 Functional tests

Refer to section 6.2 of this MID for the general requirements of the tests.

8.2 Parallel measurements with a SRM

Application of the SRMs

Five tests are the minimum requirement, however, the test laboratory is advised to carry out a greater number in case any tests are deemed invalid. Additionally, the length of the sampling day should not compromise safety. Therefore, the length of the sampling day should balance the requirements for representative data against the requirements for safety.

Note: If the test laboratory is using instrumental methods for SRMs, then the SRM monitoring system may be operated continuously over the entire duration of the AST.

8.3 Treatment of NO_x calibration functions during ASTs

Where there are existing NO and NO₂ calibration functions from the previous QAL2, and where the NO₂ data is below 20% of the NO_x ELV, carry out the following:

- Check the current NO function against a total NO_x figure. If it passes the variability and validity acceptance tests, then no further action is needed, beyond reporting.
- If the AST tests result in a failure, then regenerate the function for total NO_x from the original QAL2 data and check the AST using total NO_x.
- If this new function passes, state this in the report and advise the site that the calibration function has changed.
- If the new calibration function and AST data results in a failure of the variability and/or validity acceptance tests, then a new QAL2 will be required.

8.4 Data Evaluation

Data from the AST may be used to extend the valid calibration range:

- Up to the maximum measured calibrated CEM value at standard conditions determined during the AST plus 10%, provided this does not exceed 50% of the ELV.
- If the AST data are within the 95% CIs of the calibration range.

8.5 Test of variability and validity of the calibration function

Note that the daily average ELV is applied. In practice, an uncertainty of 10% for CO is very difficult to achieve, whilst the risks of applying a higher uncertainty of 20% are very low.

Therefore, test laboratories may use a 95% confidence interval of 20% for CO.

The test should be based on the results of parallel measurements from the stack only. It shall not include data obtained by use of reference materials.

EN 14181, Annex I contains k_v values and t-factors for three to 30+ pairs of data.

Refer to EN 14181 for an example calculation.

8.6 AST report

Refer to section 6.8(i) of this MID for the requirements of the AST report.

Appendix 1: Pro-forma for assessing & reporting the results of the functional tests

Requirement	✓	Notes
1. Alignment and Cleanliness		
A visual inspection, with reference to the CEMs manuals, shall be carried out on the following when applicable:		
• Internal check of the CEM		
• 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		
• Contamination control (internal check of optical surfaces)		
2. Sampling Systems		
A visual inspection of the sampling system shall be performed, noting the condition of the following components, when fitted:		
• Sampling probe		
• Gas conditioning systems		
• Pumps		
• All connections		
• Sample lines		
• Power supplies		
• Filters		
• NOx converters – if the sampling system contains a NOx converter, then the test laboratory shall record when the last efficiency test was performed, and the result of this test.		
• The sampling system shall be in good condition and free of any visible faults which may decrease the quality of data		
3. Leak testing		
• Leak testing shall be performed according to the CEMs manuals. The test shall cover the entire sampling system.		
4. Zero and Span check		
• Reference zero and span materials shall be used to verify the corresponding readings of the CEM.		
• For non-extractive CEMs, zero and span checks shall be performed using a reference-path free of flue gas before and after readjustment, and after re-assembly of the CEM at the measurement location.		
5. Linearity		

Requirement	✓	Notes
<ul style="list-style-type: none"> During the calibration/linearity tests the applied concentrations should be logged onto the DAHS to prove the complete system (i.e. concentration applied to the instrument is represented by the instrument output and identical to the value logged on the DAHS). DAHS logged values should be included in the instrument service report. The linearity of the CEMs' response shall be checked using five different reference materials, including a zero concentration. 		
<ul style="list-style-type: none"> The reference material with zero concentration, as well as the reference materials with four different concentrations, shall have a verifiable quantity and quality. 		
<ul style="list-style-type: none"> 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. 		
<ul style="list-style-type: none"> The reference material concentrations shall be selected such that the measured values are at approximately 20 %, 40 %, 60 % and 80 % of a range that is at least the short-term ELV. 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. 		
<p>The individual CEMs are tested using the following concentrations applied in a randomised sequence:</p>		
<ul style="list-style-type: none"> Reference material with zero concentration; 		
<ul style="list-style-type: none"> Reference material concentration approximately 20 % of the range 		
<ul style="list-style-type: none"> Reference material concentration approximately 40 % of the range 		
<ul style="list-style-type: none"> Reference material concentration approximately 60 % of the range 		
<ul style="list-style-type: none"> Reference material concentration approximately 80 % of the range 		
<ul style="list-style-type: none"> Reference material with zero concentration; 		
<p>After each change in concentration, the first instrument reading shall ordinarily 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, six readings shall be taken at zero. The time period between the start of each of the three readings shall be separated by at least four times the response time.</p> <p>A risk-based approach to linearity testing may be applied in order to reduce the time for the tests. For example, the readings may be taken after less than 3x the response time, however, if the CEM fails the linearity test, then the test shall be repeated after a period of at least 3x the response time as stated above. Alternatively, the number of repetitions of the test may be reduced if the CEM passes the required performance criteria by a factor of</p>		

Requirement	✓	Notes
<p>at least 2 (i.e. half the allowable residual). Increasing the waiting time to 5x the response time, for example, may be a means of meeting this requirement.</p> <p>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.</p> <p>The linearity shall be calculated and tested using the procedure as given in EN 14181, Annex B. If the CEM does not pass this test, then the problem shall be identified and rectified.</p>		
6. Interferences		
<ul style="list-style-type: none"> A test shall be undertaken if the process gases to be monitored contain components that are known interferences, as identified during QAL1 and there is a failure of the QAL2 or AST which could be due to interferences. 		
7. Zero and Span drift (Audit)		
<ul style="list-style-type: none"> 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. 		
8. Response Time		
<ul style="list-style-type: none"> 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 response time shall not exceed the performance requirement applied during the QAL1 tests. 		
9. Service Report		
As a minimum requirement the service report should include the following:		
<ul style="list-style-type: none"> Document reference for work instruction for the type of work being undertaken 		
<ul style="list-style-type: none"> Instrument manufacturer 		
<ul style="list-style-type: none"> Instrument type 		
<ul style="list-style-type: none"> Instrument model 		
<ul style="list-style-type: none"> Instrument Serial No 		
<ul style="list-style-type: none"> Operating principle 		
<ul style="list-style-type: none"> Operating range 		
<ul style="list-style-type: none"> Certification details 		
<ul style="list-style-type: none"> Compliance with MCERTS (including certificate no.) 		
<ul style="list-style-type: none"> Location 		
<ul style="list-style-type: none"> Date and time work was undertaken 		

Requirement	✓	Notes
<ul style="list-style-type: none"> Equipment used – type, serial no's, calibration dates 		
<ul style="list-style-type: none"> Gases used – certificate numbers, expiry dates, binary / mix 		
<ul style="list-style-type: none"> NOx converter efficiency test, if applicable 		
<ul style="list-style-type: none"> Calibration and linearity data (as required by EN 14181) where linearity testing is carried out during the service 		
<ul style="list-style-type: none"> Logged data for period of calibration and linearity where linearity testing is carried out during the service <p>Note: There may be gaps in the data, however, for various reasons; for example, if the CEMs are removed from the stack for the linearity test. In such cases, the test laboratory shall state why there are gaps in the data.</p>		
<ul style="list-style-type: none"> Name and signature of service engineer 		

Note: Annex A of EN 14181 specifies requirements for Documentation and Records (A4) and Serviceability (A5). These requirements are not included in this Appendix, which focuses on data and information for the monitoring provisions and functional tests on the CEMs.

Appendix 2: Template for a report for QAL2

Foreword

This template specifies the minimum requirements for reports for QAL2 and ASTs, as required by EN 14181. It is a specification for both the contents of a report, and the order of the contents. **This means that every single item included in this template must be included in the test reports for QAL2 and ASTs. We may reject any test reports that do not comply with these requirements.** Test laboratories may include additional information, and also present much of the information specified below within tables. However, additional information should be within the annexes, in order to keep the main body of the report as short as possible. The full data and supplementary information should be included in annexes.

The template is based on Microsoft Word but a test laboratory can use any type of software provided that the minimum requirements set out in this template are included.

Note: The above requirements mean that the test laboratory has to use the same numbering for headings in this template, i.e. the same sequence for the contents.

This template is divided into six core sections and supporting Annexes, which are:

- Section 1 – Executive summary/title page
- Section 2 – Information about the regulated installation, and its provisions for monitoring
- Section 3 – Information about the monitoring that the test laboratory performs
- Section 4A – Data and calculations – QAL2
- Section 4B – Data and calculations - AST
- Section 5 – Results of the functional tests, and who performed the tests.

Annexes

- Any supporting data which the test laboratory decides to include in the annexes
- Any supporting information about the test laboratory, e.g. a copy of the scope of accreditation

This template has been designed with flexibility in mind, insomuch as test laboratories may use different means of producing the reports, such as word-processing or spreadsheet software.

All pages header/footer to include the following:

- Report reference number
- Permit number
- Operator and installation name
- Year of monitoring
- Sequential number of the visit in the year (if applicable)
- Version number
- Page number (page X of Y)

Section 1 – Executive Summary/title pages

Cover sheet - to include the following:

- MCERTS and UKAS logos, and registration number of monitoring organisation
- Title including type of report (QAL2 and/or AST)
- Permit number
- Operator name
- Installation name
- Dates of monitoring visits
- Contract number of reference (if applicable)
- Name and address of client organisation
- Name and address of monitoring organisation
- Date of report
- Name, MCERTS registration number and function of the person approving the report
- Signature of person approving the report

Contents

1.1

Summary of results

- Whether the test is an AST or a QAL2
- The stack designation
- The determinands
- Value for a in the calibration function
- Value for b in the calibration function
- The valid calibration range based on calibrated CEMs data from the QAL2
- The valid calibration range based on calibrated CEMs data from the AST
- The extrapolated range based on reference materials
- A statement of a pass or fail for the variability test (QAL2 and AST)
- A statement of a pass or fail for the calibration test (AST)
- Recommendations where applicable
- A firm statement that the calibration function, once applied, only remains valid as long as the QAL3 data remains within control limits, and that there are no manual adjustments made to the CEMs other than those allowed to bring the settings back within the QAL3 control limits

1.2	<p>Deviations</p> <ul style="list-style-type: none"> • If there any are deviations from the SRMs, and reasons for this • If there any are deviations from EN 14181, and reasons for this • Any impacts on the results • Any actions required.
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Section 2 – Information about the Regulated Installation

2.1 Regulatory information				
2.1.1	Name of the installation			
2.1.2	Address of the installation			
2.1.3	Sector for the installation			
2.1.4	Date of the last QAL2/AST			
2.1.5	Regulated determinands and emission limit values			
Determinand	Emission point	Short-term ELV	Daily average ELV	Uncertainty requirement
<i>Notes</i>	<i>These will be specified in the permit</i>	<i>This will typically be a 30-minute average or a 1-hour average, but may differ for large combustion plants.</i>	<i>This will typically be a daily average, but may be a 48-hour average for some types of large combustion plants</i>	<i>This will be expressed as a 95% confidence interval within the IED</i>
2.2 Operational information and site monitoring provisions				
2.2.1	Process type and variations in emissions.			
	<ul style="list-style-type: none"> • Continuous or batch process - describe the operating phases. Indicate the percentage of the load of normal runs and expected variations of emissions. • Explain how the expected emissions and variations in the emissions influence the sampling times and duration, in order to capture a representative set of samples. • Include any other factors which would affect the monitoring results e.g. automatic zero and span operations, or low-emissions values. • It is also essential to check historical data beforehand, to check if the emissions are at or near zero and to report these. • If the check reveals that the emissions are at or near zero, then include provisions to deal with these low emissions. • If the CEM is reading zero then investigate to ensure that the CEM is working. An agreement with the client that the implications are understood and that these discussions and findings are documented. 			
2.2.2	Type of fuel			
	<ul style="list-style-type: none"> • Describe the types of fuels and their proportions used during the QAL2/AST, and during a normal operating year; also whether multiple calibration-functions are required. • If the process is co-incineration, then what types and proportions of fuels were used? 			

2.2.3	<p>Abatement</p> <ul style="list-style-type: none"> Type of abatement plant and how this affects emissions.
<p>2.3 Monitoring provisions at the installation – periodic monitoring</p>	
2.3.1	<p>Stack and sampling ports</p> <ul style="list-style-type: none"> Rectangular or round stack/duct Dimensions/diameter of stack Location of the sampling ports Number of sampling ports Include a diagram (and preferably photographs) of the emission point, platform and location.
2.3.2	<p>Monitoring platform and site-provisions</p> <p>Record the following:</p> <ul style="list-style-type: none"> The extent to which there is a safe and clean working environment with sufficient space and weather protections. Whether there is easy and safe access to the CEM, Whether there are adequate supplies of reference materials, tools and spare parts, Whether there are facilities to introduce the reference materials for gaseous-monitoring systems, both at the inlet of the sampling line (where present), and at the inlet of the CEM. The degree of compliance with the requirements of MID 15259.
2.3.2	<p>Sample – how representative is it?</p> <ul style="list-style-type: none"> Grid measurements – compliance with MID 15259. State whether the site has had a homogeneity assessment to EN 15259, when and where this is reported. Ratio of highest to lowest flow-rates.
<p>2.4 Continuous Emission Monitoring systems (CEMs) at the installations</p>	
2.4.1	<p>Types of CEMs for each main determinand, oxygen and moisture</p> <ul style="list-style-type: none"> Type, e.g. cross-duct, in situ, or extractive Brand Model Certification range Principle Location of sampling/measurement Statement of QAL1 compliance Statement whether moisture is by measurement or calculation <p>Note: If there are CEMs for moisture, then state how moisture is measured, e.g. infra-red measurements, or wet/dry oxygen measurements.</p>

2.4.2	Types of monitoring for peripheral determinands
	<ul style="list-style-type: none"> Monitoring for temperature and pressure, and a statement whether temperature and pressure are recorded.

Section 3 – Information about the monitoring campaign

3.1	Test laboratory staff						
Name	MCERTS Registration Number	Certification level with expiry date					
		L1	L2	TE1	TE2	TE3	TE4
3.2	Standard Reference Methods (SRMs) - include the following, e.g. in a table.						
	<ul style="list-style-type: none"> Determinand SRM standard applied Type and principle Operational range Certification range of any instrumental methods used Uncertainty UKAS accreditation 						

Section 4A – Data and calculations – QAL2

Section 4A – Monitoring data and calculations	
This section specifies the minimum number of tables and charts, and the minimum requirements for each table. Test laboratories may combine tables where data would be repeated, e.g. in Table 4.1 and 4.2, where it is necessary to convert data to standard conditions in order to determine the procedure to be used.	
A4.1	Table 4.1 - Raw monitoring data <ul style="list-style-type: none"> Start and end times of each pair of data Raw CEM results Stack/CEM peripheral determinands for temperature, pressure, oxygen and moisture (if measured) Raw SRM results SRM peripheral determinands for temperature, pressure, oxygen and moisture SRM results expressed under the same conditions as the CEM results
A4.2	Table 4.2 – standardised monitoring data <ul style="list-style-type: none"> Standardised CEM results (i.e. STP, dry and to the reference O₂ concentration) Standardised SRM results (i.e. STP, dry and to the reference O₂ concentration)
A4.3	Plot 1 – mandatory <ul style="list-style-type: none"> Time series of standardised CEM versus standardised SRM data
A4.4	Calculation and procedure – Elimination of outliers <ul style="list-style-type: none"> Outliers should be clearly indicated in the averaged raw-data set <p>Note: The procedure described in M20, section 3.5.13 (ii) shall be used.</p>
A4.5	Calculation – determination of Procedure

Section 4A – Monitoring data and calculations	
A4.6	Table 4.3 – data used to determine the calibration function <ul style="list-style-type: none"> SRM results expressed under the same conditions as the CEM results Raw CEM results
A4.7	Calculation – determination of the calibration function
A4.8	Table 4.4 – Calculation of calibrated CEM values <ul style="list-style-type: none"> Raw CEM values Calibrated CEM values, at CEM conditions Peripheral determinands for CEMs Calibrated CEM values, standardised
A4.9	Plot 2 – mandatory <ul style="list-style-type: none"> x-y plot of CEM versus SRM data, both at conditions measured by the CEM, and not standardised Calibration function, including R² value.
A4.10	Table 4.5 – Data used for the variability test <ul style="list-style-type: none"> Calibrated CEM values, standardised SRM values, standardised Difference between each pair of values Difference minus the average of the differences Difference minus the average of the differences, squared
A4.11	Calculation - the variability test <ul style="list-style-type: none"> The calculations, as set out in EN 14181 The variability test Statement of the results
A4.12	Plot 3 – Mandatory <ul style="list-style-type: none"> x-y plot of calibrated, standardised CEM data versus standardised SRM data, Indication of the valid calibration range Extrapolation of the valid calibration range, using surrogates Parallel lines above and below the regression line through the standardised, calibrated CEM values and standardised SRM values. The parallel lines should indicate the derived uncertainty (σ_o) of the allowable 95% confidence interval of the daily average ELV (sometimes called 'tramlines').

Section 4B – Data and calculations – AST

Section 4B – Monitoring data and calculations	
This section specifies the minimum number of tables and charts, and the minimum requirements for each table. Test laboratories may combine tables where data would be repeated.	
B4.1	Table 4.1 - Raw monitoring data

Section 4B – Monitoring data and calculations	
	<ul style="list-style-type: none"> • Start and end times of each pair of data • Raw CEM results • Stack/CEM peripheral determinands for temperature, pressure, oxygen and moisture (if measured) • Raw SRM results • SRM peripheral determinands for temperature, pressure, oxygen and moisture • SRM results expressed under the same conditions as the CEM results
B4.2	<p>Table 4.2 – standardised monitoring data</p> <ul style="list-style-type: none"> • Standardised CEM results (i.e. STP, dry and to the reference O₂ concentration) • Standardised SRM results (i.e. STP, dry and to the reference O₂ concentration)
B4.3	<p>Plot 1 – mandatory</p> <ul style="list-style-type: none"> • Time series of standardised CEM versus standardised SRM data
B4.4	<p>Calculation and procedure – Elimination of outliers</p> <ul style="list-style-type: none"> • Outliers should be clearly indicated in the averaged raw-data set <p>Note: The procedure described in M20, section 3.5.13 (ii) shall be used.</p>
B4.5	<p>Table 4.3 – data used to calculate calibrated values</p> <ul style="list-style-type: none"> • Raw CEM values • The original calibration function from the previous QAL2 • Calibrated CEM values, at CEM conditions • Peripheral determinands for CEMs • Calibrated CEM values, standardised
B4.6	<p>Table 4.4 – Data used for the variability test</p> <ul style="list-style-type: none"> • Calibrated CEM values, standardised • SRM values, standardised • Difference between each pair of values • Difference minus the average of the differences • Difference minus the average of the differences, squared
B4.7	<p>Calculation - the variability and validity acceptance tests</p> <ul style="list-style-type: none"> • The calculations, as set out in EN 14181 • The variability test • The validity acceptance test • Statement of the results
B4.8	<p>Plot 2 – Mandatory</p>

Section 4B – Monitoring data and calculations

- x-y plot of calibrated, standardised CEM data versus standardised SRM data
- Indication of the valid calibration range
- Parallel lines above and below the regression line through the calibrated, standardised CEM values and standardised SRM values. The parallel lines should indicate the derived uncertainty (σ_o) of the allowable 95% confidence interval of the daily average ELV (sometimes called 'tramlines').
- Extrapolation of the valid calibration range, using surrogates, if applied

Section 5 – Results of the functional tests

5.1	Results of functional tests
5.2	Information on test personnel <ul style="list-style-type: none">• Name of person/s performing the functional tests• Name of person witnessing the tests where applicable

Glossary

Glossary of terms

AST	Annual Surveillance Test
CEM	Continuous Emission Monitoring system
CI	Confidence Interval
ELV	Emission Limit Value
IED	Industrial Emissions Directive
JEP	Joint Environmental Programme
QA	Quality Assurance
QAL	Quality Assurance Level
SD	Standard Deviation
SRM	Standard Reference Method
UKAS	United Kingdom Accreditation Service
VCR	Valid Calibration Range