Environmental Protection Agency Office of Environmental Enforcement (OEE)

Air Guidance Note on the Implementation of I.S. EN 14181 (AG3)

Version 4 – (February 2021)

Contents

Preface

The Office of Environmental Enforcement (OEE) is one of the five offices in the Environmental Protection Agency. The OEE's functions include the regulation of activities licensed under the EPA and WMA Acts. It is the policy of the OEE to provide information and advice via published guidance to those it regulates, to secure environmental improvements, while ensuring value for money.

This Air Guidance Note on the Implementation of I.S. EN 14181 (AG3) is one of a series of guidance notes that the OEE has published on the general theme of air pollution monitoring. A forerunner to this document is Guidance Note No. 1 Air Emissions Sampling Facilities which describes the facilities that must be provided for the safe and effective monitoring of emissions, and the Air Emission Monitoring Guidance Note (AG2) which is aimed at improving the overall quality of stack emission monitoring by emphasising best practice standards and techniques.

The guidance note is intended for use by all Agency staff involved with IE plant (e.g. licensing and enforcement staff), the licensed operator, and test houses that provide an air emissions monitoring service. The document is intended to give clear and practical guidance on how to implement EN 14181 in Ireland, which is mainly based on an interpretation of the experiences to date in the rest of Europe.

This is the fourth version of this guidance note to be published. Major changes in this version include:

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EPA Accreditation Policy

From 1 January 2014, the EPA required that contractors carrying out monitoring of stack gas emissions to atmosphere were accredited to the ISO17025 standard (including relevant requirements of CEN/TS 15675 and IS EN 15259) and the scope of accreditation held by contractors for the following parameters, if they wish to monitor these parameters at IE licensed sites, shall as a minimum be:

- From 1 January 2014: Total particulates (low and high range), NOX, SO_2, CO, TVOC (by FID), dioxins, velocity and temperature, oxygen, and moisture. Where monitoring for other parameters is to be carried out, the parameter must be included within the 17025 management system documentation (procedures, etc..) to assure the quality of the monitoring.

- From 1 January 2015, the following additional parameters: HCl, formaldehyde, metals, and speciated organics. Where monitoring for other parameters is to be carried out, the parameter must be included within the 17025 management system documentation (procedures, etc.) to assure the quality of the monitoring.

- From 1 January 2019, the following additional parameters: Ammonia, hydrogen fluoride and CO_2 (for air density calculation in combustion processes). Where monitoring for other parameters is to be carried out, the parameter must be included within the 17025 management system documentation (procedures, etc.) to assure the quality of the monitoring.

A contractor may choose not to include some of the specific parameters listed above within their scope of accreditation, but in such cases, the Agency will not accept any monitoring results for those parameters, which are not within the contractor's scope of accreditation (once the relevant deadline has passed). Where a contractor wishes to monitor for parameters which are not specifically listed above, the parameter to be monitored must still be included within the 17025 management system and documentation, to ensure an equivalent level of data quality is maintained.

From 2019, the Agency recommends that any additional parameters that may be considered as being viable, e.g. odour, PM10, etc. should be added to the scope of accreditation, however failing this, where a contractor wishes to carry out monitoring for a given pollutant, inclusion within the ISO17025 management system will suffice for these parameters. Monitoring for such parameters shall as a minimum be carried out in line with the requirements of the Agency's AG2 guidance document. For those parameters where mandatory accreditation is not required, the Agency still recommends that ISO17025 accredited analytical laboratories are used for sample analyses. However, the impact of not having certain parameters within the scope of accreditation should be considered carefully where the contractor is considering working in other jurisdictions where ISO17025 accreditation is required for stack emissions monitoring.

Any testing company carrying out EN14181 works in Ireland must be ISO 17025 accredited, and shall:

- adhere to the EPA monitoring policy above described;
- comply with all requirements of this guidance. Should this guidance be in conflict with other country's guidance or with accreditation provided by a foreign accreditation body, the EPA AG3 guidance will prevail, even if that results in losing the accreditation on the EN14181 report (not the individual parameters monitoring)
- adhere to the EPA Proficiency Test Scheme on EN14181, when available.

EN14181 EPA PT Scheme

Air monitoring test houses who want to carry out EN14181 works in Ireland must join the EPA Proficiency Testing (PT) Scheme, by emailing airthematic@epa.ie. The PT scheme will run once a year and will consist of exclusively desktop work, where a spreadsheet containing a number of measurements and process information are provided for the test house to work out the required QAL2 or AST items (calibration function, variability tests, calibration ranges, etc). The results shall be submitted back to the EPA.

Participation is mandatory although failure will not result in the test house being disqualified from conducting EN14181 works in Ireland. Results will be discussed with the contactors individually, and will serve as a spot check on the accuracy of methodology and calculations.

Revision of this document

This guidance note may be the subject of periodic review and amendment. The most recent version of this note is available on the Agency website: *http://www.epa.ie/downloads/advice/air/emissions/*. If you have any queries on this document then please contact airthematic@epa.ie*.*

Abbreviations

AMS	Automated Measuring System (sometimes referred to as CEMS)
AST	Annual Surveillance Test
CEMS	Continuous Emissions Measuring System (also AMS)
CEN	European Committee for Standardisation
DAHS	Data Acquisition and Handling System
IED	Industrial Emissions Directive
ISO	International Standards Organisation
ELV	Emission limit value
LCPD	Large Combustion Plant Directive (replaced by IED)
MCERTS	Monitoring Certification Scheme
QAL	Quality Assurance Level
SRM	Standard reference method
TUV	German Technical Inspection and Monitoring Union
UBA	German Federal Environment Agency
WID	Waste Incineration Directive (replaced by IED)

1. Regulatory Requirements for the International Standards

IS EN 14181, and the related standards IS EN13284-2 for dust monitoring, and IS EN 14884 for mercury monitoring were developed mainly to support two EU Directives – The European Directive 2000/75/EC on the incineration of waste (WID) and the European Directive 2001/80/EC on the emissions into air from large combustion plant (LCPD). These Directives were replaced by the European Directive 2010/75/EU on industrial emissions (IED), which has been implemented through national legislation, and the EN standards that support this legislation became mandatory.

1.1. Monitoring Requirements in the Industrial Emissions Directive (IED)

The IED specifies performance requirements for Automated Monitoring Systems (AMS) used to monitor relevant industrial plants.

Firstly, the Directive prescribe that EN Standards must be used for monitoring when AMS are employed, and that EN Standard Reference Methods (SRM) must be used for the calibration of the AMS.

Secondly, the EU Directive specifies overall performance requirements for the AMS (and also discontinuous monitoring devices) to be used for IED applications for each species being monitored. These are expressed as measurement uncertainty allowances for the results expressed as a percentage of the emission limit value (ELV*). This measurement uncertainty covers overall requirements for all the parameters that affect it including the precision of the AMS, and this uncertainty is expressed at a confidence level of 95% (Table 1), in keeping with normal statistical measurement practices.

* ELV refers to the daily or 48 hourly ELV unless otherwise specified

1.2. The Concept behind EN 14181 and Related Standards

EN 14181 needs to be applied to AMS that are permanently installed at WI & LCP under IE licence installations. It does not need to apply to portable AMS, those used as SRMs, or to those used for Industrial Emissions (IE) or Integrated Pollution Control (IPC) installations. Nonetheless, application of the principles of EN14181 is regarded as good practice and should be applied to non-IE AMS where possible.

The requirements for these are described in other standards (Section 7 - Bibliography of Relevant European Documents, for EN Standards for SRMs). It should also be noted that EN 14181 applies to the complete AMS, including all the sampling train, and sample conditioning system where present, but currently does **not** apply to the data installation, data recording and data processing system used with the AMS. This will be addressed in a future CEN Standard. A brief explanation of data treatment is included in Section 5.3.

EN 14181 specifies requirements for three Quality Assurance Levels (QALs), and an additional annual surveillance test (AST). These are:

QAL1: A process by which a suitable AMS is selected as being potentially fit for the applications in terms of its measurement uncertainty capability, etc. This requires a procedure to demonstrate that the AMS is potentially suitable for its purpose generally, before its sale and installation, by conformance testing (sometimes popularly known as 'type approval') to demonstrate that it can achieve the performance requirements specified in the EU Directives. This procedure is **referred to** in EN 14181, but is **not** described in this standard. The test procedures used to assess an AMS as well as the criteria it must adhere to is specified in EN 15267-3, and the methodology used to calculate the total uncertainty of the AMS is covered in EN ISO 14956.

QAL2: The procedure for calibrating the AMS against the appropriate SRM, once the specific AMS has been installed. The calibration is performed by the implementation of a calibration function (y = bx + a) that it is applied in the DAHS to the values provided by the AMS. The SRM is deemed to provide the correct results within certain tolerances. The process also verifies the installation of the AMS through functionality testing, and that it meets the measurement uncertainty requirements.

QAL3: A procedure for assessing, in an on-going manner, the quality of AMS results when it is operating normally on the plant, in order to demonstrate and maintain the required quality of the results. This is done by checking the readings of the AMS that are obtained when implementing zero and span checks on a regular basis, so as to confirm that the repeatability of these checks are consistent with those obtained during the QAL1 conformance tests.

AST: A procedure to evaluate the AMS on a yearly basis to show that it continues to function correctly, the calibration function remains valid, and that the variability remains within acceptable levels. The process involves carrying out functionality testing and parallel measurements on the AMS.

These quality assurance levels follow a logical sequence and aim to demonstrate the correct selection, installation, calibration, and continuously valid operation of the AMS on the plant. These are shown in Figure 1.

- EN standard 13284-2 provides specific requirements for dust monitoring in the context of the more general requirements of EN 14181, and as such is a detailed interpretation of EN 14181 for the monitoring of dust under the requirements of the IED, where compliance with emission limit values of less than 50mg/m3 under standard conditions is required. The QAL2 procedure for dust must be performed against the SRM specified in EN 13824-1.

- EN standard 14884 provides a more detailed interpretation of requirements for an AMS used for gaseous mercury monitoring.

- EN standard 16911-2 describes the requirements for volumetric flow monitoring by AMS. Equally, this standard includes procedures to calibrate the AMS using a SRM and it is applicable in conjunction with the general document, EN 14181. The procedures described for the calibration of Volumetric flow CEMS apply when CEMS data are obtained by measurements or by calculation in accordance with Annex E in the EN16911-1 standard. If the calculation method is used, a validation exercise by means of QAL2 shall verify the accuracy of calculated results, which shall also be checked on an annual basis by means of an AST.

- EN standard 17255-1 deals with data acquisition and handling systems (DAHS) and it specifies the requirements for the handling and reporting of data. Its scope is outside the requirements in EN14181, however licensees subject to EN14181 compliance must also comply with the requirements in EN 17255-1.

NOTE 1: Subsequently within this document 'EN 14181' is used to refer generically to the four standards; EN 14181, EN 13284-2, EN 14884 and EN16911-2. Where specific reference to an individual standard is required it will be clearly indicated.

2. Overview of QAL1, QAL2, QAL3, AST

The European standards EN 14181, EN 13284 and EN 14884 provide a framework for the Quality Assurance and Quality Control of AMSs for stack emissions monitoring. This framework consists of three Quality Assurance Levels (QALs), and an Annual Surveillance Test (AST).

The stages address;

- the selection of an appropriate AMS (QAL1);
- installation and calibration of the AMS (QAL2);
- the ongoing quality control (QAL3);
- and regular checks of the calibration by performing an AST.

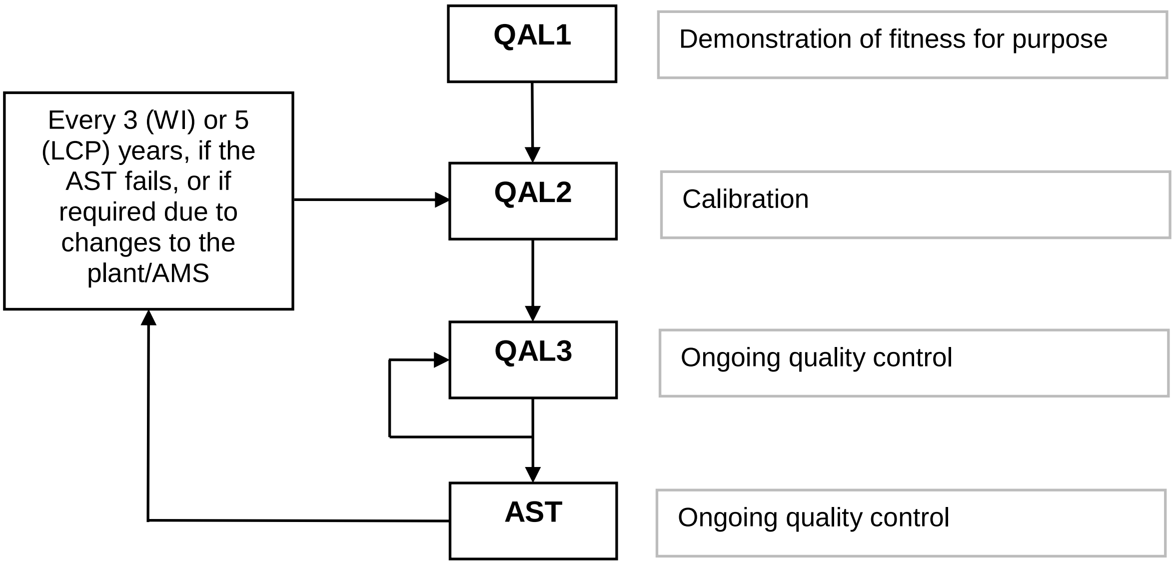


Figure 1: The Sequence of Quality Assurance and Quality Control activities covered in EN 14181

It is the legal responsibility of the process operator to ensure the implementation of the requirements of EN 14181. Operators may make use of external contractors to meet these requirements, as described in Figure 4.

The different stages are as follows:

2.1 QAL1 - Initial selection of AMS

QAL1 provides a mechanism for demonstrating the fitness of purpose of an AMS, and determining if it is suitable for use on a particular plant. Under QAL1, AMS are required to have been tested by a laboratory, approved and accredited to ISO/IEC/EN 17025, and for information to be available on a number of performance characteristics.

The testing should be carried out within a conformance testing regime, in which the instrument type is tested; the performance characteristics determined are then valid for all instruments of this type (i.e. for a given manufacturer’s model number).

Controls are put in place to require the manufacturer to declare any changes to the design of the instrument that may affect its performance. If changes are made, then retesting by a certified testing laboratory may be required.

A further aim of QAL1 is to enable the uncertainty of results produced by the AMS to be predicted. Plant specific information, for example interferent levels, and external conditions specific to the site can be used during the calculation of measurement uncertainty. The purpose of this is to predict whether the AMS will be able to meet the data quality objectives of the Directives. Currently EN 14181 refers to EN ISO 14956 as the method to use to calculate the measurement uncertainty from the AMS performance data.

CEN has produced a standard EN 15267-3, which provides an implementation of EN 14956 to enable the calculation of the measurement uncertainty of an AMS from performance data. This enables the performance of an AMS in the type approval process to be compared with the data quality requirements of the Directives.

It is not the responsibility of the operator to implement QAL1. It is sufficient to ensure that any new analyser purchased has MCERTS, TUV, or other approved certification showing that the instrument is suitable for the intended use. At a minimum, for parameters other than volumetric flow, the following suitability criteria must be met:

1. Instrument field trials must have been carried out on a similar process (e.g. boiler, incinerator, etc.), with a similar stack gas matrix and measuring conditions, to the proposed application;

2. Instrument field trials must have been carried out using a gas sampling and conditioning system similar to the proposed application;

3. Certified range must be less than 2.5 times the daily or 48-hourly ELV for large combustion plant, and less than 1.5 times the daily or 48-hourly ELV for waste incineration plant;

4. The physical measurement range of the instrument must be sufficient to include the highest short-term ELV as well as any higher concentrations that may occur during operation;

5. The certificate must provide the uncertainty information required to implement QAL3.

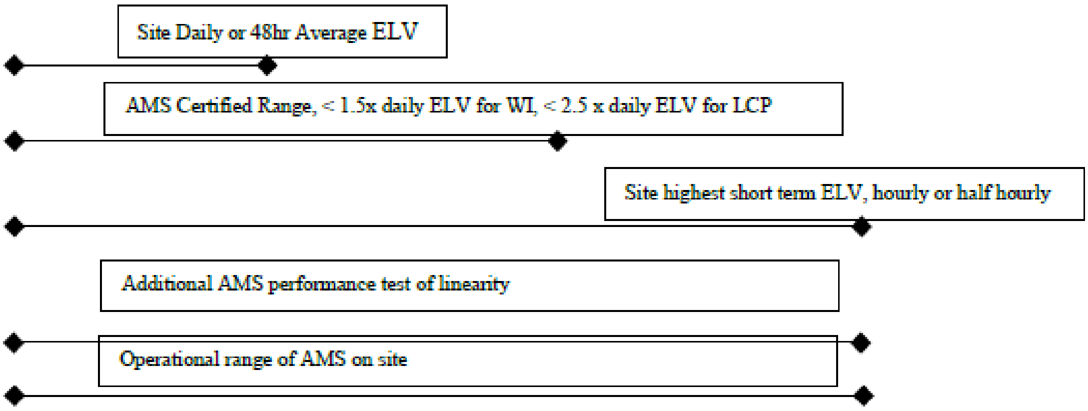
For volumetric flow the following suitability criteria must be met:

1. Flow monitoring system shall consist of all necessary parts (i.e air-purging systems) to keep the flow monitor operating within a specified uncertainty.

2. The relevant performance characteristics of the AMS shall be documented by the manufacturer and/or his European representative by suitability tests performed according to the relevant European Standards.

3. These tests are usually carried out in the framework of certification or type approval procedures according to EN 15267, and the AMS shall have the same characteristics as the tested devices. The test report shall include the total AMS uncertainty calculated according to EN 14181 and ISO 14956.

4. EN 15267-3 requires the manufacturer to describe the QAL3 functionality. EN ISO 16911-2 also requires the manufacturer to describe the capability of the AMS to be linearity tested as a part of the functional test.



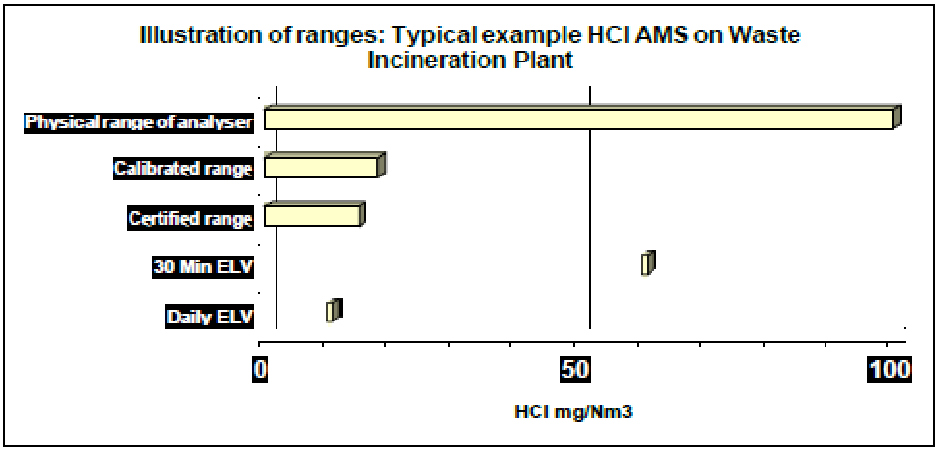


Figure 2, Illustration of ranges appropriate for QAL1 testing

The calibrated range of the AMS is defined by the range over which the QAL2 is performed. However, the measuring range of the AMS should encompass all expected peaks in emissions.

2.2 Functional tests

The functional tests are a series of checks carried out on the AMS. These tests must be performed up to one month prior to the start of the QAL2/AST parallel measurements. The functional tests shall be carried out as a separate visit to the QAL2/AST, in case any corrective action is required, before the parallel measurements are performed. Several different parties will be required to carry out these tests, due to the variety of tasks, and they should be recognised as competent by the EPA. The responsibilities for carrying out the functional tests are outlined in Figure 5.

2.3 QAL2 – Installation and calibration of the AMS

QAL2 covers the installation of the AMS and its calibration by means of parallel measurements against a Standard Reference Method (SRM). QAL2 also includes a set of functional tests to check that the instrument is installed correctly, and can achieve the uncertainty required by the IED.

The QAL2 procedure is required on installation in the following situations:

1. Within 6 months of the start of commissioning of the AMS.
2. Every three years for waste incineration plant, and five years for large combustion plant.
3. If the AMS has had a significant repair or upgrade, which affects the calibration (See Note 2).
4. If there has been a major change to the plant including a significant change of fuel (See Note 2).
5. If AST shows that a new calibration is required (refer to FAQs).
6. If the QAL3 checks show that the CEMS no longer satisfy the drift allowance in the QAL1 certificate.
7. If the AMS exceeds the limits for operating outside the valid calibration range (See Note 3).
8. If the operator chooses to calculate the volumetric flow (instead of continuously measuring it). A QAL2 campaign on flow would validate the accuracy of the methodology used.

NOTE 2 - Changes to the plant or fuel can have an effect on the emissions profile of the process, and may require a new QAL2 procedure. The following is considered a significant change in fuel:

1. The change in fuel alters the flue gas emission profile.
2. The change in fuel results in a licence revision.
3. The fuel is changed from one to another of the following types – solid, liquid, and gaseous.
4. The fuel is changed from a single type to a mixture of fuel types, or vice versa.
5. The thermal input is more than 10% per year for the alternative fuel.

If the process operator can prove that the calibration function is still valid this will not be required. An immediate AST shall be performed and if the variability and acceptance tests pass the calibration function remains valid.

NOTE 3 - If AMS measured values exceed the valid calibration range, a new QAL2 may be required. This is necessary if either of the following occurs:

1. More than 5% of AMS calibrated and standardised values during a weekly period are outside the valid calibration range for more than five weeks between two ASTs.
2. More than 40% of AMS calibrated and standardised values during a weekly period are outside the valid calibration range for one or more weeks.

Multiple calibration functions will be required on processes that have distinct operating modes, for example a change in fuel. Separate sets of parallel measurements shall be performed during each mode to establish multiple calibration functions.

New installations may have had AMS installed in order to carry out commissioning, and subsequently been kept by the process operator. The AMS should be checked that it meets the QAL1 requirements for the site and that it is installed in a location that will provide representative sampling, before the initial QAL2 is carried out.

Once the need for a new QAL2 has been triggered, the new calibration function must be implemented as soon as practicable, but within three months. During this time, the previous calibration function must be used until the new calibration function has been determined.

After the first QAL2 has been performed on an AMS, an AST (see section 2.4) may be performed instead of subsequent QAL2s, if all of the following criteria are met:

1. There has been no significant change to the plant operation or fuel since the last AST.
2. At least 95% of the AMS measured values at standard conditions since the last AST are less than the maximum permissible uncertainty specified in the IED.

Permission from the EPA must be obtained before adopting this approach.

FIELD MEASUREMENTS

IS EN 14181 requires **at least 15 valid parallel measurements** spread over three days. These three days do not need to be consecutive, but must be performed within a period of at most 4 weeks. The time interval between the start of each parallel measurement must be at least one hour. Synchronisation of watches/clocks with the DAHS must be carried out before parallel measurements commencement. It is advised to carry out at least two additional parallel measurements than the minimum in case some are deemed as invalid (outliers). The calibration procedure needs a good spread of concentrations to provide a reliable calibration function. Parallel measurements should ideally be performed when emissions are at their highest and most varied. This approach may not be possible though due to process type and plant conditions. In general, one of three situations will arise;

CALIBRATION FUNCTION

Procedure A - A good spread of data. A dataset is deemed to have a wide spread when the difference between the highest and lowest SRM parallel measurements at reference conditions* is greater than the maximum permissible uncertainty, in which case the first procedure for calculating the calibration curve given in EN 14181 ('Procedure A') must be followed. See Section 6.4.3 of EN14181.

Procedure B - A high-level cluster, this occurs when there is little variation in emissions. A data set is defined as a high-level cluster when the difference between the highest and lowest SRM parallel measurements at reference conditions* is less than the maximum permissible uncertainty, and the lowest SRM parallel measurement at standard conditions is greater than 15% of the ELV. If the dataset is classed as a high cluster 'Procedure B' in EN 14181 must be used to calculate the calibration function.

Procedure C - A low-level cluster, this occurs when emissions are controlled. A data set is defined as a low-level cluster when the difference between the highest and lowest SRM parallel measurements at reference conditions* is less than the maximum permissible uncertainty, and the lowest SRM parallel measurement at standard conditions is less than 15% of the daily ELV. If the dataset is classed as a low-level cluster, 'Procedure C' in EN 14181 must be used to calculate the calibration function.

* Please note that the EN 14181 standard reads “standard conditions” when it actually means “reference conditions as per licence/permit” as both the uncertainty and the ELV are expressed at reference conditions. This would include temperature, pressure, oxygen and moisture corrections when applicable.

EN 14181 also requires confirmation that the AMS can read zero. This can be obtained when the plant is turned off, or a surrogate zero reading from the functional tests can be used to provide a zero reading to include in the calculations. The gases used for surrogate values must be ISO 17025 certified and shall have an uncertainty ≤ 2%.

Use of surrogates:
The calibration function procedure selection (A, B or C) must be carried out exclusively from the analysis of at least 15 valid measurements dataset. **No surrogate values shall be added to the dataset for procedure selection**. If after assessment of the dataset Procedure B is selected, a single zero surrogate value shall be included along with the dataset for the calibration function calculation. In the case of Procedure C, a single zero surrogate and a single span surrogate at ELV level* shall be included to the dataset for the calibration function calculation. No surrogates shall be added to the dataset in case of Procedure A. The QAL2 report shall clearly present the data used for procedure selection and the data used for further calculation if surrogates are added. (2 data tables may be necessary).

Calculating a calibration function using Procedure C is not possible for particulates, as there are no suitable surrogate materials. If expected emissions are likely to be low resulting in a low-level cluster, a reduced set of parallel measurements may be performed (unless this is the first QAL2), and if agreed with the EPA. Five parallel measurements may be performed over three days with a total sampling time of at least seven hours and thirty minutes. Performing fewer measurements but sampling over longer durations will allow the collection of more particulate and reduces the uncertainty. If this approach has been agreed and followed, the AMS shall be used as an indicative monitor (qualitative purposes), and a procedure shall be established by the operator to track changes in concentration, establish limits that would indicate a significant change in emissions, and outline what actions shall be undertaken to investigate and correct any exceedances.

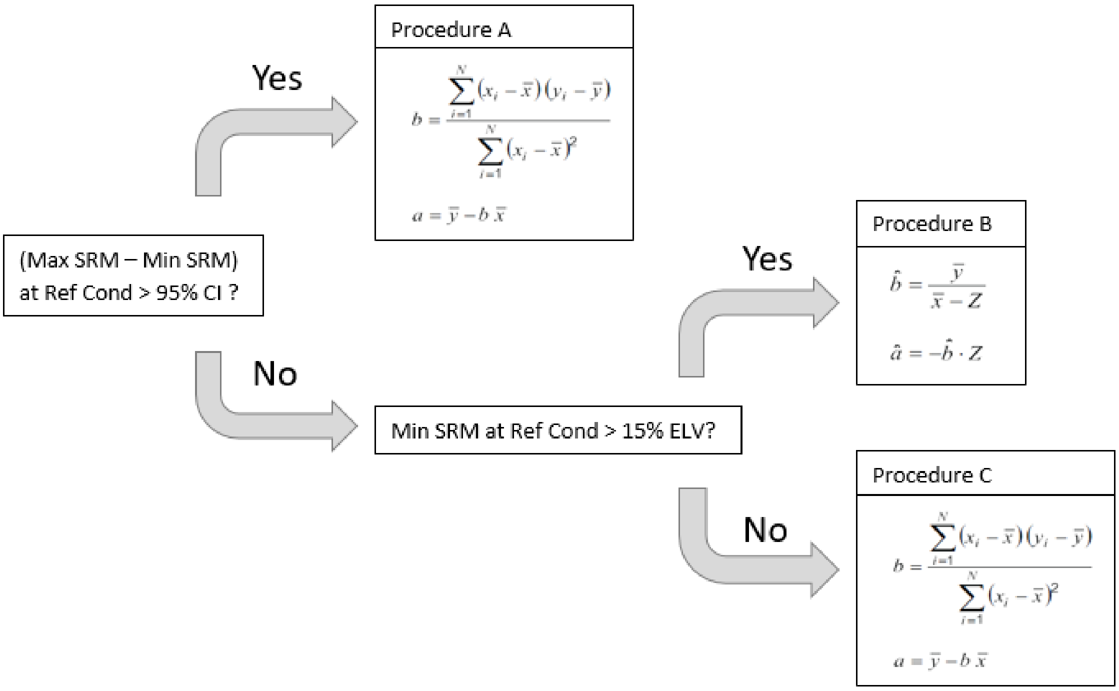


Figure 3: Calibration function Procedure selection flowchart

NOTE 4: It is recommended to use a calibrated gas blender device to supply a surrogate span gas concentration at the ELV level since a different concentration would lead to an inaccurate calibration function.

Procedure D – this procedure is exclusively relevant to volumetric flow/velocity AMS calibration. It forces the calibration function to zero provided that the AMS is capable to operate and generate results at zero. In practice, it is similar to Procedure B, although no surrogates are added to the dataset.

VARIABILITY TEST

For Procedures A, B, C and D:

The variability test determines if the calibration function obtained for a parameter is valid. The calibration function is accepted when the standard deviation of the difference between calibrated AMS and SRM values (both at reference conditions) is less than the maximum acceptable uncertainty in legislation (IED).

The variability test shall be carried out exclusively from the analysis of at least 15 valid measurements dataset. No surrogate values shall be added to the dataset for the variability test.

R^2 is a figure of merit for a linear fit, derived from the residuals of the data from the best fit line, and provided as an output from most fitting routines, and while it is not a rigorous measure, it can be used to provide a basic indication of the quality of a fit. In general, a fit with an $R^2 > 0.9$ can be considered linear although it does not qualify the test as a pass.

For Procedure D only:

For volumetric flow/velocity AMS, the requirement of $R^2 > 0.9$ becomes mandatory, if the data spread for both AMS and SRM values are lower than 15%.

CALIBRATION RANGE

For Procedures A, B, C and D:

A valid calibration range is also determined at the same time the calibration function is calculated. This is either the highest calibrated AMS parallel measurement at reference conditions plus 10% (or plus 100% for particulate AMS), or 20% of the ELV, whichever is the greater. The calibration range may also be extended to the ELV, if suitable reference material is available. The extrapolation is valid if the difference between a reference material measurement at the ELV and the extrapolated calibration line at the ELV is less than the uncertainty specified in the relevant legislation. The difference at zero shall be less than 10% of the ELV.

No moisture or O_2 corrections shall be carried out on surrogate values when extending the calibration range up to the ELV. Surrogates are injected into the analyser as dry gas and in most of cases, the cylinder containing the surrogate species does not contain O_2 in the mix.

For Procedure D only:

For volumetric flow/velocity AMS, the calibration range is calculated as 120% of the maximum SRM value in the dataset.

QAL2 IMPLEMENTATION

Once the calibration functions for all applicable parameters have been obtained and all variability tested have successfully passed, the operator must implement the calibration function in their DAHS (see Figure 6). The operator must seek approval from the EPA before new calibration functions are implemented as a result of a QAL2 campaigned. This would generally require a detailed review of the QAL2 report.

2.4 QAL3 – Ongoing quality assurance

QAL3 addresses the ongoing quality assurance of the AMS in operational use. It requires the operator to ensure that zero and span measurements are carried out periodically. The results of these measurements are used in a control procedure, examples of which are Shewhart or CUSUM control charts, to check that the AMS has not drifted out of control, and that precision has not deteriorated. If the AMS exceeds pre-determined alarm limits, it is deemed to be out of control resulting in a QAL3 failure. Adjustment or maintenance of the AMS will be required.
If an AMS fails a QAL3, corrective action is required, the nature of which depends upon the control procedure the operator has in place. If control charts that determine drift and precision separately have been used, adjustments can be made to the AMS. Combined drift and precision control charts, however; do not allow any adjustment of the AMS, and instead require maintenance on the system.

Annex C of the EN14181 standard provides further information covering the QAL3 process.

2.5 AST – Annual surveillance test

The AST is carried out yearly, and its purpose is to check that the calibration function of the AMS is still valid, and that the instrument variability is still within required limits as set out in legislation. The tests comprise a reduced QAL2 test, with fewer parallel SRM tests. **At least five parallel measurements are required**, it is advised to carry out at least one more in case a test is deemed as invalid. The time interval between the start of each parallel measurement must be at least one hour.

The requirements at each stage are described in detail below:

	Stage	Role	Requirement
Pre 14181	Process licensed under IED, ELVs available. Monitoring requirements specified	Regulator to issue the Licence Process Operator, responsible for implementation of EN 14181 and ensure location of instrument meets requirements of relevant standards and sampling locations suitable for parallel SRM testing are available.	Requirements in Directive / Monitoring standards
QAL1	Selection of instrument – based on ELV, species, performance characteristics from type testing, application specific information. Ability of instrument to meet QAL2 and QAL3 requirements: Zero and span / Reference materials / Live output	Process Operator responsible for selecting instrument. Instrument manufacturer is responsible for having instrument certificated, and providing information.	EN 14181 / CEN guidance / Test reports from type approval
Functional test	Functional Tests, prior to QAL2/ASTs	Operator to commission service engineer. Responsibilities in Section 3 for functional tests. Test house to submit report.	EN 14181
QAL2	Commissioning of a Test House to carry out parallel measurements.	Process Operator responsible for selecting an approved contractor.	SRM standards
	Monitoring campaign	Test house - Overall responsibility for QAL2: review functional tests, undertake parallel SRM tests, produce calibration function and report. Process Operator: supply CEMS data.	EN 14181 / CEN guidance / SRM standards
	Report is complete	Instrument manufacturer; may be required to implement new calibration function. Operator – review report and submit to regulator. Regulator – review report.	EN 14181 / CEN guidance
QAL3	Commissioning of AMS	Instrument manufacturer to install and configure instrument, set up QAL3 and ensure instrument capable of carrying out QAL3.	EN 14181 / CEN guidance
	During normal operation	Operator ensures QAL3 procedure, manually or by automatic instrument function. Operator to check control chart and implement any action requirements – maintenance or repeat QAL2.	EN 14181 / CEN guidance / Gases traceable to national standards
AST	Commissioning of a Test House to carry out parallel measurements.	Process Operator responsible for selecting an approved contractor	SRM standards
	Monitoring campaign	Test house - Overall responsibility for AST: review functional tests, undertake parallel SRM tests, produce report. Process Operator: supply CEMS data.	EN 14181 / CEN guidance / SRM standards
	Report is complete	Operator – review report and submit to regulator. If fails, then instrument may need repair and repeat QAL2 will be required. Regulator – review report.	EN 14181 / CEN guidance

Figure 4. Summary of requirements and responsibilities of each stage of IS EN 14181

2.6 Implementation dates for the Industrial Emissions Directive (IED)

- Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control).
- Supersedes the large combustion plant directive (LCPD) and waste incineration directive (WID).
- Applies to new plant after 27 November 2002.
- Applies to existing plant (plant granted a licence before 27 November 2002, or the operators of which had submitted a complete application for a licence before that date, provided that the plant was put into operation no later than 27 November 2003) with some less stringent ELV requirements.

2.7 EN 14181 Timescales

The timescales for implementing the different stages of EN 14181 are:

1. QAL1 – before an AMS can be installed on site;

2. Functional tests – one month prior to QAL2/AST;

3. QAL2 – within 6 months of any requirement for a QAL2 (i.e. initial commissioning, changes to plant conditions or maintenance of the AMS);

4. QAL3 – continuously from installation. It is advisable to commence the QAL3 procedures as soon as the instrument is installed, before the initial QAL2 tests.

5. AST – annually.

3. Responsibilities

3.1. QAL1, QAL2, QAL3, AST, Functional Tests

Although responsibilities are given in EN14181, this is an area where experience of the implementation of the standard in Ireland has shown there is scope for misinterpretation. The Directives and EN14181 refer to a competent authority; in Ireland, this is the EPA.

Activity	**QAL2 & AST**		**Responsibility**
	Extractive AMS	**In-situ AMS**	
Alignment & cleanliness		X	Instrument engineer, or test laboratory or in-house personnel under direct supervision of the Instrument engineer
Sampling train	X		
Documentation and records	X	X	
Serviceability	X	X	
Leak test	X		
Zero and span check	X	X	
Linearity	X	X	
Interferences	X	X	
Zero and span drift (audit)	X	X	
Response time	X	X	
Report	X	X	Test laboratory

Figure 5. Responsibilities for functional tests

There is a wide variety of activities required to complete the functional test audit, which often relies upon a collaborative effort between different parties. Responsibilities for functional tests shall be as per the requirements laid out in Figure 5. Additional guidance describing each activity required during the audit can be found in Annex B.

4. Existing Guidance/Documentation

The following provides a review of existing (and anticipated) guidance, which relates to the implementation of EN 14181. Summaries of the documents are provided, including information on how they may be used by operators, test houses and regulators. Issues related to the relevance of the existing guidance to specific aspects of the implementation of EN 14181 in Ireland will be identified, and advice provided on how these should be addressed.

4.1 Industrial Emissions Directive (IED)

The Directive defines the requirements for monitoring of large combustion plant and waste incineration plant. The directive places requirements on the use of CEN standard methods where these exist. If relevant CEN standards do not exist then a hierarchy of standards may be used, with preference for ISO or other internationally recognised standards, followed by National Standards, such as those produced by BSI, VDI, ASTM, or the US EPA, and finally other methods. The directives provide for certain derogations for particular plant, and define both limit values, and data quality objectives.

4.2 EN 14181, EN 14884, EN 13284-2, EN ISO 16911-2

These standards are addressed by this guidance document. EN 14181 primarily covers AMS which monitor gaseous compounds, EN 13284-2 covers particulate AMSs, and is an extension to EN 14181. EN 14884 is a standard, which covers AMSs that monitor mercury. This standard is based on EN 14181, however it does not address many of the issues which are specific to mercury monitors, and so is somewhat lacking as a full standard for providing quality assurance of mercury AMSs, for example it does not cover issues relating to elemental mercury. EN ISO 16911-2 covers procedures to be used when calibrating flow AMS.

4.3 Standard Reference Methods

Standard reference methods have been developed by CEN and ISO, which address all of the determinants covered by the IED. These include:

Particulates (Total dust)	EN 13284-1
Nitrogen oxides	EN 14792
Carbon monoxide	EN 15058
Sulphur dioxide	EN 14791
Total organic carbon	EN 12619
Hydrogen chloride	EN 1911
Hydrogen fluoride	ISO 15713
Oxygen	EN 14789
Water vapour	EN 14790

These methods are recommended to be used as the SRMs employed by the test house carrying out the QAL2 and AST procedures. FTIR equipment can also be used for the gaseous parameters monitoring. The test houses shall be accredited to ISO 17025 for the relevant methods and carry out measurements within the specified ranges. It is not necessary for the operator to be familiar with these methods, but they should be aware of which SRMs are required for the different determinands required by the directives. This also includes methods for measuring the peripheral parameters required to normalise the stack measurements to standard conditions, including (possibly) water vapour and oxygen.

Where the SRMs are instrumental methods then the equipment used by the test house should be able to be demonstrated to be fit for purpose, within the context of the test house's accreditation to ISO 17025.

The use of other methods as Alternative Reference Methods is addressed by the EN Technical Specification TS 14793, and suitable methods are listed in AG2, Index of Preferred Methods.

4.4 EN 15267-3 (QAL1), EN ISO 14956

These standards provide procedures for the calculation of measurement uncertainty. EN 14181 references EN ISO 14956 to provide a method to calculate the measurement uncertainty of an AMS. EN 15267-3 provides an interpretation of EN ISO 14956 specifically for use in QAL1.

5. Interpretation/Implementation of EN14181 – FAQ

This section provides specific guidance on a number of key areas. The topics are grouped in terms of the different stages, QAL1, QAL2, QAL3 and AST, together with general implementation issues.

The issues covered have been drawn from the questions raised by the EPA, from M20 and the UK implementation, from feedback from operators and test houses, and issues raised within European fora.

5.1 General Questions

How do we apply the standard for low use combustion plants, or for little used fuels?

The standard should be applied as normal. However, there are a number of exclusions listed in the IED for low use combustion plants or little used fuels. These decisions would need to be made on a site/process specific basis, and this would need to be reviewed in conjunction with the relevant directive and in consultation with the EPA.

What ELV’s do we use, and what are their accuracy requirements?

The operators should use the ELV listed in their IE licence. The IED provides data quality objectives. In general, when EN 14181 refers to an ELV in assessment criteria, it is referring to the average daily limit value. It is recommended that AMS have a measurement range, which encompasses at least the half hourly ELV. However, the maximum QAL1 certification range should be 1.5 times the daily average ELV for waste incineration or 2.5 times the daily average ELV for large combustion plant. Where clarification is required operators should refer to their IE licence or the EPA for further guidance. The measurement uncertainty requirements are the figures stated on the IE licence.

Allowable Uncertainties

Species	**Data Quality Standard**
Sulphur Dioxide	20%
Oxides of Nitrogen (as NO_2)	20%
Carbon Monoxide	20%
TOC	30%
HCl	40%
Particulates	30%
Ammonia	40%
Volumetric flow / Velocity	10%

Table 1: 95% Confidence Intervals (CI)

Please note that the confidence intervals for CO and Volumetric flow have been modified in this revision of AG3. This is to prevent a possible failure of the variability test during the QAL2/AST. These revised confidence intervals are not relevant for the validation of normal monitoring results. For normal compliance monitoring, the original confidence intervals stipulated in the Industrial Emissions Directive and your IE licence apply

What do you do if there is no ELV assigned to that species?

The operator should use the general ELV guideline figures from the relevant directive, but if no ELV is given to the species then they should refer to their IE licence or the EPA for further guidance.

What is the significance of the uncertainty of the SRM?

The SRM uncertainty is not directly taken into account in QAL2 and AST tests. However, the operator should require all SRM results to be reported with their uncertainty, in order to assess the validity of the SRM results.

Is all the downtime from EN14181 included in reported downtime as part of IED?

The downtime due to the EN 14181 functional tests should be logged on site, as the instrument will be off line during these tests. QAL3 and auto-calibration procedures will also count as downtime. However, downtime resulting from QAL2 and AST testing will be minimal.

5.2 QAL1 Questions

How do I do a QAL1?

QAL1 refers to requirements for an AMS to be certified under a type approval scheme. Currently in Europe this means for example MCERTS in the UK, or the UBA/TUV scheme in Germany.

The requirement on the operator in terms of QAL1 is that they should select an AMS which has been certified for use over a relevant certification range for the relevant process type for the required determinants (all parameters in the licence with continuous monitoring requirements). It is mandatory that suitable certification ranges should be less than 1.5 times the daily average ELV for waste incineration and 2.5 times the daily average ELV for large combustion plant. In addition, it is suggested the measurement ranges should encompass likely excursions above the ELV, at least to the half hourly ELVs. The linearity of the AMS should be demonstrated up to the measurement range.

How do I decide if an AMS is suitable for my application?

The AMS chosen should be tested and certified (through QAL1) for the determinands (species to be measured) specified in the relevant directive and licence where continuous monitoring is required.

The AMS needs to be certified for a range that is suitable for the operator’s application. The operator needs to ensure that specific site conditions do not reduce the performance of the AMS to below the required standards, and it is recommended that the intended AMS be proven on comparable installations.

All AMS must have provisions that allow either operators, suppliers or test laboratories to perform zero, span and linearity tests by direct injection of calibration gases into the AMS, and also through the whole sampling train, or the introduction of other reference material (e.g. particulate reference filters) once an AMS has been installed. QAL3s require direct injection into the AMS only.

When selecting a suitable AMS, the operators shall select an AMS with a certification range which is not more than 1.5 times the ELV daily average for waste incineration installations, and not more than 2.5 times the ELV daily average for large combustion plant installations.

What do you do if your AMS doesn’t have QAL1?

For an AMS already installed on site or for the measurement of components not yet assessed, since the QAL1 phase cannot be validated, the uncertainty of the values measured can be considered satisfactory if the instrument passes the QAL2, AST and QAL3 requirements of EN 14181. If buying a new AMS, it must have a QAL1 or equivalent certification.

If the AMS does not meet the QAL2/AST/QAL3 requirements and cannot be adjusted or modified to fulfil the requirements, then the operator will be required to replace them within one year (or as agreed with the Agency) with a suitably approved AMS.

What is the difference between certified, supplementary, and measurement ranges of the AMS?

The certified range is used to carry out the QAL1 performance testing and certification of an AMS. The performance criteria for each characteristic under test is based upon this range, therefore the lower this is the better it is likely to operate. The certified range will have been chosen based upon what application the AMS is intended for.

A supplementary range demonstrates that the AMS performance is acceptable above the certified range. Additional testing of the response time and lack of fit of the analyser is carried out for each supplementary range.

The measurement range is the spread of values that the AMS is setup to measure. Some measurement ranges have fixed lower and upper values, whereas others are auto ranging. The AMS measurement range shall be setup to encompass all expected peaks in emissions, yet still meet the uncertainty requirements of the ELV.

Is the AMS approved with the entire sampling train included? What do you do if you change it?

The AMS comprises the analyser(s) and additional devices, which includes the sampling train for obtaining a measurement result. It is the complete system, including the sampling train that has been tested and certified.

There are several types of sampling train, such as:

- Simple heated lines coupled to heated analysers that measure gases in a hot, wet form.
- Heated lines and chiller-driers, delivering the sampled gases to the analyser in cooled, dry form.
- Heated lines and permeation-driers, delivering the sampled gases to the analyser in cooled, dry form.
- The stack-mounted probe is coupled directly to a permeation drier, which then passes the cooled, dry sample gas via an unheated line to an analyser.

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

As industrial processes often differ in their requirements, some flexibility is allowed in the selection of the sampling train with the AMS. However, the installed AMS must not deviate from the type of sampling train specified on the certificate to ensure the AMS is not degraded, such that it no longer meets the required performance specifications.

Allowable variations could include:

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

Any other changes to the system would require a review of the changes by the regulator, and may result in a re-certification of the whole system including the analyser.

5.3 QAL2 Questions

When should you do a QAL2?

A QAL2 should be carried out:

- Within 6 months of the commissioning of a new AMS system;
- On existing AMS system(s) that have the relevant accreditation to comply with the standards;
- At least every five years for large combustion plant installations, and three years for waste incineration installations;
- If a QAL3 evaluation or AST demonstrates a need for a QAL2;
- If there are significant changes, upgrades or repairs to the AMS, which will influence and change the results significantly (Section 2.3);
- If there is a change of fuel (Note 2);
- Whenever there is a significant change in plant operation, which changes the emissions.
- If the AMS exceeds the limits for operating outside the valid calibration range, as defined in EN 14181 (Note 3).
- If the operator chooses to calculate the volumetric flow (instead of continuously measuring it). A QAL2 campaign on flow would validate the accuracy of the methodology used.

A new QAL2 shall be performed and implemented within three months of establishing the need for one.

How do we carry out a QAL2 when the emissions are always near zero? (Is an AST acceptable?)

If SRM and AMS parallel measurements result in a low cluster of data points, then ‘Procedure C’ must be used to calculate the calibration function (see Section 2.3)

What data do you use for a QAL2 or AST?

When conducting parallel measurements, the measured signals from the AMS (referred as first level data [FLD] in EN17255) shall be taken directly from the AMS (e.g. expressed as analogue or digital signal) during the QAL2 and AST procedures specified in this standard, by using an independent data collection system provided by the organisation(s) carrying out the QAL2 and AST tests.

All data shall be recorded in their uncorrected form (without corrections for temperature, pressure, moisture or oxygen). A plant data collection system with ongoing quality control can alternatively be used to collect the measured signal from the

AMS. The plant data collection system can be used to record the analogue data but should not be used to normalise the data. In other words, **the data collected must be in the uncorrected form**. AMS values used should be the values output from the analyser prior to any subsequent corrections/calculations.

Since the purpose of a QAL2 is to calculate a calibration function to be implemented in the DAHS software, the CEMS data used for a QAL2 must not have the calibration function implemented, raw data directly from the analyser must be used.

How to implement the calibration function

The calibration function shall be calculated by the test house carrying out the QAL2 procedure, and reported to the process operator who is responsible for its implementation. Depending on the AMS, it can either be used to set calibration functions in the analyser, or applied as a correction to the results in the data handling software (DAHS). The AMS provider shall either train the process operator to enter the calibration functions into the analyser software/data handling system, or be available to carry this out themselves. A flow chart illustrating the process used to calculate the calibration function is included in Annex E of the EN 14181 standard.

The sequence of data treatment should be as follows (refer to EN17255 for further information):

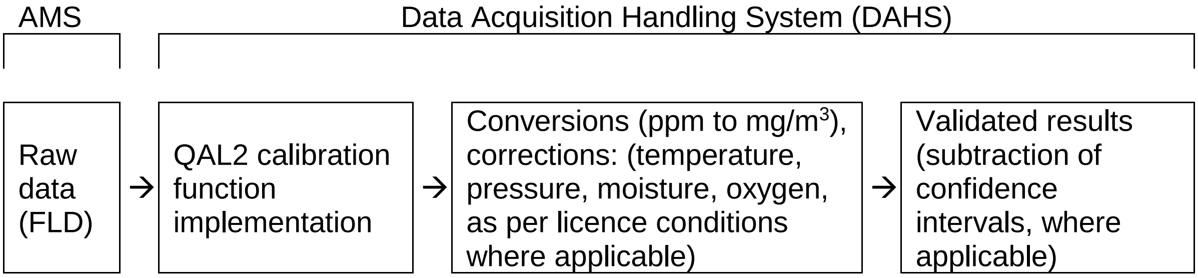


Figure 6: Sequence of data treatment

NOTE: There are 3 ways to apply the confident intervals to validate continuous monitoring results and the EPA will accept any of them:

1. Subtraction of the uncertainty calculated in a QAL2 report
2. Subtraction of the confidence interval at the measured level (provided that is lower than the ELV)
3. Subtraction of the confidence interval at the ELV level

Result correction after calibration implementation

When peripheral instruments (moisture/O_2 monitors) are included in the QAL2 campaign, the calibration function for those peripheral instruments shall be implemented before applying moisture or oxygen corrections to other results Equally, if oxygen is measured on a wet basis and the reference conditions require dry basis results, the oxygen values shall be corrected for moisture before applying oxygen corrections to other parameters.

The above figure highlights the importance of using raw data for the calibration function calculation. If the data used to calculate the calibration function is already corrected, the output of the derived calibration function will be in conflict with the data treatment sequence, possibly double-correcting the data (corrected data as an output of the calibration function & further correction by the DAHS software) as seen in the above sequence.

The below table summarises the actions to take depending on the kind of analysers used (wet/dry) during the QAL2 campaign. This is also applicable to ASTs.

AMS wet + SRM wet →	No dataset corrections. Moisture corrections set in the DAHS software after QAL2 calibration function implementation (if applicable)
AMS wet + SRM dry →	Revert SRM to AMS conditions (wet). Moisture corrections set in the DAHS software after QAL2 calibration function implementation (if applicable)
AMS dry + SRM wet →	Revert SRM to AMS conditions (dry). No moisture corrections apply in the DAHS software.
AMS dry + SRM dry →	No dataset corrections. No moisture corrections apply in the DAHS software.

Table 2: AMS types and required conversions / corrections

It may also be necessary to correct the SRM for temperature and pressure if the AMS analyses at stack conditions. For example, raw data from some particulate AMS are not corrected for temperature and pressure.

NOTE 5: Most of AMS for EN 14181 sites are extracting systems, meaning that the sample is extracted through a conditioning system (heated line), and the analysis is carried out of the stack, in the CEMS hut at AMS conditions of temperature and pressure. In those cases, no stack temperature or pressure corrections apply and doing so would lead to inaccuracies in results. The typical example would be an FTIR installed for an incineration process, where results by AMS (in mg/m^3) are already provided at standard temperature and pressure (mg/Nm^3).

How do we extend the calibration range so it covers up to the ELV?

If the valid calibration range does not cover up to the ELV, and greater confidence in the performance of the AMS at the ELV is required, reference materials at zero and at a concentration close to at the ELV shall be used, where available, as part of the calibration procedure to confirm the suitability of the linear extrapolation.

In this case, calculate the deviation between the calibrated measured value of the AMS at zero and ELV and the corresponding reference values. The deviation at ELV should be less than the uncertainty specified by legislation. The deviation at zero should be less than 10% of the ELV. See worked example for HCl in Annex B

What happens if the instrument fails a QAL2?

If the instrument fails a QAL2 calibration, then the relevant problem, e.g. instrument modification or variability test will need to be addressed immediately before carrying out an immediate repeat QAL2 test on the AMS. Without a satisfactory working AMS, the process may have to cease. Backup AMS are recommended for this eventuality. Failure of the QAL2 test may also be caused by poor quality SRM measurements, and this should be considered when reviewing the possible causes of failure.

How do we avoid cluster effects or what do we do with them, at high levels and at low levels?

The test laboratory must select a set of representative operating conditions that covers as wide a range as possible to avoid cluster effects, without modifying the process to artificially increase emissions. Ideally operators should select a time when the emissions are likely to be their highest and most varied, but the process may not be deliberately varied in order to create higher than normal emissions. For example, this can be carried out immediately after bag filters are replaced, when emissions of particulate are temporarily higher, and this is an ideal time to measure a wider range of emissions.

Depending on the process and type of plant it is not always possible to get a good spread of data. For a high level cluster a calibration function can be determined using ‘Procedure B’, for a low level cluster a calibration function can be determined using ‘Procedure C’ (Section 2.3).

What’s the best way to incorporate peripheral measurements, as they can have a large effect on the variability test?

AMSs for oxygen and moisture (if used) must be certified to MCERTS/TUV or other approved performance standards. The same applies to SRMs that use instrumental techniques. Functional checks should be performed on the AMSs for oxygen and moisture..

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

SRM monitoring for oxygen is required in any event for the QAL2 tests for other parematers, so the 15 sets (or more) 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%, Uncertainty (CI) = 10%
Moisture:	ELV = 30%, Uncertainty (CI) = 30%

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

How do you correct to reference conditions?

See first worked examples in Annex A.

How do we treat negative numbers from the SRM & AMS?

In order to correctly identify offsets, which may form part of the calibration function, negative values should be included in the QAL2 process, and not be converted to zero values.

How do we treat laboratory results for SRM monitoring reported as <LOD?

In such cases where the analytical results are reported below the limit of detection (i.e. wet chemistry parameters such as SO_2 or HCl), a value of 0 must be used in the datasets for the relevant SRM monitoring runs.

Should the sample ports and platform, and AMS location conform to relevant standards? Are they co-located?

For installation of the AMS the operators should follow the provisions for location and access described in EN 15259, in order to determine the optimum location for a representative sample. Before installing the AMS, the stack gas must be characterised in order to determine whether there are variations across the stack, such that the sampling position will have a significant bias on the readings. It is critical that AMS are not only located at a point where there is access and other provisions for the effective and continued operation of the AMS, but also in a location which complies with the requirements of applicable standards. This is because the SRM measurements must be representative, or the bias in the readings will be so great that the AMS may not meet the requirements of QAL2.

Additionally, the AMS must be located at a point where the sample is representative, and the SRM and the AMS (or its sampling location) should be located in the same sampling plane, and so that they do not interfere with each other.

The sample ports and platform should conform to the relevant sections in IS EN 13284-1 where isokinetic sampling is required – primarily for particulate measurements. The port dimensions shall allow sufficient space for insertion and withdrawal of the sampling equipment. A minimum diameter of 125 mm or surface areas of 100 mm x 250 mm are recommended. This is described in EPA Guidance Note AG1.

If a new installation has had an AMS installed in order to carry out commissioning operations, it is important to note that testing is still required to find a suitable position that will allow representative sampling by the AMS. If the homogeneity test proves that the AMS is not in a suitable position, it must be relocated to a position that is.

When should you do a QAL2 after installation?

The initial QAL2 is required six months after AMS commissioning. It is recommended that the QAL3 process be implemented as soon as possible after installation in order to assess the AMS performance, before the QAL2 is carried out.

Can you use $R^2 > 0.9$ as a guide? What if it is below that?

The use of R^2 greater than 0.9 provides a reasonable guide that the calibration function is acceptable. When R^2 is less than 0.9, it may still be acceptable to use the calibration function, however there will be a greater risk that the AMS will fail the variability test.

Should there be a special case for VOCs, which are present in very low concentrations?

There is no special case for speciated VOC measurements, which are addressed as total organic carbon in the IED. These measurements will often need to be treated as low emission cases, and very often will have clusters of results around zero.

How should NO_2, NO, and NO_X measurements be handled?

The QAL2 calibration function should be determined as appropriate to the data, which will be reported under the IED, and for which the ELVs are prescribed. Where NO and NO_2 are measured separately, the QAL2 calibration should be performed using the combined NO_X values with NO and NO_2 values expressed as NO_2. Equally, the calibration function must the implemented to the combined NO and NO_2 values expressed as NO_2.

NOx (ppm) = NO (ppm) + NO_2 (ppm), if measured separately
NOx (mg/m^3) = NO x 46/30 (mg/m^3) + NO_2 (mg/m^3), if measured separately

For low level testing, is it possible to change the range to its most sensitive?

The AMS 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 AMS to achieve this requirement, the AMS shall be verified for monitoring the higher ranges.

What should I do about outliers?

The data set obtained from the parallel measurements shall be checked for outliers. It is important to carry out at least two more than the minimum amount of tests for a QAL2, and at least one more than the minimum for an AST in case some are invalidated. The following method must be used~~,~~ and any outliers identified and removed from the data set must be highlighted. A standardised approach for dealing with outliers has been created, and the following method is recommended:

1. Create a plot of raw AMS and raw SRM data, expressed under the same conditions as the AMS.
2. As a guide, if the R^2 value of the dataset is greater than 0.9, an outlier test is likely not necessary.
3. Calculate the difference, D_i, between the SRM and the AMS values.
4. Calculate the average of these differences, as well as the standard deviation of the differences (S_D).
5. If Di for any paired sample is greater or smaller than D_{ave} by more than two times the standard deviation (2 x Sd) then that paired sample is most likely an outlier and must be rejected
6. This procedure only needs to be carried out once, further repetition is not required.

A worked example is available in Annex A.

How long should I sample with the SRM?

The sampling time for each parallel measurement shall be at least 30 min, or at least 4 times the response time of the AMS, including the sampling train (as determined during the response time measurements carried out during QAL1), whichever is the greater. In general, the sampling time should equal the shortest averaging time, which is required by the ELV specification. If the sampling time is shorter than 1 hour, then the time interval between the start of each sample shall be at least 1 hour. These measurements shall be uniformly spread both over at least 3 days and over each of the measuring days of normally 8 hours to 10 hours (e.g. not 5 measurements in the morning and none in the afternoon) and be performed within a period of four weeks.

For volumetric flow, the parallel measurements shall be performed to obtain data points that are evenly spread out over a minimum of 5 h and the requirement of performing the tests over a minimum of 3 days is not required.

Do I need to do QAL2 on flow?

Yes, you do. The EN 16911-2 standard brought requirements for the calibration of automatic monitoring systems for velocity/volumetric flow, including flow determination by calculation.

How is a QAL2 campaign carried out when the operator calculates the volumetric flow as per Annex E of the EN1699-1 standard?

When the operator chooses to calculate the volumetric flow results (as opposed to direct measurements) as per Annex E of the EN16911-1 standard, the first level of results obtained for flow are expressed at the following basis: dry, 0% O_2, 273.15K and 101.3Kpa. The results obtained by this method shall be used as AMS raw data (x) in the dataset. The SRM values obtained by direct measurement shall be expressed at the same conditions before incorporating them to the dataset as SRM (y) values.

The DAHS settings in this case would only include the implementation of the calibration function followed by oxygen correction as per Licence conditions.

5.4 QAL3 Questions

How can QAL3 be applied to older/existing AMSs?

The existing AMS should be able to carry out zero and span checks for QAL3 directly into the analyser, as the QAL3 is for checking the AMS, and not the sampling line.

The AMS and the data recording systems must be able to:

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

The EPA should be consulted, if an AMS is unable to perform a QAL3.

What is the interval between QAL3 measurements?

The minimum period between QAL3 measurements is decided by the maintenance interval of the AMS derived during the analyser performance testing, but in any case there must not be more than 2 weeks between QAL3 checks. If operators are using CUSUM charts, then weekly zero and span checks shall be implemented.

What happens when the AMS does its own internal zero/span?

Operators may use AMS that carry out internal QAL3 zero/span checks, as long as this had been validated and approved during the QAL1 performance testing.

What are the benefits of using either CUSUM, Shewhart or EWMA charts?

A Shewhart chart tracks zero drift and span drift over time using two separate charts. Alarm levels are set using the associated standard deviations, which will alert the operator to any potential problem with the AMS. This chart is simple to use but does not allow any external adjustment of the AMS.
A CUSUM (Cumulative Sum) chart provides enough information on changes in analyser performance to allow adjustment of the zero and span to bring the analyser back under control but it is more complicated to implement than the Shewhart chart.

A EWMA (Exponentially Weighted Moving Average) chart uses the average of previous measurements, giving less weight to older values, to detect any changes in the AMS results. It is simpler to use than a CUSUM chart, and can detect small amounts of drift a lot better than a Shewhart chart.

What do you do with cross-duct systems?

EN 13284-2 provides specific guidance for particulate monitors including cross stack optical instruments. It is the responsibility of the manufacturer to provide the QAL3 procedure.

How do you handle readjustments?

With the use of CUSUM control charts, zero and span adjustments can be made to the analyser, if the QAL3 checks determine drift of the analyser has occurred. Other adjustments are not allowed, and care should be taken to ensure instruments with direct remote links (i.e. to the manufacturer) are not altered between QAL2 tests. Some AMS carry out automatic zero and span checks, as well as minor adjustments. This is acceptable if this was tested and certified under QAL1. For other charts, the operator is not allowed to make adjustments.

What levels of span gas should I use for QAL3?

Zero and span checks shall be performed using reference materials, such as calibration gases, which are traceable to national standards and manufactured in accordance with ISO 6142.

There are no specific requirements on what span gas value should be used when performing the QAL3 checks, however, it is recommended that a concentration of somewhere between 80% and 100% of the half hour ELV be used.

What if reference materials aren’t available?

Surrogates for true reference materials will be required for performing zero and span checks on particulate monitoring AMS, and these should be assessed as part of the QAL1 testing for their validity in providing an appropriate QAL3 check.

How should I carry out an HCl/HF QAL3?

Performing QAL3 checks with reactive gases can take a long time whilst the system is purged. As a result, large quantities of span gases will be used, becoming expensive, especially with more frequent checks. Consequently, it is current best practice to carry out these tests every three months instead. In some cases, HCl and HF can be excluded from QAL3 requirements with the agreement of the Agency.

When is a QAL3 test said to have failed?

The QAL3 test 'fails' when the process control mechanism being followed (which may be a CUSUM, Shewhart, EWMA or other approach) identifies that the drift or variance of the AMS has exceeded the pre-determined alarm levels (See Annex C of EN 14181). Warning levels should also be established to help indicate that the AMS is beginning to drift out of control. The process operator should establish procedures describing what action should be taken when these levels are exceeded. A check should be made that the failure of the QAL3 is not due to a fault in the zero and span procedure. If this is the case, then these data points may be excluded from the QAL 3 calculations, and this should be logged on site. The criteria to establish that the AMS is out of control are detailed in Annex F.

What do you do if an AMS fails a QAL3?

If the process operator uses control charts that determine drift and precision separately (e.g. CUSUM charts), then adjustments to the AMS may be carried out. However, if the operator uses control charts that combine drift and precision maintenance of the AMS will be necessary. The AMS manufacturer and service engineer will have to be called to service the AMS. A QAL3 failure may trigger a repeat QAL2.

5.5 AST Questions

Extension of calibration range from QAL2

Once a QAL2 has been performed, a valid calibration range will also be set, this is the range that the calibration function will be valid over. If an AST shows that the calibration function is valid beyond the existing valid calibration range (i.e. the AST passes) it can be extended. This valid calibration range can be extended to the highest calibrated AMS value at standard conditions, plus 10%, so long as it does not exceed 50% of the ELV.

What is the time between parallel measurements?

The start times between parallel measurements shall be at least one hour, as in a QAL2.

What AMS data should be recorded for the calibration function calculation?

When conducting AST measurements, the measured signals from the AMS shall be taken directly from the AMS system if possible (e.g. expressed as analogue or digital signal) or the plant data collection system with ongoing quality control can additionally be used to collect the measured signal from the AMS.

All data shall be recorded in their uncorrected form (without corrections, e.g. for temperature and oxygen). QAL2/AST reports using data that is not in uncorrected form may be rejected.

Can an AST be used to check the single calibration function is valid with new or little used fuel types, rather than a new function QAL2?

An AST can be used to check the single calibration function instead of carrying out a QAL2 if the fuel type does not change significantly. Examples are when:

- The operator can demonstrate that the change in process does not affect the emissions profile and the original calibration factor remains valid;
- The thermal input is less than 10% per year for the alternative fuel, and/or;
- The change in fuel use can be shown to have no significant effects on emissions, when compared to the original fuel.

If there is a significant change of fuel, then the operator should first perform an AST. If the results fit within the 95% confidence interval of the calibration function, then no further testing is required. If not, then a full QAL2 is required. A change of fuel is considered significant if:

- The change of fuel is known to result in a change in the emissions profile.
- The change of fuel requires a licence review.
- The change is from any one of the following types to another – gaseous fuel, liquid fuel, and 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).

How do you perform calculations for an AST? When should it be done?

An AST shall be performed 12 months (plus or minus two months) after the previous QAL2/AST. Therefore, if a QAL2 test was undertaken in 2016 than an AST will be undertaken in 2017 and then annually after that until a new QAL2 is required as defined in EN 14181.

5.6 Functional Test Questions

Who does them and when?

A functional test must be undertaken before any QAL2 or AST testing is carried out, as a separate event. These tests shall be carried out before the parallel measurements, but within a month previous to the QAL2, in case there are any problems that require resolving. It is the responsibility of the operator to ensure that the functional tests are carried out and they shall not be completed more than one month earlier to the QAL2/AST measurements. The functional tests may be performed by the AMS supplier/manufacturer/service engineer, by the testing laboratory under the direct supervision of the AMS supplier/manufacturer/service engineer or by on-site personnel trained by the AMS supplier/manufacturer/service engineer on the specific AMS instrument (make and model) installed on site, and they should be recognised as competent by the EPA and have a deep and proved understanding of the requirements of EN 14181 standard. The requirements for the functional tests are listed in Figure 4.

How do I carry out a functional test audit?

The functional test audit involves an assessment of the AMS and its entire sampling train (from the tip of the probe to the analyser), as well as the ongoing quality control systems that maintain proper operation. A list of what the requirements are, as well as a guide to completing it can be found in Annex A of EN14181.

What should a service engineer be doing?

The service engineer should carry out instrument maintenance as part of the functional tests, prior to the QAL2/AST being carried out. They will have in depth knowledge of the AMS and associated systems and should assist with the visual and practical checks that are required. The service engineer should not alter any parameters once a QAL2 or an AST has been carried out unless CUSUM control charts indicate an adjustment is required or the AMS requires major repair. Any alterations to the AMS could affect the calculated calibration function and would probably mean a repeat QAL2.

6. Worked Examples

Several specific worked examples are included in Annex A. In addition, where appropriate, example spreadsheets can be found at the web sites detailed below. **The example spreadsheets are for guidance only and users should validate their own calculation procedure**.

The examples cover the following aspects of EN 14181.

Conversion of Data to Reference Conditions		Annex A
QAL2		
	Flow Chart for QAL2 Calibration of an AMS	Annex B
	Outliers	Annex A
	Calculations - Procedure A	Annex B
	Calculations - Procedure B	Annex B
	Calculations - Procedure C	Annex B
	Calculations - Procedure D (flow)	Annex B
	Functional Test Sheet	Annex D
AST		
	Flow Chart for Annual Surveillance Test of an AMS	Annex C
	Outliers	(as per QAL2)
	Calculations - AST	Annex C
QAL3		
	Shewhart chart	Annex F
	CUSUM chart	Annex F

Please note that for the calculations including in this guidance, the reader may obtain slightly difference results depending on the number of decimal figures used.

7. Bibliography of Relevant European Documents

A summary is provided here of the status of implementation of European Standard EN14181 and related EN standards in certain countries of the European Union in order to give some background to their implementation in Ireland. European and International standards, European Union Directives, and other documentation that are already published or being drafted, referred to in this Guidance Document include:

1. **EN 14181:** Stationary Source Emissions
   Quality assurance of automated measuring systems; published 2014

2. **EN 13284-2:** Stationary Source Emissions
   Determination of low-range mass concentration of dust – Part 2: Automated measuring systems; published 2004

3. **EN 14884:** Stationary Source Emissions
   Determination of total mercury: Automated measuring systems;

4. **EN 16911-2:** Stationary Source Emissions
   Manual and automatic determination of velocity and volume flow rate in ducts. Part 2: Automated measuring systems

5. **EN 15259:** Stationary source emissions – Air quality - Measurement of stationary source emissions - Requirements for measurement sections and sites and for the measurement objective, plan and report

6. **EN 17255-1:** Stationary source emissions - Data acquisition and handling systems. Part 1: Specification of requirements for the handling and reporting of data.

7. **A Suite of EN standards prescribing the implementation of Standard Reference Methods (SRMs)**
   EN 1911: Stationary source emissions – Determination of mass concentration of gaseous chlorides expressed as HCl - Standard reference method
   EN 12619: Stationary source emissions – Determination of the mass concentration of total gaseous organic carbon — Continuous flame ionisation detector method
   EN 13284-1: Stationary source emissions – Determination of low range mass concentration of dust – Part 1: Manual gravimetric method
   EN 14789: Stationary source emissions –Determination of volume concentration of oxygen –Reference method;
   EN 14790: Stationary source emissions – Determination of water vapour in ducts;
   EN 14791: Stationary source emissions –Determination of mass concentration of sulphur dioxide – Reference method;
   EN 14792: Stationary source emissions – Determination of mass concentration of nitrogen oxides - Reference method: Chemiluminescence
   EN 15058: Stationary source emissions – Determination of the mass concentration of carbon monoxide — Standard reference method: non-dispersive infrared spectrometry
   EN 16911-1: Stationary source emissions – Manual and automatic determination of velocity and volume flow rate in ducts. Part 1: Manual reference method
   ISO 15713: Stationary source emissions – Sampling and determination of gaseous fluoride content

   (see also CEN/TS 14793: stationary source emissions – Intralaboratory validation procedure for an alternative method compared to a reference method)

8. **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: Performance criteria and test procedures

10. **EN ISO/IEC 17025:**
    General requirements for the competence of testing and calibration laboratories;

11. **Directive 2010/75/EU:**
    The Industrial Emissions Directive;

12. **ISO 11095:**
    Linear calibration using reference materials;

13. **Draft EN Standard (of CEN Technical Committee 264, Working Group 9)**
    TC264 WI264076: Draft Title: Stationary source emissions: Quality assurance of the treatment of AMS outputs, (data processing, data reduction, and data substitution), for monitoring of environmental data

Annex A – Worked Examples for EN 14181

Conversion of Data to Normalised Conditions and Useful Equations

Equation 1. Calculating the Concentration of Particulate

$$C_{meas} = \frac{m_{meas}}{v_{meas}}$$

C_{meas}	Concentration of Particulate, (Stack Temperature and Pressure, uncorrected for oxygen, dry gas basis), in mg/m^3
C_{meas}	Total mass of Particulate collected on filter, in mg
V_{meas}	Volume of Gas Sampled (Stack Temperature and Pressure, uncorrected for oxygen, dry gas basis), in m^3

Equation 2. Conversion of Pollutants from ppm to mg/m^3

It is accepted that the main combustion gas species are reported in a mass per volume basis and as many analysers output data on a volume per volume basis (parts per million, ppm), a conversion is required. The following equation is used to convert concentrations in ppm to mg/m^3

$$C_{mg/m^3} = C_{ppm}\, x \frac{mol\,wt}{22.414}$$

$C_{mg/m3}$	Pollutant Concentration (273.15K, 101.3 kPa)
C_{ppm}	Pollutants Concentration (output from analyser) mol
mol. wt	molecular weight of the species being measure
22.414 l/mol	The molar volume of any gas at 273.15K, 101.3 kPa

Table of conversion factors of the major combustion gas species

Species	Molecular Weight (mol. wt)	Conversion Factor
Sulphur dioxide (SO_2)	64	2.857
Carbon Monoxide (CO)	28	1.249
Nitrogen Oxide* (NO)	30	1.338 (2.052)*
Nitrogen Dioxide (NO_2) / (NOx)	46	2.052
Hydrogen Chloride (HCl)	36	1.607
Hydrogen Fluoride (HF)	20	0.892
Ammonia (NH_3)	17	0.759
Propane (for TVOC as C)	36	1.607

*Nitrogen oxide when present in ambient air converts quickly to nitrogen dioxide. Therefore, the operating authority asks for all oxides of nitrogen to be reported as NO_2 so 2.052 should be used as the conversion factor for all oxides of nitrogen when reporting data to the operating authority

Equation 3. Correcting a concentration to Reference Oxygen Conditions

In order to compare concentrations of pollutants from one site to another, the dilution effect of air must be taken into account, as the concentration of the pollutant would vary depending on how much excess air there is in the flue gas. The following equation is used to correct the concentration of the pollutant.

$$Co = Cmeas\ x\ \frac{20.9 - 02\,ref}{20.9 - 02\,meas}$$

c_o	Pollutant Concentration (corrected for oxygen), mg m^{-3}
c_{meas}	Pollutant Concentration, (uncorrected), mg m^{-3}
O_2 ref	Oxygen Reference value, % Vol
O_2 meas	Measured Oxygen Concentration, on a Dry Gas Basis, %Vol

Note: when correcting a gas volume for oxygen the above equation is inverted.
Note 2: The operating authority will stipulate which O_2% reference values shall be used. As a guideline the below values are used:

3%	Gas/Liquid fired boilers
6%	Solid fuel firing boilers
11%	Incinerators
15%	Gas Turbines

Equation 4. Correcting a Concentration to Dry Gas Basis

In order to compare concentrations of pollutants from one site to another, the dilution effect of water must be taken into account, as the concentration of the chemical would vary depending on how much moisture there is in the flue gas. Therefore, pollutants should be corrected for zero moisture, or dry gas basis, and the following equation is used to correct the pollutant.

$$C_{dry} = C_{meas} \times \frac{100}{(100 - H_2O\%)}$$

C_{dry}	Pollutant Concentration, (Dry Gas Basis) mg m-3
C_{meas}	Pollutant Concentration, (Wet Gas Basis), mg m-3
H2O%	Measured Moisture Concentration, %Vol

Note: When correcting a gas volume for water the above equation is inverted

Equation 5. Correcting to Standard Temperature and Pressure

In order to compare concentrations of pollutants from cross duct measurements, the effects of temperature and pressure must be taken into account, as the concentration of the chemical would vary depending on the temperature and pressure in the flue gas. It is normal to correct all concentrations to 273.15 Kelvin and 101.3 kilopascals.

$$C_{ref} = \frac{T}{273} \times \frac{101.3}{P}$$

c_{ref} = Pollutant Concentration (corrected to 273.15K, 101.3 kPa) T= Stack Temperature, K
P = Pressure at the measuring point, kPa

Example Calculation 1. Measurement of particulate and correction to reference conditions.

A cross-duct optical analyser measures an average raw output of 5.5 mg m^{-3} over an hour period. The process is a gas-fired boiler and the peripheral measurements at the time measured the stack conditions of 140°C, 99.8 kPa and 18%Vol moisture and 4.2%Vol oxygen.

To correct this value to reference conditions:

$$C_{corr} = 5.5 \times \left(\frac{273+140}{273}\right) K \left(\frac{101.3}{99.8}\right) kPa \left(\frac{20.9-3}{20.9-4.2}\right) \%O_2 \left(\frac{100}{100-18}\right) \%H_2O$$

C_{corr} = 11.0 mg Nm^{-3} at 273.15K, 101.3 kPa, 3% O_2, Dry Gas Basis.

Example Calculation 2. Measurement of SO_2 and correction to reference conditions.

A SO_2 NDIR analyser records a reading of 10.2 ppm from an incinerator. The oxygen analyser records a reading of 8.6%Vol. The NDIR analyser is situated at the bottom of the stack after a gas conditioning system.

To correct this value to reference conditions:

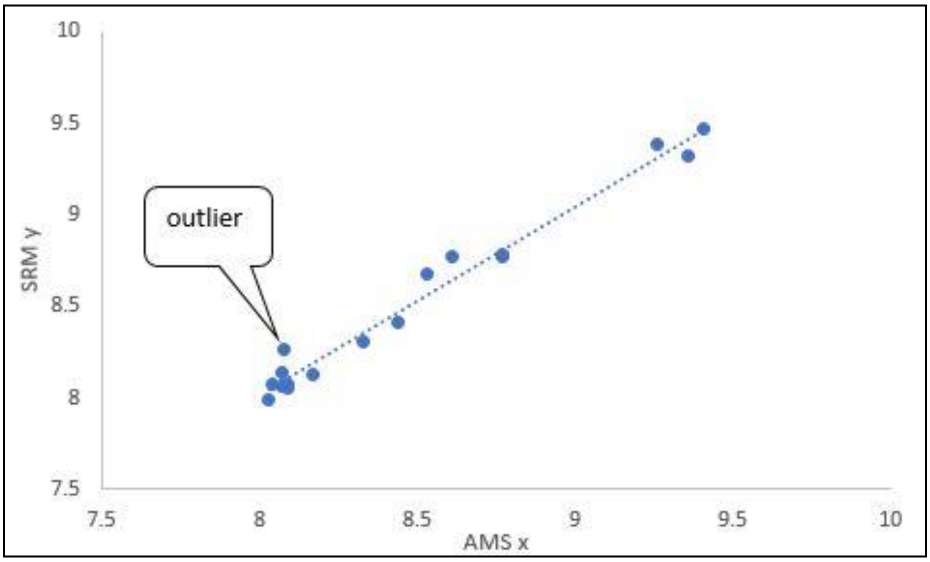
$$C_{corr} = 10.2 \times 2.857 \times \left(\frac{20.9-11}{20.9-8.6}\right) mgNm^{-3}$$

C_{corr} = 23.5 mg Nm^{-3} at 273.15K, 101.3 kPa, 11% O_2, Dry Gas Basis.

Outliers identification

Worked example following the procedure in the QAL2 questions section:

N	AMS x	SRM y	D_i: (y-x)	A: abs(D_i – D_{ave})	B: 2 x Sd	A > B?
1	9.26	9.38	9.38-9.26 = 0.12	|0.12-0.0329| = 0.0871	0.1570	
2	9.36	9.32	-0.04	0.0729	0.1570	
3	8.44	8.41	-0.03	0.0629	0.1570	
4	8.61	8.77	0.16	0.1271	0.1570	
5	8.33	8.31	-0.02	0.0529	0.1570	
6	8.77	8.77	0	0.0329	0.1570	
7	8.04	8.08	0.04	0.0071	0.1570	
8	8.08	8.27	0.19	0.1571	0.1570	outlier
9	8.07	8.06	-0.01	0.0429	0.1570	
10	9.41	9.47	0.06	0.0271	0.1570	
11	8.53	8.68	0.15	0.1171	0.1570	
12	8.17	8.13	-0.04	0.0729	0.1570	
13	8.03	7.99	-0.04	0.0729	0.1570	
14	8.09	8.05	-0.04	0.0729	0.1570	
15	8.09	8.07	-0.02	0.0529	0.1570	
16	8.07	8.14	0.07	0.0371	0.1570	
17	8.77	8.78	0.01	0.0229	0.1570	
		D_{ave}	0.0329			
		Sd	0.0785			



NOTE 6: The assessment of outliers for readings at or around zero values may be statistically challenging and may be omitted. An explanation must be included in the report.

Annex B – Flow Chart for QAL2 Calibration of an AMS

1 Carry out Functional Test on AMS

▼

2 a Time synchronization

▼

b Carry out 15+ SRM tests Record AMS raw data (as recorded by the instrument without calibration function implementation, corrections or uncertainty subtraction) over same periods

▼

c Collection of AMS raw data

▼

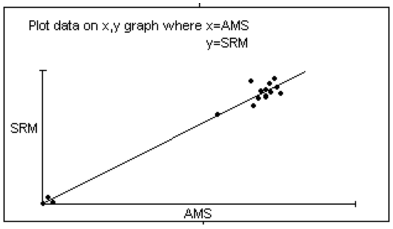
3 a Identify and remove outliers

▼

b Convert SRM tests to same conditions as AMS. (e.g. ppm, 273.15K, 101.325 kPa, dry gas basis)

▼

c Plot the dataset values (raw data at AMS conditions)



▼

Convert SRM data at Reference Conditions

▼

d Determine Procedure A, B or C for calculation.

▼

e Add surrogate data to the dataset as required

▼

f Determine Calibration Function of AMS

▼

Use function to calculate calibrated AMS values

▼

Convert calibrated AMS to reference conditions

▼

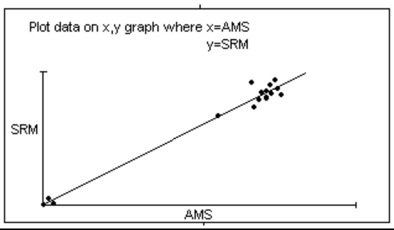
g Perform Variability test

▼

h Calculate the Calibration range

▼

i Plot calibrated AMS vs SRM (both at Ref Cond)



Detailed sequence of steps in a QAL2 campaign and reporting

1. Functional tests. ISO17025 gases for linearity tests. An accredited gas blender is recommended to produce the different concentrations (20%, 40%, 60%, 80% of the ELV) as well as 0 and 100% of the ELV that may be used as surrogates for the calibration function calculation as well as for the extension of the calibration range to the ELV.

2. Monitoring campaign
   a. Synchronization of watches with the Control Room

   b. Measurements (at least 15 valid measurements over 3 days) as per AG2 guidance. Peripherals monitoring to be carried out in parallel with monitoring.

   c. Collection of raw data (uncorrected) from CEMS

3. Reporting
   a. Assess for outliers as per Section 5.3. Discard data pairs accordingly. If peripheral data pairs (moisture and/or oxygen) are discarded as outliers and/or there are no synchronised peripheral runs for the pollutant runs, the average of the closest 2 valid peripheral runs shall be used (i.e. the previous and the following valid runs or 2 next/previous valid runs, on the same day).

   b. Create the dataset using the data obtained during the monitoring campaign. SRM data must be expressed at the same conditions and units as CEMS (unless CEMS data is provided in mA). This may require conducting reverse corrections of temperature and pressure values (for in-stack CEMS) and/or reverse corrections of moisture values (for wet basis CEMS). The headers of the columns in the dataset tables in the report shall clearly indicate the units and basis of the data in the column.

      NOTE 7: for particulates and wet chemistry sampling, average stack temperature and pressure values over the individual monitoring runs shall be used to conduct reverse corrections.

   c. Plot the AMS (x axis) and the SRM (y axis) values

   d. Determine the relevant Procedure (A, B or C) for the calculation of the calibration function using exclusively raw data pairs (Figure 3). Assessment shall be carried out attending to the values of SRM data at Reference Conditions (as per licence requirements, conversion of units, temperature, pressure, moisture and oxygen corrections may apply)

      NOTE: There might be cases where the dataset includes a low cluster of values and the assessment of data requires Procedure A to be followed (i.e. SO_2 ranging from -2ppm to 2ppm), in such cases Procedure C would seem more reasonable to use. An explanation note shall be included in the report.

   e. Add surrogate data to the dataset as required (zero surrogate for Procedure B and zero + span for Procedure C)

      NOTE 8: Surrogates can be obtained on the day of the monitoring campaign or during the Functional Tests. The concentration of the surrogate gases should be around the ELV level. However, for some pollutants this may not be practical due to low ELVs (i.e. An ELV for SO_2 of 10 mg/m^3 would require a 3.5ppm gas cylinder). In such cases, higher surrogate concentrations may be used although gas blending (using suitable and accredited equipment) would be the preferred option. An explanation note shall be included in the report.

f. Obtain the calibration function using the determined Procedure
    i. If relevant, obtain the calibration function for moisture first
    ii. Obtain the calibration function for oxygen.
    iii. Obtain the calibration function for the rest of parameters.

g. Perform the variability test exclusively from raw data pairs (no surrogates).
    i. Calculate the calibrated AMS by applying the calibration function to the AMS values.
    ii. Convert Calibrated AMS values at reference conditions, it may require:
        - units conversion to mg/m3
        - Temperature and Pressure corrections
        - Moisture corrections, in such case the moisture calibration function obtained for the campaign shall be applied to AMS moisture values before performing moisture corrections on AMS data
        - Oxygen corrections, in such cases the oxygen calibration function obtained for the campaign shall be applied to AMS oxygen values. After that, if AMS oxygen is measured at wet basis, moisture corrections shall be applied using the AMS calibrated values (after applying the moisture calibration function – as per above bullet point)
    iii. The SRM values at reference conditions have been already calculated for the Procedure selection (bullet point c)
    iv. The variability test is accepted if Sd ≤ Q_0 x Kv, where:
        - Sd is the standard deviation of (SRM at Reference conditions – Calibrated AMS at Reference Conditions)
        - Q_0 is the maximum acceptable uncertainty in legislation: ELV x CI /100 /1.96
        - Kv is the value obtained from Annex I of the EN14181 standard for the relevant number of data pairs.

h. Calculate the calibration range from the maximum AMS calibrated value at Reference Conditions, plus an extension of 10% of the maximum AMS calibrated value or 20% of the ELV, whichever the greater. If the valid calibration range does not cover up to the ELV it is possible to extend it to the ELV using reference materials (surrogate gases) if the following conditions are satisfied:

    The difference between a reference material measurement at the ELV and the extrapolated calibration line at the ELV is less than the uncertainty specified in the relevant legislation:

    [(AMS value at ELV level – (b(ELV) + a)] ≤ ELV x CI /100 /1.96

    The difference at zero shall be less than 10% of the ELV:
    [(AMS value at zero level – a)] ≤ 10% of ELV

    where b and a are the calibration function parameters.

    Despite values at reference conditions are used to calculate the calibration range, no moisture or oxygen corrections shall apply to the surrogate gas values.

i. Plot the Calibrated AMS at Reference Condition vs the SRM at Reference Conditions. Include also in the plot:

    - indication of the valid calibration range;
    - the extrapolation of the valid calibration range, using surrogates;
    - Parallel lines above and below the regression line through the plotted values. The parallel lines should indicate the derived uncertainty (σo) of the allowable 95% confidence interval of the daily average ELV (sometimes called ‘tramlines’).

PROCEDURE B: MOISTURE

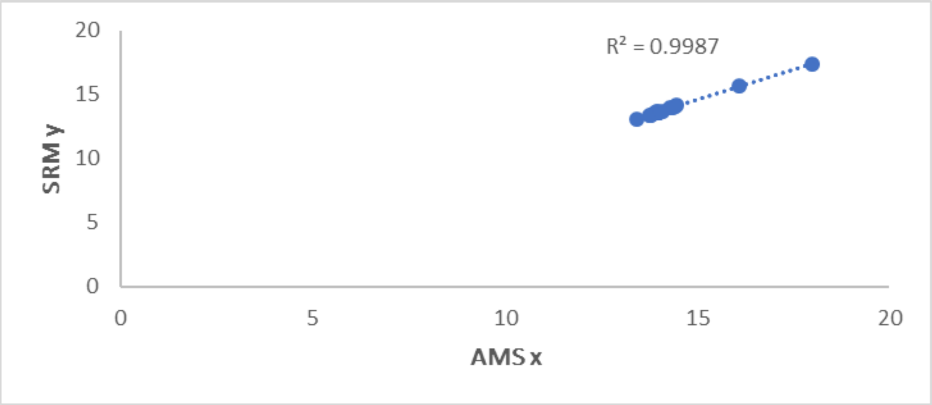
Param	Moisture
Ref O_2	n/a
ELV	30
CI (%)	30

AMS	FTIR (%)
SRM	Gravimetry (%)

a. Assess for outliers (as per Annex A)
b. Dataset: both AMS and SRM in % units.

	x AMS (%)	**y SRM (%)**
1	13.79	13.43
2	14.29	13.99
3	13.95	13.65
4	13.99	13.62
5	13.93	13.56
6	14.43	14.04
7	14.37	14.02
8	14.00	13.60
9	13.97	13.60
10	13.97	13.67
11	13.89	13.54
12	14.08	13.73
13	16.09	15.71
14	14.44	14.14
15	13.77	13.43
16	13.42	13.10
17	18.00	17.43
average	**14.38**	**14.02**

c. Plot the values



d. Select the Procedure to calculate the calibration function

	x AMS (%)	**y SRM (%)**	**SRM at Ref Cond**
1	13.79	13.43	13.43
2	14.29	13.99	13.99
3	13.95	13.65	13.65
4	13.99	13.62	13.62
5	13.93	13.56	13.56
6	14.43	14.04	14.04
7	14.37	14.02	14.02
8	14.00	13.60	13.60
9	13.97	13.60	13.60
10	13.97	13.67	13.67
11	13.89	13.54	13.54
12	14.08	13.73	13.73
13	16.09	15.71	15.71
14	14.44	14.14	14.14
15	13.77	13.43	13.43
16	13.42	13.10	13.10
17	18.00	17.43	17.43
average	**14.38**	**14.02**	
		min SRM at Ref Cond	13.10
		max SRM at Ref Cond	17.43
		max - min	4.33
		Uncertainty	9.00
		15% of ELV	4.5
		Procedure	**B**

Apply relevant corrections:
For water vapour no O_2 corrections apply

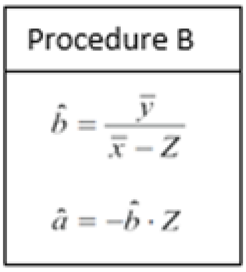
Maximum permissible uncertainty = ELV x CI /100 = 30 x 30 / 100 = 9
(max-min) < Maximum permissible uncertainty &
Max SRM at Ref Cond > 15% of the ELV → **Procedure B**

e. Addition of surrogates (for Procedure B, 1 x surrogate at zero)

	x AMS (%)	y SRM (%)
surrogate	0.2	0
1	13.79	13.43
2	14.29	13.99
3	13.95	13.65
4	13.99	13.62
5	13.93	13.56
6	14.43	14.04
7	14.37	14.02
8	14.00	13.60
9	13.97	13.60
10	13.97	13.67
11	13.89	13.54
12	14.08	13.73
13	16.09	15.71
14	14.44	14.14
15	13.77	13.43
16	13.42	13.10
17	18.00	17.43
average	**13.59**	**13.24**

Note that the average values have decreased

f. Calibration function calculation



Procedure B

$$\hat{b} = \frac{\bar{y}}{\bar{x} - Z}$$

$$\hat{a} = -\hat{b} \cdot Z$$

y = bx + a
b = average(y) / (average(x) – offset) = 13.24 / (13.59 – 0.2) = 0.9887
a = -b x offset = -0.9750 x (0.2) = -0.1977

Calibration function: y = 0.9887x – 0.1977

g. Variability test

Apply the obtained calibration function for moisture to AMS H_2O values (x) and express results at Reference Conditions (no corrections apply to moisture)

	x AMS	y SRM (%)	Cal AMS Ref	SRM Ref	SRM Ref – AMS Ref
1	13.79	13.43	13.79 x 0.9887 - 0.1977 = 13.4366	13.4300	-0.0066
2	14.29	13.99	13.9310	13.9900	0.0590
3	13.95	13.65	13.5948	13.6500	0.0552
4	13.99	13.62	13.6343	13.6200	-0.0143
5	13.93	13.56	13.5750	13.5600	-0.0150
6	14.43	14.04	14.0694	14.0400	-0.0294
7	14.37	14.02	14.0101	14.0200	0.0099
8	14.00	13.60	13.6442	13.6000	-0.0442
9	13.97	13.60	13.6146	13.6000	-0.0146
10	13.97	13.67	13.6146	13.6700	0.0554
11	13.89	13.54	13.5355	13.5400	0.0045
12	14.08	13.73	13.7233	13.7300	0.0067
13	16.09	15.71	15.7106	15.7100	-0.0006
14	14.44	14.14	14.0793	14.1400	0.0607
15	13.77	13.43	13.4168	13.4300	0.0132
16	13.42	13.10	13.0708	13.1000	0.0292
17	18.00	17.43	17.5991	17.4300	-0.1691
				SD	0.05
				σ	4.59
				Kv for N=17	0.9791
				σ x Kv	4.50
				Test	**Pass**

σ (Maximum permissible uncertainty) = ELV x CI / 100 / 1.96 = 30 x 30 / 100 / 1.96 = 4.59
Pass if SD ≤ σ x Kv → 0.05 ≤ 4.50 → **Pass**

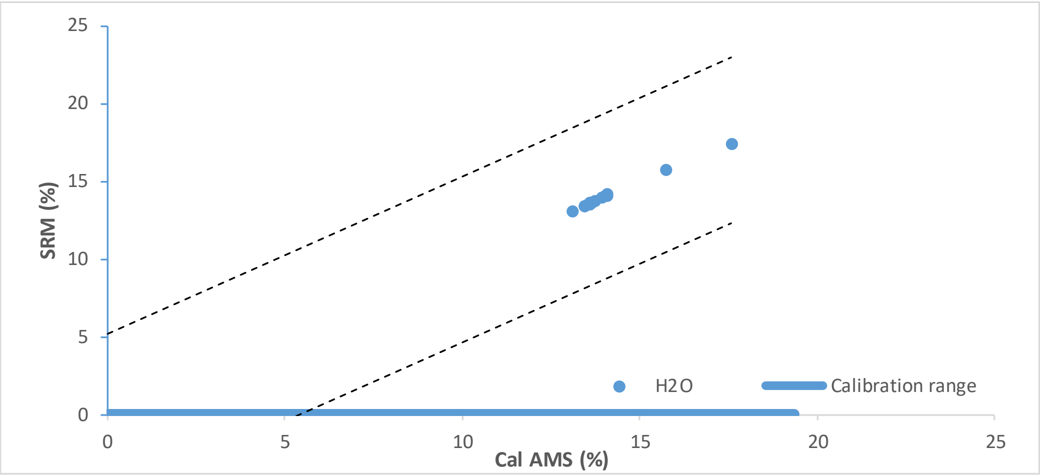
h. Calibration range

It can be extended to +10% of the maximum AMS calibrated value or 20% of the ELV, whichever the greater;

	Cal AMS Ref
1	13.4366
2	13.9310
3	13.5948
4	13.6343
5	13.5750
6	14.0694
7	14.0101
8	13.6442
9	13.6146
10	13.6146
11	13.5355
12	13.7233
13	15.7106
14	14.0793
15	13.4168
16	13.0708
17	17.5991
max	17.60
+ 10% max	19.36
20% ELV	6.00
Range: 0 to	**19.36**

+10% of max Cal AMS: 17.60 x 1.1 = 19.36
20% of ELV = 20 x 30 / 100 = 6

i. Plot Cal AMS @ Ref Cond vs SRM @ Ref Cond



PROCEDURE A: OXYGEN

Param	O_2
Ref O_2	n/a
ELV	21
CI (%)	10

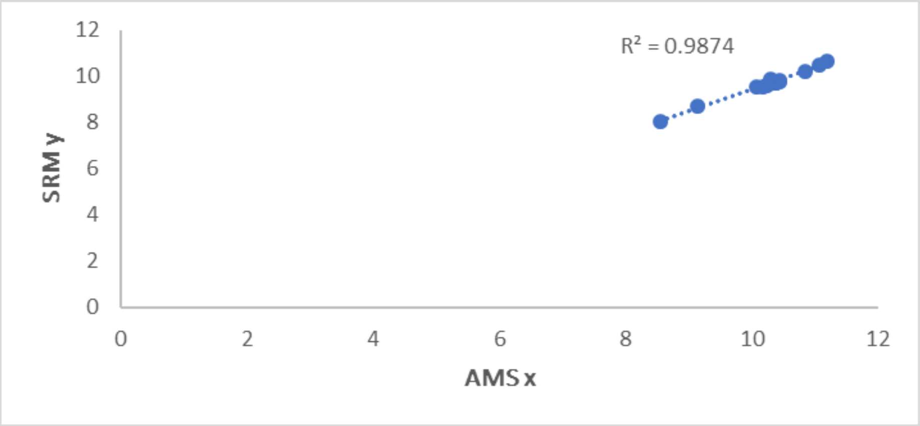
AMS	Zirconia (%, wet)
SRM	Zirconia (%, dry)

a. Assess for outliers (as per Annex A)

b. Dataset: Transform SRM values (dry) to the same basis as the AMS (wet)

	x AMS (%, wet)	y SRM (%, wet)
1	10.30	9.91
2	10.07	9.56
3	10.44	9.84
4	10.33	9.74
5	10.44	9.75
6	10.23	9.63
7	10.17	9.56
8	10.38	9.74
9	10.37	9.72
10	10.36	9.76
11	10.36	9.77
12	10.25	9.66
13	9.15	8.69
14	10.84	10.24
15	11.08	10.48
16	11.20	10.66
17	8.55	8.06
average	**10.27**	**9.69**

c. Plot the values



d. Select the Procedure to calculate the calibration function

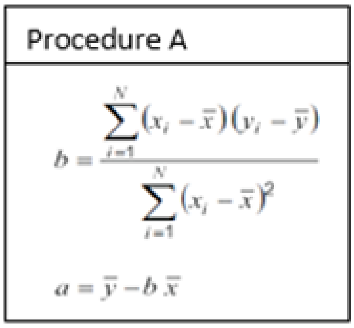
Apply relevant corrections (moisture) to SRM O_2 values (y):

	x AMS (%, wet)	**y SRM (%, wet)**	**H_2O SRM (%)**	**SRM at Ref Cond (%, dry)**
1	10.30	9.91	13.43	9.91 x 100 / (100 – 13.43) = 11.45
2	10.07	9.56	13.99	11.11
3	10.44	9.84	13.65	11.40
4	10.33	9.74	13.62	11.28
5	10.44	9.75	13.56	11.28
6	10.23	9.63	14.04	11.20
7	10.17	9.56	14.02	11.12
8	10.38	9.74	13.60	11.27
9	10.37	9.72	13.60	11.25
10	10.36	9.76	13.67	11.31
11	10.36	9.77	13.54	11.30
12	10.25	9.66	13.73	11.20
13	9.15	8.69	15.71	10.31
14	10.84	10.24	14.14	11.93
15	11.08	10.48	13.43	12.11
16	11.20	10.66	13.10	12.27
17	8.55	8.06	17.43	9.76
average	**10.27**	**9.69**		
			min SRM at Ref Cond	9.76
			max SRM at Ref Cond	12.27
			max - min	2.51
			Uncertainty	2.10
			15% of ELV	3.15
			Procedure	**A**

Maximum permissible uncertainty = ELV x CI /100 = 21 x 10 / 100 = 2.1
(max-min) > Maximum permissible uncertainty ➔ **Procedure A**

e. Addition of surrogates (for Procedure A, no surrogates)

f. Calibration function calculation



Procedure A

$$b = \frac{\sum_{i=1}^{N}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

$$a = \bar{y} - b\,\bar{x}$$

	x AMS (%, wet)	**y SRM (%, wet)**	**A: x - x_{av}**	**B: y - y_{av}**	**A x B**	**A x A**
1	10.30	9.91	0.0341	0.2176	0.0074	0.0012
2	10.07	9.56	-0.1959	-0.1324	0.0259	0.0384
3	10.44	9.84	0.1741	0.1476	0.0257	0.0303
4	10.33	9.74	0.0641	0.0476	0.0031	0.0041
5	10.44	9.75	0.1741	0.0576	0.0100	0.0303
6	10.23	9.63	-0.0359	-0.0624	0.0022	0.0013
7	10.17	9.56	-0.0959	-0.1324	0.0127	0.0092
8	10.38	9.74	0.1141	0.0476	0.0054	0.0130
9	10.37	9.72	0.1041	0.0276	0.0029	0.0108
10	10.36	9.76	0.0941	0.0676	0.0064	0.0089
11	10.36	9.77	0.0941	0.0776	0.0073	0.0089
12	10.25	9.66	-0.0159	-0.0324	0.0005	0.0003
13	9.15	8.69	-1.1159	-1.0024	1.1185	1.2452
14	10.84	10.24	0.5741	0.5476	0.3144	0.3296
15	11.08	10.48	0.8141	0.7876	0.6412	0.6628
16	11.20	10.66	0.9341	0.9676	0.9039	0.8726
17	8.55	8.06	-1.7159	-1.6324	2.8009	2.9443
average	**10.27**	**9.69**		**SUM**	**5.8886**	**6.2110**
				b	**0.9481**	
				a	**-0.0406**	

y = bx + a
b = (A x B) / (A x A) = 5.8886 / 6.2110 = 0.9481
a = average(y) – (b x average(x)) = 9.69 – (0.9481 x 10.27) = -0.0406

Calibration function: y = 0.9481x – 0.0406

g. Variability test

Apply the obtained calibration function for moisture to H_2O AMS values

Apply the obtained calibration function for O_2 to AMS values (x) and express results at Reference Conditions (dry) using the calibrated moisture values

	x AMS (%, wet)	y SRM (%, wet)	H_2O AMS (%)	Cal H_2O AMS (%)	H_2O SRM (%)	Cal AMS at Ref Cond (%, dry)	SRM at Ref Cond (%, dry)	SRM Ref – AMS Ref
1	10.30	9.91	13.79	13.79 x 0.9887 – 0.1977 = 13.45	13.43	11.2353*	11.4474	0.2121
2	10.07	9.56	14.29	13.93	13.99	11.0456	11.1150	0.0694
3	10.44	9.84	13.95	13.60	13.65	11.4092	11.3955	-0.0137
4	10.33	9.74	13.99	13.64	13.62	11.2936	11.2758	-0.0179
5	10.44	9.75	13.93	13.58	13.56	11.4067	11.2795	-0.1272
6	10.23	9.63	14.43	14.07	14.04	11.2397	11.2029	-0.0368
7	10.17	9.56	14.37	14.01	14.02	11.1659	11.1189	-0.0470
8	10.38	9.74	14.00	13.65	13.60	11.3498	11.2731	-0.0766
9	10.37	9.72	13.97	13.62	13.60	11.3350	11.2500	-0.0850
10	10.36	9.76	13.97	13.62	13.67	11.3240	11.3055	-0.0185
11	10.36	9.77	13.89	13.54	13.54	11.3138	11.3000	-0.0138
12	10.25	9.66	14.08	13.73	13.73	11.2172	11.1974	-0.0198
13	9.15	8.69	16.09	15.69	15.71	10.2410	10.3096	0.0687
14	10.84	10.24	14.44	14.08	14.14	11.9140	11.9264	0.0123
15	11.08	10.48	13.77	13.43	13.43	12.0870	12.1058	0.0188
16	11.20	10.66	13.42	13.08	13.10	12.1704	12.2670	0.0966
17	8.55	8.06	18.00	17.55	17.43	9.7824	9.7614	-0.0209

SD	0.08
σ	1.07
Kv for N=17	0.9791
σ x Kv	1.05
Test	**Pass**

*(10.30 x 0.9481 - 0.0406) x 100 / (100 – 13.45) = 11.2353

σ (Maximum permissible uncertainty) = ELV x CI / 100 / 1.96 = 21 x 10 / 100 / 1.96 = 1.07
Pass if SD ≤ σ x Kv → 0.08 ≤ 1.05 → **Pass**

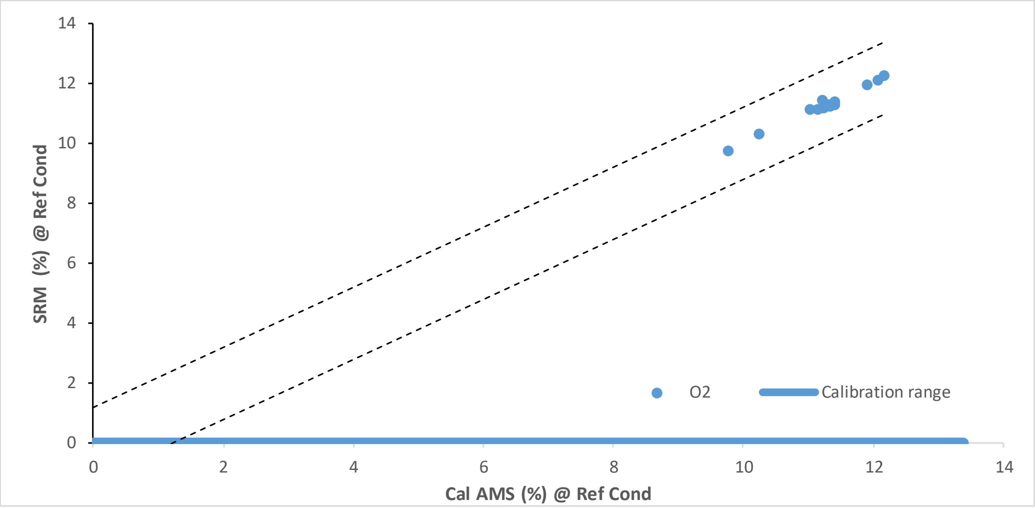
h. Calibration range:

It can be extended to +10% of the maximum AMS calibrated value or 20% of the ELV, whichever the greater;

	Cal AMS at Ref Cond (%, dry)
1	11.2353
2	11.0456
3	11.4092
4	11.2936
5	11.4067
6	11.2397
7	11.1659
8	11.3498
9	11.3350
10	11.3240
11	11.3138
12	11.2172
13	10.2410
14	11.9140
15	12.0870
16	12.1704
17	9.7824
max	12.17
+ 10% max	13.39
20% ELV	4.20
Range: 0 to	**13.39**

+10% of max Cal AMS: 12.17 x 1.1 = 13.39
20% of ELV = 20 x 21 / 100 = 4.2

i. Plot Cal AMS @ Ref Cond vs SRM @ Ref Cond



PROCEDURE C: HYDROGEN CHLORIDE

Param	HCl
Ref O_2	15
ELV	10
CI (%)	40

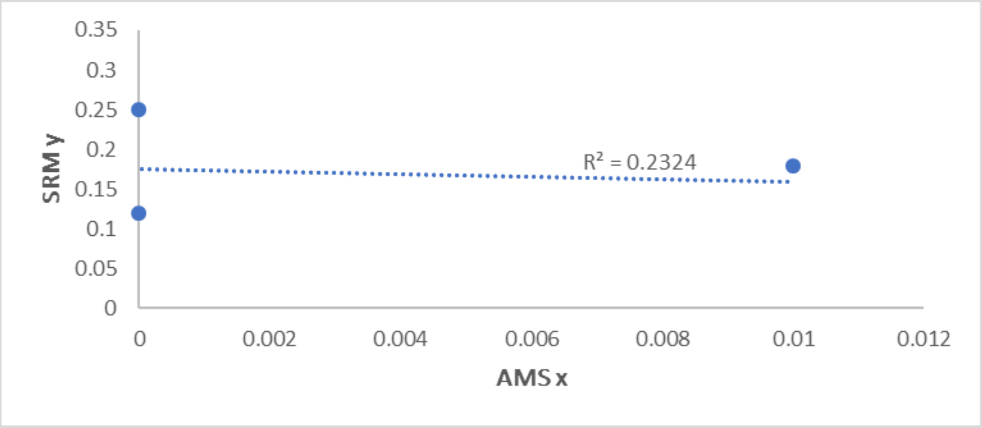
AMS	FTIR (mg/Nm^3, wet)
SRM	Wet chemistry (sample volume at gas meter conditions, dry)

a. Assess for outliers (as per Annex A)

b. Dataset: Transform SRM values to STP and wet basis (AMS conditions)

	x AMS (mg/Nm^3, wet)	y SRM (mg/Nm^3, wet)
1	-0.02	0.33
2	-0.04	0.3
3	-0.05	0.24
4	-0.05	0.26
5	-0.05	0.25
6	-0.03	0.28
7	-0.05	0.25
8	-0.06	0.24
9	-0.05	0.25
10	-0.06	0.25
11	0	0.25
12	-0.02	0.3
13	0.01	0.18
14	-0.02	0.12
15	0	0.12
16	-0.01	0.08
17	-0.01	0.09
average	**-0.03**	**0.22**

c. Plot the values



d. Select the Procedure to calculate the calibration function

Apply relevant corrections (moisture and O_2) to SRM HCl values (y): Note that O_2 **dry** values must be used

	x AMS (mg/Nm^3, wet)	**y SRM (mg/Nm^3, wet)**	**H_2O SRM (%)**	**O_2 SRM (%, wet)**	**SRM at Ref Cond (mg/Nm^3, dry, O_2 corr)**
1	-0.02	0.33	13.43	9.91	0.24*
2	-0.04	0.3	13.99	9.56	0.21
3	-0.05	0.24	13.65	9.84	0.17
4	-0.05	0.26	13.62	9.74	0.18
5	-0.05	0.25	13.56	9.75	0.18
6	-0.03	0.28	14.04	9.63	0.20
7	-0.05	0.25	14.02	9.56	0.18
8	-0.06	0.24	13.6	9.74	0.17
9	-0.05	0.25	13.6	9.72	0.18
10	-0.06	0.25	13.67	9.76	0.18
11	0	0.25	13.54	9.77	0.18
12	-0.02	0.3	13.73	9.66	0.21
13	0.01	0.18	15.71	8.69	0.12
14	-0.02	0.12	14.14	10.24	0.09
15	0	0.12	13.43	10.48	0.09
16	-0.01	0.08	13.1	10.66	0.06
17	-0.01	0.09	17.43	8.06	0.06
average	**-0.03**	**0.22**			

min SRM at Ref Cond	0.06
max SRM at Ref Cond	0.24
max - min	0.18
Uncertainty	4
15% of ELV	1.5
Procedure	**C**

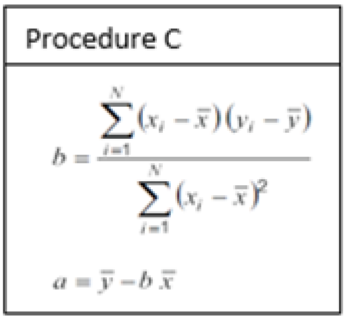
*0.33 x 100 / (100 – 13.43) x (20.9 – 15) / (20.9 – 9.91 x (100 / (100 - 13.43))) = 0.24

Maximum permissible uncertainty = ELV x CI /100 = 10 x 40 / 100 = 4
(max-min) < Maximum permissible uncertainty
Max SRM at Ref Cond < 15% of the ELV → **Procedure C**

e. Addition of surrogates (for Procedure C, 1 x surrogate at zero & 1 x surrogate at span (ELV))

	x AMS (mg/Nm^3, wet)	**y SRM (mg/Nm^3, wet)**
surrogate	0	0
surrogate	9.9	10
1	-0.02	0.33
2	-0.04	0.3
3	-0.05	0.24
4	-0.05	0.26
5	-0.05	0.25
6	-0.03	0.28
7	-0.05	0.25
8	-0.06	0.24
9	-0.05	0.25
10	-0.06	0.25
11	0	0.25
12	-0.02	0.3
13	0.01	0.18
14	-0.02	0.12
15	0	0.12
16	-0.01	0.08
17	-0.01	0.09
average	**0.49**	**0.73**

f. Calibration function calculation



Procedure C

$$b = \frac{\sum_{i=1}^{N}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

$$a = \bar{y} - b\,\bar{x}$$

	x AMS (mg/Nm^3, wet)	y SRM (mg/Nm^3, wet)	A: x - x_{av}	B: y - y_{av}	A x B	A x A
Zero	0	0	-0.4942	-0.7258	0.3587	0.2442
Span	9.9	10	9.4058	9.2742	87.2313	88.4689
1	-0.02	0.33	-0.5142	-0.3958	0.2035	0.2644
2	-0.04	0.3	-0.5342	-0.4258	0.2275	0.2854
3	-0.05	0.24	-0.5442	-0.4858	0.2644	0.2962
4	-0.05	0.26	-0.5442	-0.4658	0.2535	0.2962
5	-0.05	0.25	-0.5442	-0.4758	0.2589	0.2962
6	-0.03	0.28	-0.5242	-0.4458	0.2337	0.2748
7	-0.05	0.25	-0.5442	-0.4758	0.2589	0.2962
8	-0.06	0.24	-0.5542	-0.4858	0.2692	0.3071
9	-0.05	0.25	-0.5442	-0.4758	0.2589	0.2962
10	-0.06	0.25	-0.5542	-0.4758	0.2637	0.3071
11	0	0.25	-0.4942	-0.4758	0.2351	0.2442
12	-0.02	0.3	-0.5142	-0.4258	0.2189	0.2644
13	0.01	0.18	-0.4842	-0.5458	0.2643	0.2345
14	-0.02	0.12	-0.5142	-0.6058	0.3115	0.2644
15	0	0.12	-0.4942	-0.6058	0.2994	0.2442
16	-0.01	0.08	-0.5042	-0.6458	0.3256	0.2542
17	-0.01	0.09	-0.5042	-0.6358	0.3206	0.2542
average	**0.49**	**0.73**		SUM	92.0576	93.3931
				b	**0.9857**	
				a	**0.2386**	

y = bx + a
b = (A x B) / (A x A) = 92.0576 / 93.3931 = 0.9857
a = average(y) – (b x average(x)) = 0.73 – (0.9857 x 0.49) = 0.2386

Calibration function: y = 0.9857x + 0.2386

g. Variability test

Apply the obtained calibration function for moisture to H_2O AMS values

Apply the obtained calibration function for O_2 to O_2 AMS values

Apply the obtained calibration function for HCl to AMS values (x) and express results at Reference Conditions (dry, O_2) using the calibrated moisture values and the dry calibrated O_2 values (O_2 calibrated values corrected for moisture using the calibrated moisture values)

	x AMS (%, wet)	**y SRM (%, wet)**	**H_2O AMS (%)**	**Cal H_2O AMS (%)**	**H_2O SRM (%)**	**O_2 AMS (%, wet)**	**Cal O_2 AMS (%, wet)**	**O_2 SRM (%, wet)**	**Cal AMS at Ref Cond (%, dry)**	**SRM at Ref Cond (%, dry)**	**SRM Ref – AMS Ref**
1	-0.02	0.33	13.79	13.79 x 0.9887 – 0.1977 = 13.45	13.43	10.30	10.30 x 0.9481 - 0.0406 = 9.72	9.91	0.1544*	0.2379	0.0835
2	-0.04	0.3	14.29	13.93	13.99	10.07	9.51	9.56	0.1386	0.2103	0.0717
3	-0.05	0.24	13.95	13.60	13.65	10.44	9.86	9.84	0.1363	0.1725	0.0363
4	-0.05	0.26	13.99	13.64	13.62	10.33	9.75	9.74	0.1347	0.1845	0.0498
5	-0.05	0.25	13.93	13.58	13.56	10.44	9.86	9.75	0.1362	0.1774	0.0412
6	-0.03	0.28	14.43	14.07	14.04	10.23	9.66	9.63	0.1486	0.1982	0.0496
7	-0.05	0.25	14.37	14.01	14.02	10.17	9.60	9.56	0.1335	0.1754	0.0419
8	-0.06	0.24	14	13.65	13.6	10.38	9.80	9.74	0.1284	0.1702	0.0418
9	-0.05	0.25	13.97	13.62	13.6	10.37	9.79	9.72	0.1352	0.1769	0.0417
10	-0.06	0.25	13.97	13.62	13.67	10.36	9.78	9.76	0.1280	0.1781	0.0500
11	0	0.25	13.89	13.54	13.54	10.36	9.78	9.77	0.1699	0.1777	0.0078
12	-0.02	0.3	14.08	13.73	13.73	10.25	9.68	9.66	0.1546	0.2115	0.0568
13	0.01	0.18	16.09	15.69	15.71	9.15	8.63	8.69	0.1631	0.1190	-0.0442
14	-0.02	0.12	14.44	14.08	14.14	10.84	10.24	10.24	0.1673	0.0919	-0.0754
15	0	0.12	13.77	13.43	13.43	11.08	10.46	10.48	0.1845	0.0930	-0.0915
16	-0.01	0.08	13.42	13.08	13.1	11.2	10.58	10.66	0.1779	0.0629	-0.1150
17	-0.01	0.09	18	17.55	17.43	8.55	8.07	8.06	0.1473	0.0577	-0.0895

SD	0.06
σ	2.04
Kv for N=17	0.9791
σ x Kv	1.9982
Test	**Pass**

*(-0.02 x 0.9857 + 0.2386) x 100 / (100 – 13.45) x (20.9 – 15) / (20.9 – (9.72 x 100 / (100 – 13.45))) = 0.1544

σ (Maximum permissible uncertainty) = ELV x CI / 100 / 1.96 = 10 x 40 / 100 / 1.96 = 2.04
Pass if SD ≤ σ x Kv → 0.06 ≤ 1.9982 → **Pass**

h. Calibration range

It can be extended to +10% of the maximum AMS calibrated value or 20% of the ELV, whichever the greater;

	Cal AMS at Ref Cond (mg/Nm^3, dry)
1	0.1544
2	0.1386
3	0.1363
4	0.1347
5	0.1362
6	0.1486
7	0.1335
8	0.1284
9	0.1352
10	0.1280
11	0.1699
12	0.1546
13	0.1631
14	0.1673
15	0.1845
16	0.1779
17	0.1473
max	0.18
+ 10% max	0.20
20% ELV	2.00
Range: 0 to	**2.00**

+10% of max Cal AMS: 0.18 x 1.1 = 0.2
20% of ELV = 20 x 10 / 100 = 2

The calibration range is lower than the ELV. It may be extrapolated to the ELV if:

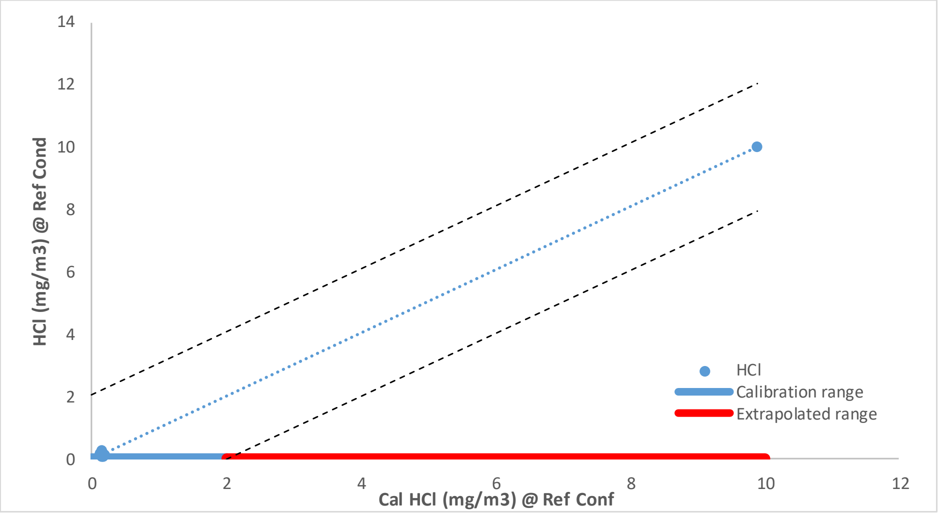
- [(AMS value at ELV level – (b(ELV) + a)] ≤ ELV x CI /100 /1.96
- [(AMS value at zero level – a)] ≤ 10% of ELV

9.9 – ((0.9857 x 10) + 0.2386) = - 0.1956
10 x 40 /100 / 1.96 = 2.0408
-0.1956 ≤ 2.0408 → **Satisfied at ELV level**

0 – 0.2386 = – 0.2386
0.1* 10 = 1
– 0.2386 ≤ 1 → **Satisfied at zero level**

The calibration range can be extrapolated to the ELV level using surrogate gases

i. Plot Cal AMS @ Ref Cond vs SRM @ Ref Cond



PROCEDURE D: VELOCITY / VOLUMETRIC FLOW

Param	velocity
Ref O_2	n/a
ELV	120% of max (SRM)
CI (%)	10

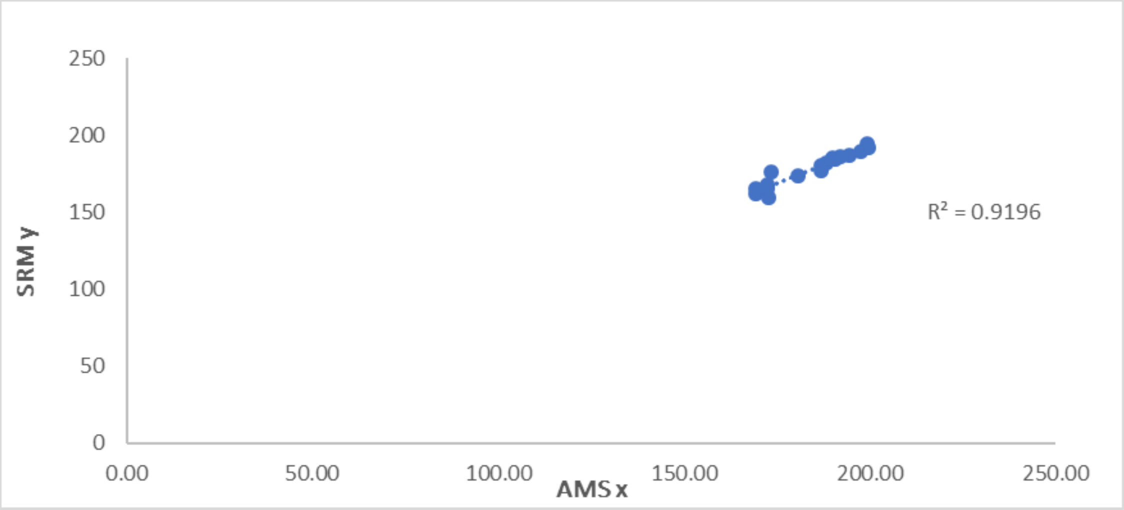
AMS	m^3/s (stack conditions)
SRM	m^3/s (stack conditions)

a. Assess for outliers (as per Annex A)

b. Dataset:

	x AMS (m^3/s, wet)	**y SRM (m^3/s, wet)**
1	188.32	182.41
2	172.60	165.76
3	169.33	162.00
4	197.75	189.79
5	180.75	173.37
6	186.89	176.98
7	187.07	180.36
8	190.63	184.59
9	189.90	185.10
10	169.40	165.62
11	191.97	185.80
12	194.46	187.25
13	172.94	159.54
14	199.47	194.25
15	199.67	191.94
16	172.46	167.67
17	173.64	175.80
average	184.54	178.13

c. Plot the values



d. Calculate:

- ELV: 120 % of Max (SRM) → Max SRM = 194.25 → ELV = 1.2 x 194.25 = 233.1
- 30% of Max (SRM) → 0.3 x 194.25 = 58.28
- Data spread: 100 x (max-min)/average for both AMS and SRM

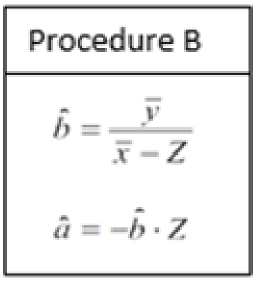
	x AMS	y SRM
Average	184.54	178.13
N	17	17
Min	169.33	159.54
Max	199.67	194.25
Max-Min	30.34	34.71
Spread	16.4%	19.5%

e. Determine calculation method (A or D)

SRM Data spread (19.5) < 30% of Max SRM (58.28) → **Method D**

f. Obtain calibration function

METHOD D:



Procedure B

$$\hat{b} = \frac{\bar{y}}{\bar{x} - Z}$$

$$\hat{a} = -\hat{b} \cdot Z$$

but →

- No surrogate added (Z = 0)
- a = lowest test point of the functionality test. If the flow AMS cannot measure at zero, the lowest test point shall be zero

y = bx + a
b = average(y) / average(x) = 178.13 / 184.54 = 0.9652
a = 0

Calibration function: y = 0.9652x

g. Variability test

- CI = 10%
- Values are not expressed at Reference Conditions (no temperature, pressure, moisture or oxygen corrections apply)

Apply the obtained calibration function for flow to AMS flow values

	x AMS (m^3/s, wet)	Cal AMS	y SRM (m^3/s, wet)	SRM – Cal AMS
1	188.32	188.32 x 0.9652 = 181.7758	182.4100	0.6342
2	172.60	166.6021	165.7600	-0.8421
3	169.33	163.4458	162.0000	-1.4458
4	197.75	190.8782	189.7900	-1.0882
5	180.75	174.4689	173.3700	-1.0989
6	186.89	180.3955	176.9800	-3.4155
7	187.07	180.5693	180.3600	-0.2093
8	190.63	184.0056	184.5900	0.5844
9	189.90	183.3009	185.1000	1.7991
10	169.40	163.5133	165.6200	2.1067
11	191.97	185.2990	185.8000	0.5010
12	194.46	187.7025	187.2500	-0.4525
13	172.94	166.9303	159.5400	-7.3903
14	199.47	192.5384	194.2500	1.7116
15	199.67	192.7314	191.9400	-0.7914
16	172.46	166.4670	167.6700	1.2030
17	173.64	167.6060	175.8000	8.1940
			SD	3.0876
			σ	23.31
			Kv for N=17	0.9791
			σ x Kv	22.82
			Test	Pass

σ (Maximum permissible uncertainty) = ELV x CI / 100 = 233.1 x 10 / 100 = 23.31
Pass if SD ≤ σ x Kv → 3.0876 ≤ 22.82 → **Pass**

h. R^2 test

- Required if AMS and SRM data spread > 15%

	y AMS	y SRM
Spread	16.4%	19.5%

→ Required

	x AMS (m^3/s, wet)	**y SRM (m^3/s, wet)**	**B: y - yav**	**Cal AMS**	**B x B**	**D: SRM – Cal AMS**	**(D-Dav)^2**
1	188.32	182.41	182.41 – 178.13 = 4.2788	188.32 x 0.9652 = 181.7758	4.2788^2 **=** 18.3083	182.41 – 181.7758 = 0.6342	0.6342^2 = 0.4022
2	172.60	165.76	-12.3712	166.6021	153.0460	-0.8421	0.7092
3	169.33	162.00	-16.1312	163.4458	260.2149	-1.4458	2.0902
4	197.75	189.79	11.6588	190.8782	135.9282	-1.0882	1.1841
5	180.75	173.37	-4.7612	174.4689	22.6688	-1.0989	1.2076
6	186.89	176.98	-1.1512	180.3955	1.3252	-3.4155	11.6659
7	187.07	180.36	2.2288	180.5693	4.9677	-0.2093	0.0438
8	190.63	184.59	6.4588	184.0056	41.7164	0.5844	0.3416
9	189.90	185.10	6.9688	183.3009	48.5645	1.7991	3.2366
10	169.40	165.62	-12.5112	163.5133	156.5295	2.1067	4.4381
11	191.97	185.80	7.6688	185.2990	58.8109	0.5010	0.2510
12	194.46	187.25	9.1188	187.7025	83.1529	-0.4525	0.2047
13	172.94	159.54	-18.5912	166.9303	345.6318	-7.3903	54.6166
14	199.47	194.25	16.1188	192.5384	259.8165	1.7116	2.9296
15	199.67	191.94	13.8088	192.7314	190.6836	-0.7914	0.6264
16	172.46	167.67	-10.4612	166.4670	109.4362	1.2030	1.4472
17	173.64	175.80	-2.3312	167.6060	5.4344	8.1940	67.1420
Ave	184.54	178.13				0	
Sum					1896.24		152.54

R^2 = 1 – sum(D – Dav)^2 / sum(y – yav)^2 = 1 – 152.54 / 1896.24 = 0.9196
Pass if R^2>0.9 → 0.9196 > 0.9 → **Pass**

Annex C – Flow Chart for Annual Surveillance Test of an AMS

1 Carry out Functional Test on AMS

2 a Time synchronization

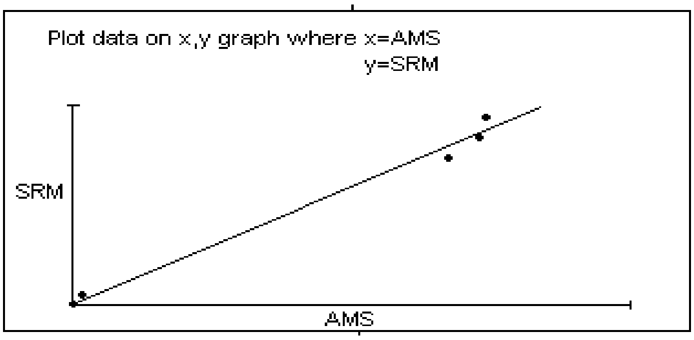
b Carry out 5+ SRM tests Record AMS raw data (as recorded by the instrument without calibration function implementation, corrections or uncertainty subtraction) over same periods

c Collection of AMS raw data

3 a Identify and remove outliers

b Convert SRM tests to same conditions as AMS. (e.g. ppm, 273.15K, 101.325 kPa, dry gas basis)

c Plot dataset values



Use function to calculate calibrated AMS values

Convert AMS and SRM to Reference Conditions

d Carry out the Variability Test

e Carry out the Calibration Test

Detailed sequence of steps in an AST campaign and reporting

1. Functional tests. ISO17025 gases for linearity tests. An accredited gas blender is recommended to produce the different concentrations (20%, 40%, 60%, 80% of the ELV) as well as 0 and 100% of the ELV that may be used as surrogates for the calibration function calculation as well as for the extension of the calibration range to the ELV.

2. Monitoring campaign
    a. Synchronization of watches with the Control Room

    b. Measurements (at least 5 valid measurements over a day) as per AG2 guidance. Peripherals monitoring to be carried out in parallel with monitoring.

    c. Collection of raw data (uncorrected) from CEMS

3. Reporting
    a. Assess for outliers as per Section 5.3. Discard data pairs accordingly. If peripheral data pairs (moisture and/or oxygen) are discarded as outliers and/or there are no synchronised peripheral runs for the pollutant runs, the average of the closest 2 valid peripheral runs shall be used (i.e. the previous and the following valid runs or 2 next/previous valid runs, on the same day).

    b. Create the dataset using the data obtained during the monitoring campaign. SRM data must be expressed at the same conditions and units as CEMS (unless CEMS data is provided in mA). This may require conducting reverse corrections of temperature and pressure values (for in-stack CEMS) and/or reverse corrections of moisture values (for wet basis CEMS). The headers of the columns in the dataset tables in the report shall clearly indicate the units and basis of the data in the column.

    NOTE 9: For particulates and wet chemistry sampling, average stack temperature and pressure values over the individual monitoring runs shall be used to conduct reverse corrections.

    c. Plot the AMS (x axis) and the SRM (y axis) values

    d. Perform the variability test exclusively from raw data pairs (no surrogates).
        i. Calculate the calibrated AMS by applying the calibration function to the AMS values
        ii. Convert Calibrated AMS values at reference conditions. This may require:
            - units conversion to mg/m3
            - Temperature and Pressure corrections
            - Moisture corrections, in such case the moisture calibration function obtained for the campaign shall be applied to AMS moisture values before performing moisture corrections on AMS data
            - Oxygen corrections, in such cases the oxygen calibration function obtained for the campaign shall be applied to AMS oxygen values. After that, if AMS oxygen is measured at wet basis, moisture corrections shall be applied using the AMS calibrated values (after applying the moisture calibration function – as per above bullet point)
        iii. The SRM values at reference conditions have been already calculated for the Procedure selection (bullet point c)
        iv. The variability test is accepted if Sd ≤ 1.5 x Q_0 x Kv, where:
            - Sd is the standard deviation of (SRM values at Reference conditions – Calibrated AMS values at Reference Conditions)
            - Q_0 is the maximum permissible uncertainty: ELV x CI /100 /1.96
            - Kv is the value obtained from Annex I of the EN14181 standard for the relevant number of data pairs.

e. Perform the calibration test.
    v. The test is accepted if $\left|\overline{D}\right| \le t_{0,95;\,N-1} \frac{s_D}{\sqrt{N}} + \sigma_0$, where
    - |D| is the average of the difference between SRM values at Reference Condition and the Calibrated AMS at Reference Conditions
    - t0.95, N-1 is the value obtained from Annex I of the EN14181 standard for the relevant number of data pairs (N)
    - Sd is the standard deviation of (SRM values at Reference conditions – Calibrated AMS values at Reference Conditions)
    - N is the number of data pairs
    - Q_0 is the maximum permissible uncertainty: ELV x CI / 100 / 1.96

AST CALCULATIONS

Param	TVOC
Ref O_2	10
ELV	10
CI (%)	30
Cal function	y = 1.0470x

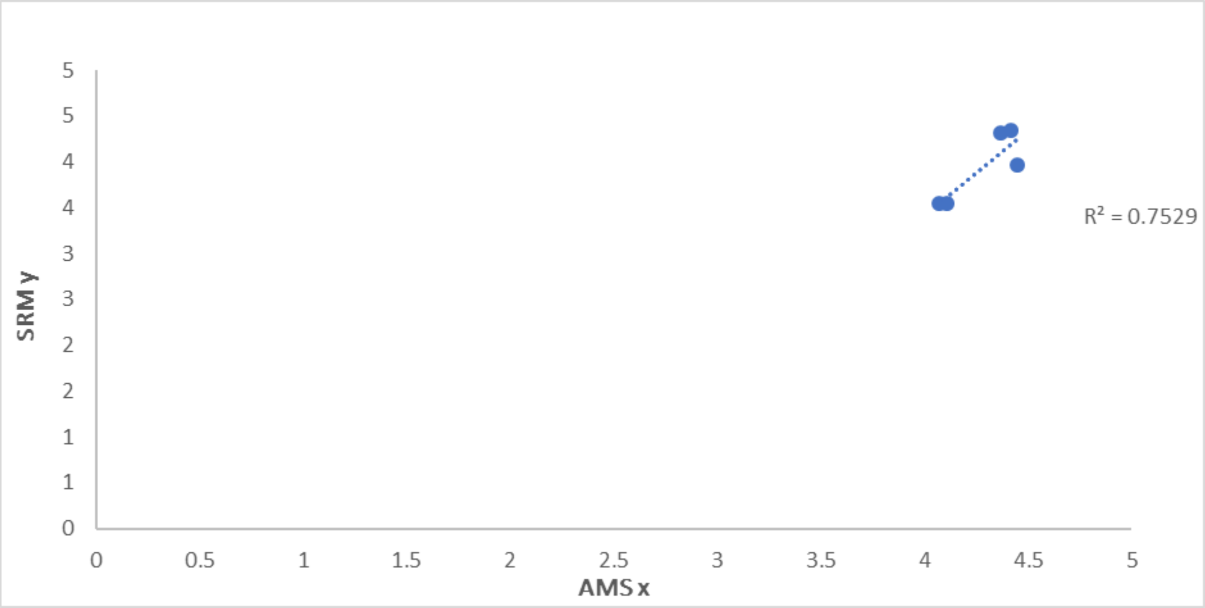
AMS	mg/Nm^3, wet
SRM	ppm, wet

a. Assess for outliers (as per Annex A)

b. Dataset: Transform SRM in ppm to mg/Nm^3

	AMS x (mg/Nm3, wet)	**SRM y (mg/Nm3, wet)**
1	4.45	3.97
2	4.37	4.31
3	4.07	3.55
4	4.42	4.35
5	4.11	3.55

c. Plot the values



d. Variability test

- Moisture calibration function: y = 0.9393x
- Oxygen calibration function: y = 0.9811x

	x AMS (%, wet)	**y SRM (%, wet)**	**H_2O AMS (%)**	**Cal H_2O AMS (%)**	**H_2O SRM (%)**	**O_2 AMS (%, dry)**	**Cal O_2 AMS (%, dry)**	**O_2 SRM (%, dry)**	**Cal AMS at Ref Cond (%, dry)**	**SRM at Ref Cond (%, dry)**	**SRM Ref – AMS Ref**
1	4.45	3.97	14.79	14.79 x 0.9393 = 13.89	13.68	10.65	10.65 x 0.9811 = 10.45	10.4	5.64*	4.77	-0.87
2	4.37	4.31	14.63	13.74	13.81	11.00	10.79	10.78	5.72	5.39	-0.33
3	4.07	3.55	12.67	11.9	11.66	11.17	10.96	10.75	5.30	4.32	-0.99
4	4.42	4.35	14.93	14.03	14.03	11.05	10.84	10.9	5.83	5.52	-0.32
5	4.11	3.55	13.02	12.23	12.11	11.27	11.05	10.86	5.43	4.39	-1.04

SD	0.36
σ	1.53
Kv (N=5)	0.9161
σ x Kv	1.4016
Test	Pass

*4.45 x 1.047 x 100 / (100 – 13.89) x (20.9 – 10) / (20.9 – 10.45) = 5.64

σ (Maximum permissible uncertainty) = ELV x CI / 100 / 1.96 = 10 x 30 / 100 / 1.96 = 1.53
Pass if SD ≤ 1.5 x σ x Kv → 0.36 ≤ 1.4016 → **Pass**

e. Calibration test

$$\left|\overline{D}\right| \leq t_{0,95,N-1}\frac{s_D}{\sqrt{N}} + \sigma_0$$

- Pass if:

|D|:

SRM Ref – AMS Ref
-0.87
-0.33
-0.99
-0.32
-1.04
Average (|D|) = 0.71

- $t_{0.95, N-1}$ = 2.132 (from EN14181 Annex I)
- N =5
- Pass if: 0.71 ≤ 2.132 x (0.36 / $\sqrt{5}$) + 1.53 → 0.71 ≤ 1.87 → **Pass**

Annex D – Functional Test Audit Guidance

A functional test audit shall be performed on the complete AMS sampling train before a QAL2 or AST is performed, in order to confirm that it has been installed correctly, and is working as expected. This will involve assessing the installation of the AMS, its response to reference materials, as well as checking the QAL3 process and all other relevant documentation.

The functional test audit shall be performed by the AMS supplier/manufacturer/service engineer, by the testing laboratory under the direct supervision of the AMS supplier/manufacturer/service engineer or by on-site personnel trained by the AMS supplier/manufacturer/service engineer on the specific AMS instrument (make and model) installed on site (evidence of training may be required). All personnel involved in Functional test must have a deep and proved understanding of the requirements of EN 14181 standard. The Functional test report shall note who carried out the tests. This is due to the wide range of tasks required to complete the functional test audit and associated expertise required. For example, an AMS supplier/manufacturer/service engineer will have the knowledge and experience required to check the sampling train, and apply the linearity reference material.

The functional test audit shall be performed no more than one month before the parallel measurements are started, and will be carried out in a separate visit to the QAL2/AST. This is to ensure that any faults or problems that are discovered can be corrected in time. It is recommended to include peripheral AMS in these audits, as measurements from these systems are used to correct to standardised conditions.

The following guidance is provided to help perform the functional test audit, and an example form is included. Not all sections need to be completed, the table below indicates which steps need to be completed, depending on what type of AMS is being audited.

Table B.1 – Functional Test Audit Requirements

Measurement Site & Installation

A risk assessment of the work area is required prior to starting the functional test audit, and checks shall be undertaken to ensure that there are suitable provisions to carry out the functional test audit and parallel measurements.

The AMS should have weather protection as well as sufficient space and safe access to perform the necessary work. Suitable tools, reference materials, and spare parts shall also be readily accessible.

The sampling location shall also be assessed to determine its suitability to carry out the QAL2/AST parallel measurements, and will meet the requirements of EN 15259.

Alignment & Cleanliness

A visual inspection of the AMS shall be carried out. This will involve checking of the internal components, assessing the amount of contamination, and checking the alignment of the system amongst other things. The AMS supplier/manufacturer should ideally carry out these checks as they will be familiar with taking apart, and reassembling the system.

Sampling Train

A visual inspection of the AMS sampling train shall be carried out by the instrument engineer or test laboratory. This will involve checking each component of the sampling train, confirming that they are working correctly, and are in good condition.

Leak Test

A leak test of the complete sampling train is required, and shall be performed in accordance with the AMS manual.

Zero & Span Checks

Appropriate zero and span reference materials shall be used to check the response of the AMS. In-situ AMS will require a reference path free of flue gas, which may require the removal of the instrument from the stack. It shall be confirmed that the AMS reads zero when a zero concentration is applied.

Response Time

The response time of the complete sampling train shall be assessed. Each species under test shall meet the requirement set for QAL1.

Linearity

A linearity test shall be performed on the AMS across a range that as a minimum covers the short term ELV. The linearity will be checked using five concentrations, which includes zero, spread equally across the range using suitable reference materials.

If reference gases are used these must be traceable to national standards and prepared under EN ISO 17025. Either separate gas cylinders can be used to achieve the required concentrations, or a single gas cylinder can be used to blend to the relevant concentration using a calibrated dilution system. Some AMS cannot use reference gases, and will require suitable surrogate reference material that have been verified to perform the linearity e.g. particulate AMS.

The linearity will be performed in a randomised order using concentrations at zero (twice) and approximately 20%, 40%, 60% and 80% of the range. For each change in concentration the first instrument reading shall be taken after a time period of at least three response times. Three readings will be taken at each concentration, and these readings will be separated by a time period of at least four response times. A reduced time may be taken between readings in order to reduce the time taken for the tests, however if this results in a failure the test shall be repeated using the standard approach.

The linearity test results shall be calculated using the procedure outlined in EN 14181 Annex B. Corrective action will be required if the AMS fails.

Interferences

If there are any components in the stack gas that have been identified as interferents during the QAL1 process, an interference test shall be undertaken.

QAL3 Audit

An audit of the process operators QAL3 records shall be undertaken. The assessment shall verify that suitable control charts are in place which include the results from zero and span checks undertaken since the last functional test audit, as well as a record of all alarm limit exceedances, and what action was taken to correct this. The functional test report shall include the type of chart used by the operator, the S_{AMS} value for the chart alarms and any out of control situation reflected in the charts. This is relevant for all charts (zero and span) for all parameters.

Documentation

The test laboratory shall check that the process operator has all the required documentation in place or readily available.

Report

If any faults or problems have been identified, these should be noted and the required corrective action undertaken. It is important to carry out the functional test audit in a separate visit, before any parallel measurements are undertaken for this reason

Annex E – Functional Test Audit Form

Fill out for each AMS

Alignment & Cleanliness	The complete sampling train shall be visually inspected to check the alignment and cleanliness of the system	
In-Situ AMS	✓	Notes
Internal check of the AMS		
Cleanliness of the optical components		
Flushing of air supply		
Any obstructions in the optical path		
The following shall be checked after the AMS has been re-assembled and installed at the sampling location		
Alignment of the measuring systems		
Contamination control (internal check of optical surfaces)		
Flushing air supply		
Sampling Train	The complete sampling train shall be visually inspected	
Extractive AMS	✓	Notes
Sampling probe		
Gas conditioning systems		
Pumps		
All connections		
Sample lines		
Power supplies		
Filters		
NOx converter efficiency (if applicable)		
Visual inspection of sampling train		
Leak Test	The complete system shall be leak tested in accordance with the AMS manual	
Extractive AMS	✓	Notes
Leak Test Result		

Zero & Span Check	Verify the zero and span of the AMS using suitable reference materials. For in-situ AMS a reference path free of flue gas is required	
In-Situ & Extractive AMS	✓	Notes
Zero Check		
Span Check		
Response Time	The response time of the AMS shall be checked through the complete sampling train, this shall not exceed the criterion specified in QAL1	
In-Situ & Extractive AMS	✓	Notes
Response Time		

Linearity	The AMS is tested using five reference concentrations including a zero, at the inlet of the analyser, the concentrations shall be spread over a range of at least the short term ELV and applied in a random order	
In-Situ & Extractive AMS	✔	Notes
What reference materials will be used to perform the linearity?		
Reference material information (e.g. cylinder IDs, dilution system ID, reference filter IDs)		
Reference material with zero concentration		
Reference material concentration approximately 20% of the range		
Reference material concentration approximately 40% of the range		
Reference material concentration approximately 60% of the range		
Reference material concentration approximately 80% of the range		
Reference material with zero concentration		
Does the AMS pass? (The procedure is described in Annex B of EN 14181)		

Interference	Tests shall be undertaken if there are interferents in the flue gas that could have an effect on the AMS. These will have been identified during the QAL1	
In-Situ & Extractive AMS	✔	Notes
Has an interference check been carried out?		

Zero & Span Drift Audit	A QAL3 audit shall be carried out in order to check that there is a procedure in place, regular zero and span measurements are being performed and that what action was taken if a QAL3 failed	
In-Situ & Extractive AMS	✔	Notes
Has a check of the QAL3 audit been performed?		
Type of chart used		
S_{AMS} per parameter		
Out of control situations		

Documentation	The process operator should have access to the following records and documents	
In-Situ & Extractive AMS	✔	Notes
A plan of the AMS		
AMS certification information		
Manuals		
Log Books (Detailing problems with the AMS and corrective action taken)		
Service Reports		
QAL3 Documentation		
Procedures for AMS maintenance, calibration and training		
Training Records		
Maintenance Schedules		
Auditing plans and records		

Report	The functional test audit shall be completed before the QAL2/AST in case any corrective action is required	
In-Situ & Extractive AMS	✓	Notes
Are there any faults that require corrective action?		
Notes:		

Personnel Involved with the Functional Test Audit

Name	Company	Date	Role

Annex F – A Guide to Performing QAL3 Checks

This annex provides a basic guide to understanding and implementing a QAL3 detailing what steps a process operator should take, and where to get further information.

1. What is a QAL3?

QAL3 testing provides ongoing quality assurance for an AMS during its operation by assessing the drift and precision of the instrument. The AMS may drift over time due to factors affecting the instrument such as contamination and ageing components requiring external correction. The AMS will also be subject to short term variations due to influencing factors, such as temperature and pressure. The QAL3 process tracks these changes and checks that any deviations are within acceptable levels. It is the process operator's responsibility to ensure that the QAL3 is carried out.

2. How is a QAL3 procedure carried out?

The QAL3 procedure involves carrying out regular zero and span checks of the AMS using certified reference materials. Some AMS may use other reference materials as long as these have been validated during the QAL1 process. The results from these checks are then plotted using control charts which track changes over time. If any zero and span measurements exceed pre-determined alarm limits, then corrective action is required. There are different types of control charts that can be used, depending upon which approach the process operator takes.

3. What Control Chart should I use for the QAL3 procedure?

The QAL3 procedure demonstrates the quality of the AMS by checking the drift and precision remains within acceptable limits. There are two methods which can be used:
The first combines the drift and precision and compares against control limits (e.g. Shewhart control charts). This is a simple method to setup and use but does not allow any zero/span adjustment of the AMS and may result in more frequent maintenance of the AMS.

The second determines drift and precision separately (e.g. CUSUM control charts). This method is more sophisticated, but allows adjustments to be made to the AMS if there is drift.

An appropriate control chart should be selected after deciding which method will be used to determine drift and precision. Detailed descriptions of the three control charts commonly used can be found in Section 9. Some AMS have built in internal zero and span checks which can be used as QAL3 checks, so long as this is certified in the QAL1 validation.

4. Selecting Control Chart Limits

The control chart will track the changes in zero/span measurements over time, but in order to know if the AMS is deviating out of specification, limits must be put in place to notify the process operator. Warning limits indicate that the AMS is beginning to drift out of control and alarm limits show that the AMS has drifted out of control and requires corrective action. There are two ways of determining the control chart limits:

The first uses performance data from the QAL1 of the AMS to determine what factors have an effect on the zero and span measurements, and calculates the standard deviation (S_{AMS}). Influencing factors include changes in ambient temperature, variations of voltage and interference from other determinands. It is important to consider the actual plant conditions, as these may be different to the conditions during the performance testing. For example, an AMS will typically be tested between 5ºC and

40ºC when carrying out a QAL1 validation, however the AMS may actually be installed in an air-conditioned room which will have a small variation in temperature.

The second method calculates the standard deviation (S_{AMS}) using formula 13 in EN 14181:2014, a worked example is also included in Annex F. If a Shewhart control chart is being used the warning limit is set as ±1 S_{AMS} and the alarm limit is set at ±2 S_{AMS}. For more complex control charts (e.g. EWMA and CUSUM) the S_{AMS} value will be combined with specific control chart parameters in order to set the warning and alarm limits.

A simpler approach can also be adopted by using the maximum permissible uncertainty (MPU). Alarm limits are set at 50% of the MPU directly in the case of simple control charts (e.g. Shewhart), or calculated by the use of specific control chart parameters and 50% of the MPU for more advanced control charts (e.g. EWMA and CUSUM). Warning limits can also be established at 25% of the MPU.

5. Performing zero and span measurements

The AMS must be able to carry out zero and span measurements, as well as measure and record negative values, in order to carry out the QAL3 checks.

Test Gases

Nitrogen or ambient air without the measured component can be used as zero gas. Span gases should be traceable to national standards and a recommended concentration of 80% - 100% of the short-term emission limit value. The exact concentration of the test gas is not important; however, the long-term stability is as any changes over time will have an effect on the QAL3 giving false results. Test gases should be injected into the front of the analyser, because the QAL3 is for checking the AMS, not the entire sampling line.

When a test gas needs to be replaced a new baseline should be established, even if the new test gas is similar or the same. This could lead to a step change making it appear that the AMS has drifted.

Due to the reactive nature of HCl or HF a QAL3 span measurement using a test gas can take a long time to stabilise. As a result, it is currently best practise to perform HCl and HF QAL3 check every three months instead when using a test gas.

Reference Materials/Surrogates

Other reference materials such as reference filters may be used for the zero and span measurements as long, as they have been validated in the QAL1 certification.

Automatic zero and span measurements

Some AMS have the facility to carry out automatic internal zero and span measurements. These are acceptable as long as this has been validated during the QAL1 certification.

6. How often should the QAL3 checks be carried out?

The minimum time between QAL3 checks is set by the maintenance interval of the AMS that was determined during the QAL1 validation of the instrument. This is the maximum amount of time the AMS will operate before any corrective action is required. If CUSUM control charts are being used, zero and span checks shall be carried out every week (See Section 9). For any other chart, the QAL3 checks shall be carried out at monthly basis as a maximum frequency, being weekly of fortnightly the recommended options.

If a plant operates two independent AMS measuring the same component (i.e. the plant is operating duty and backup analysers) the QAL3 procedure interval may be extended to one year, so long as the difference of the standardised outputs of both AMS systems do not exceed 5% of the short term ELV for more than five consecutive readings. If the backup AMS is unavailable for more than half of the maintenance interval, then a standard QAL3 procedure should be implemented. Both duty and standby AMS should be completely independent systems.

7. QAL3 Failure

As QAL3 measurements are recorded over time a visual representation of the zero and span deviations will develop on the control charts allowing the process operator to assess any potential systematic changes. Zero and span measurements that exceed the alarm limits indicate to the process operator that the AMS is out of control, and that corrective action is required. A procedure shall be put into place to outline how to investigate the problem and what corrective action to take. Control charts that determine drift and precision separately (e.g. CUSUM) allow adjustment of the AMS due to drift, whereas maintenance on the AMS is required, if control charts that combine drift and precision are used. The AMS is considered out of control if:

- one or more data points are beyond one of the upper alarm limits;
- three consecutive data points are beyond one of the warning limits;
- eight consecutive points are on the same side of the mean, unless the points are within 0.5 S_{AMS};
- six consecutive points are either increasing or decreasing.

8. QAL3 Documentation

To meet the requirements of EN 14181:2014 the control charts must be documented and stored for five years. These charts will need to be available when the functional test audit is performed before a QAL2 or AST is undertaken, along with a history of each time an alarm limit was breached, and what corrective action was taken.

9. Example Control Charts

Three commonly used control charts are summarised below. More information describing the design and operation of these control charts can be found in Appendix C of EN 14181:2014.

Shewhart Control Charts

The Shewhart control chart approach uses a pair of charts that track changes in zero and span measurements over time. These can be set up where either the measured values, or the difference between the established reference and measured values are recorded. Once the target zero and span values are determined these become the baselines. Warning and alarm limits are also calculated and inserted into the control charts. Values from subsequent QAL3 measurements are recorded on these charts giving a visual representation of the deviation away from the baseline as well as alerting the operator to alarm limit exceedance. Figure C.1 provides an example of what a Shewhart control chart may look like.

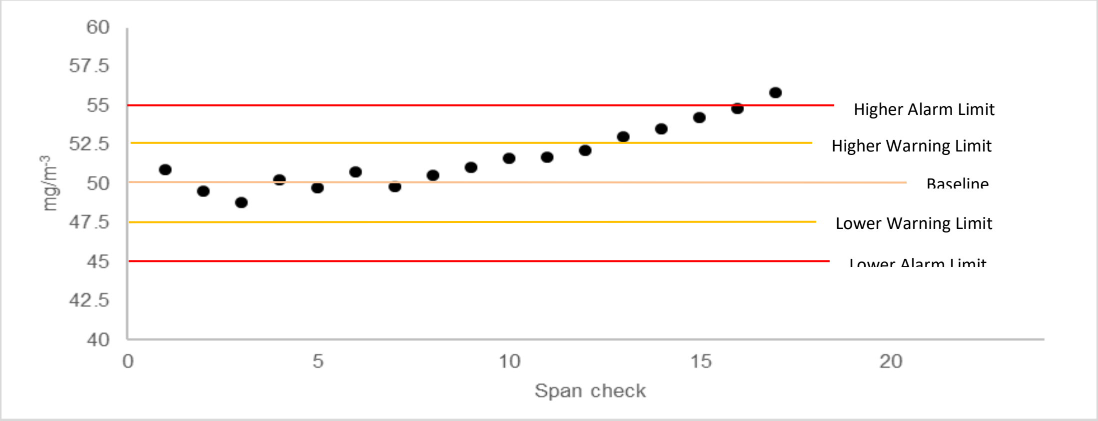


Figure C.1– An example Shewhart control chart

Exponentially Weighted Moving Average (EWMA) Chart

The EWMA chart is similar to the Shewhart chart, however it allows the process operator to detect small changes in precision and drift that happen gradually over time. Previous QAL3 measurements are used to calculate the average with greater weighting given to the most recent results. Figure C.2 provides an example of what an EMWA chart may look like.

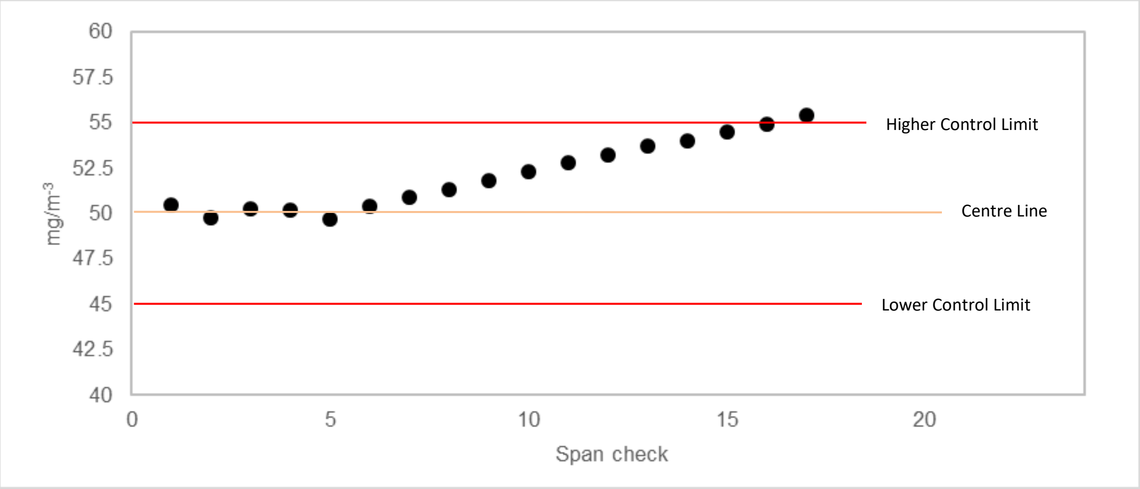


Figure C.2 – An example EWMA chart

CUSUM Chart

The CUSUM control chart is complicated to set up, however it provides the added benefit of determining drift and precision of the AMS separately. A baseline value is determined using reference material which becomes the target value. Each time a QAL3 measurement is made the difference between the result and the target value is noted and added to a cumulative sum from previous QAL3 checks, and plotted on a chart. A gradual curve away from the target value indicates that the AMS is drifting whereas loss of precision can be observed when there are abrupt changes. Appendix C in EN 14181 gives more detail in setting up and operating CUSUM control charts. Unlike other control charts where the interval between QAL3 checks can be decided upon using the AMS maintenance interval period, a CUSUM chart requires weekly QAL3 measurements. Figure C.3 gives an example of what a CUSUM chart may look like.

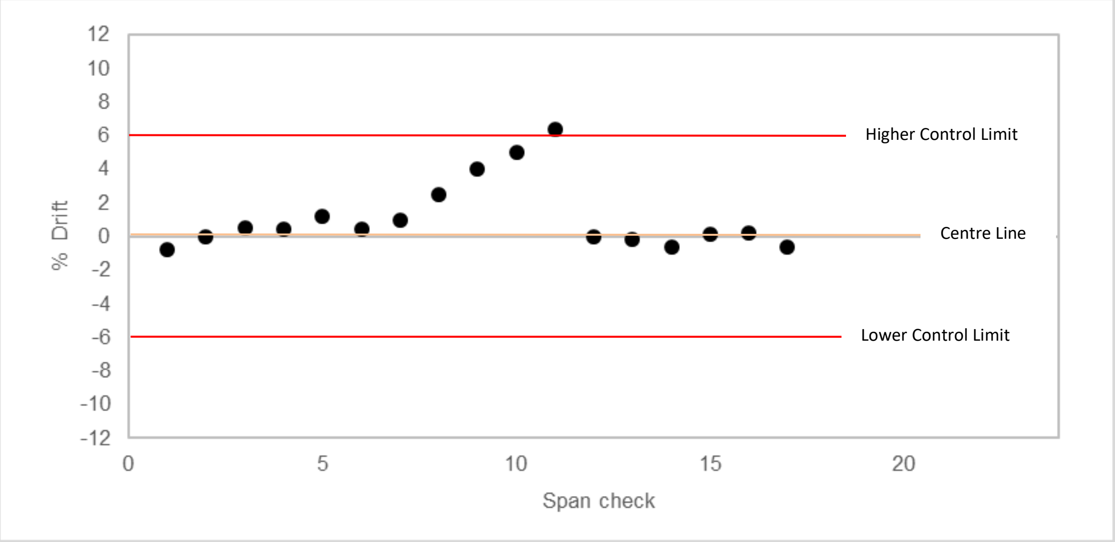


Figure C.3 – An example CUSUM chart

Annex G – Template for a report for QAL2

This template specifies the minimum requirements for reports for QAL2s 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 10: 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 – Date 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.

All pages header/footer to include the following:

- Report reference number
- Licence 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:

- Accreditation logos, and registration number of monitoring organisation;
- Title including type of report (QAL2 and/or AST);
- Licence 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 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	**Deviations** • 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.

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
Notes	*These will be specified in the permit*	*This will typically be a 30-minute average or a 1-hour average, but may differ for large combustion plants.*	*This will typically be a daily average, but may be a 48-hour average for some types of large combustion plants*	*This will be expressed as a 95% confidence interval within the IED*

2.2	**Operational Information and site monitoring-provisions**
2.2.1	**Process type and variations in emissions.** 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** 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	**Abatement** Type of abatement plant and how this affects emissions.
2.3	**Monitoring provisions at the installation – periodic monitoring**

2.3.1	**Stack and sampling ports** 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	**Monitoring platform and site-provisions** Record the following: 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	**Sample – how representative is it?** 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.
2.4	**Continuous Emission Monitoring Systems (CEMs) at the installations**
2.4.1	**Types of CEMs for each main determinand, oxygen and moisture** Type, e.g. cross-duct, in situ, or extractive; Brand; Model; Certification range; Principle; Location of sampling/measurement; Statement of QAL1 compliance; Units and basis (wet/dry, actual/STP) of CEMS raw data
2.4.2	**Types of monitoring for peripheral determinands** 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	**Function**
3.2	**Standard Reference Methods (SRMs)** - include the following, e.g. in a table. Determinand; SRM standard applied; Type and principle; Operational range; Certification range of any instrumental methods used; Uncertainty; Accreditation. Units and basis (wet/dry, actual/STP) of SRM raw data

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** Start and end times of each pair of data; Raw CEM results; Stack/CEM peripheral determinands for temperature, pressure, oxygen and moisture; 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** Standardised CEM results (i.e. STP, dry and to the reference O_2 concentration); Standardised SRM results (i.e. STP, dry and to the reference O_2 concentration).
A4.3	**Plot 1 – mandatory** Time series of CEMS versus SRM data at AMS conditions.
A4.4	**Calculation and procedure – Elimination of outliers** Outliers should be clearly indicated in the dataset. Note: The procedure described in Section 5.3 shall be used. A worked example can be found in Annex A.
A4.5	**Calculation – determination of Procedure**
Section 4A – Monitoring data and calculations	
A4.6	**Table 4.3 – data used to determine the calibration function** 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** • Raw CEM values; • Calibrated CEM values, at CEM conditions; • Peripheral determinands for CEMs; • Calibrated CEM values, standardised.
A4.9	**Table 4.5 – Data used for the variability test** 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.
A4.10	**Calculation - the variability test** The calculations, as set out in EN 14181; The variability test; Statement of the results.
A4.11	**Plot 2 – Mandatory** x-y plot of calibrated CEMS data at Ref Cond versus SRM data at Ref Cond; 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** Start and end times of each pair of data.
Section 4B – Monitoring data and calculations	
	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	**Table 4.2 – standardised monitoring data** Standardised CEM results (i.e. STP, dry and to the reference O_2 concentration); Standardised SRM results (i.e. STP, dry and to the reference O_2 concentration).
B4.3	**Plot 1 – mandatory** Time series of standardised CEM versus standardised SRM data.
B4.4	**Calculation and procedure – Elimination of outliers** Outliers should be clearly indicated in the averaged raw-data set.
B4.5	**Table 4.3 – data used to calculate calibrated values** 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; Standardised SRM values.
B4.6	**Table 4.4 – Data used for the variability test** 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	**Calculation - the variability test and the acceptance test** The calculations, as set out in EN 14181; The variability test; The acceptance test; Statement of the results.
B4.8	**Plot 2 – Mandatory** 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_0) 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** Name of person/s performing the functional tests; Name of person witnessing the tests where applicable.

Along with the report, a digital file (spreadsheet) shall be made available for inspection/submission upon request. The spreadsheet shall contain the following information per parameter in the QAL2/AST report:

- Raw data (first level data - uncorrected, uncalibrated) from CEMS before the assessment of outliers. The header of the column shall indicate the units and basis of measurement (i.e. for NOx: mg/Nm^3, wet). This shall include peripheral temperature and pressure results if relevant.
- Raw data (as measured by the SRM) before the assessment of outliers. The header of the column shall indicate the units and basis of measurement (i.e. for NOx: ppm, dry). This shall include all necessary peripheral data to express SRM results at AMS conditions.
- Sequence of calculations as per Section 5.3 (How to implement the calibration function). Each step of the calculation sequence shall be reported in different columns. The header of the columns shall indicate the units and basis of measurement (i.e. for NOx: mg/Nm3 raw / Cal mg/Nm3 / Cal mg/Nm3 dry, O_2 corr / Cal mg/Nm3 dry, O_2 corr, validated)
    - The applicable (previous) calibration function shall be indicated
    - The 95% CI at ELV calculation method shall be indicated.

The purpose of this file is to facilitate the review of the report/calculations by the Regulator. All results reported in the report shall be replicable from the raw data provided.