

BS EN 14181:2014



BSI Standards Publication

# Stationary source emissions — Quality assurance of automated measuring systems

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## National foreword

This British Standard is the UK implementation of EN 14181:2014. It supersedes BS EN 14181:2004 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee EH/2/1, Stationary source emission.

A list of organizations represented on this committee can be obtained on request to its secretary.

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EUROPEAN STANDARD  
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**EN 14181**

November 2014

ICS 13.040.40

Supersedes EN 14181:2004

English Version

## Stationary source emissions - Quality assurance of automated measuring systems

Émission des sources fixes - Assurance qualité des systèmes automatiques de mesurage

Emissionen aus stationären Quellen - Qualitätssicherung für automatische Messeinrichtungen

This European Standard was approved by CEN on 11 October 2014.

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## Foreword

This document (EN 14181:2014) has been prepared by Technical Committee CEN/TC 264 "Air quality", the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by May 2015 and conflicting national standards shall be withdrawn at the latest by May 2015.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 14181:2004.

Annex J provides details of significant technical changes between this European Standard and the previous edition.

The first edition of this document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association to support requirements in the EU Directives 2000/76/EC [1] and 2001/80/EC [2], which have been replaced by EU Directive 2010/75/EU [3], and may also be applicable for other purposes.

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

## Introduction

This European Standard describes the quality assurance procedures needed to assure that an automated measuring system (AMS) installed to measure emissions to air are capable of meeting the uncertainty requirements on measured values given by legislation, e.g. EU Directives [1], [2], [3] or national legislation, or more generally by competent authorities.

Three different quality assurance levels (QAL1, QAL2, and QAL3) are defined to achieve this objective. These quality assurance levels cover the suitability of an AMS for its measuring task (e.g. before or during the purchase period of the AMS), the validation of the AMS following its installation, and the control of the AMS during its ongoing operation on an industrial plant. An annual surveillance test (AST) is also defined.

The suitability evaluation (QAL1) of the AMS and its measuring procedure are described in EN 15267-3 and EN ISO 14956 where a methodology is given for calculating the total uncertainty of AMS measured values. This total uncertainty is calculated from the evaluation of all the uncertainty components arising from its individual performance characteristics that contribute.

## 1 Scope

This European Standard specifies procedures for establishing quality assurance levels (QAL) for automated measuring systems (AMS) installed on industrial plants for the determination of the flue gas components and other flue gas parameters.

This European Standard specifies:

- a procedure (QAL2) to calibrate the AMS and determine the variability of the measured values obtained by it, so as to demonstrate the suitability of the AMS for its application, following its installation;
- a procedure (QAL3) to maintain and demonstrate the required quality of the measurement results during the normal operation of an AMS, by checking that the zero and span characteristics are consistent with those determined during QAL1;
- a procedure for the annual surveillance tests (AST) of the AMS in order to evaluate (i) that it functions correctly and its performance remains valid and (ii) that its calibration function and variability remain as previously determined.

This European Standard is designed to be used after the AMS has been certified in accordance with the series of European Standards EN 15267.

## 2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 15259:2007, *Air quality — Measurement of stationary source emissions — Requirements for measurement sections and sites and for the measurement objective, plan and report*

EN 15267-1, *Air quality — Certification of automated measuring systems — Part 1: General principles*

EN 15267-2, *Air quality — Certification of automated measuring systems — Part 2: Initial assessment of the AMS manufacturer's quality management system and post certification surveillance for the manufacturing process*

EN 15267-3, *Air quality — Certification of automated measuring systems — Part 3: Performance criteria and test procedures for automated measuring systems for monitoring emissions from stationary sources*

EN ISO 14956, *Air quality — Evaluation of the suitability of a measurement procedure by comparison with a required measurement uncertainty (ISO 14956)*

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

### 3.1

#### **automated measuring system**

#### **AMS**

measuring system permanently installed on site for continuous monitoring of emissions or measurement of peripheral parameters

Note 1 to entry: An AMS is a method which is traceable to a reference method.

Note 2 to entry: Apart from the analyser, an AMS includes facilities for taking samples (e.g. sample probe, sample gas lines, flow meters, regulators, delivery pumps) and for sample conditioning (e.g. dust filter, water vapour removal devices, converters, diluters). This definition also includes testing and adjusting devices that are required for regular functional checks.

### **3.2 extractive AMS**

AMS having the detection unit physically separated from the gas stream by means of a sampling system

### **3.3 in-situ AMS**

AMS having the detection unit in the gas stream or in a part of it

### **3.4 peripheral AMS**

AMS used to gather the data required to convert the AMS measured value to standard conditions

Note 1 to entry: A peripheral AMS is used to measure e.g. water vapour, temperature, pressure and oxygen.

### **3.5 reference method RM**

measurement method taken as a reference by convention, which gives the accepted reference value of the measurand

[SOURCE: EN 15259:2007]

### **3.6 standard reference method SRM**

reference method prescribed by European or national legislation

Note 1 to entry: Standard reference methods are used e.g. to calibrate and validate AMS and for periodic measurements to check compliance with limit values.

[SOURCE: EN 15259:2007]

### **3.7 peripheral SRM**

SRM used to gather the data required to convert the SRM measured values to AMS or standard conditions

Note 1 to entry: A peripheral SRM is used to measure e.g. water vapour, temperature, pressure and oxygen.

### **3.8 standard conditions**

conditions to which measured values have to be standardized to verify compliance with emission limit values

Note 1 to entry: Standard conditions are specified e.g. in EU Directives [1], [2] and [3].

### **3.9 emission limit value ELV**

limit value related to the maximum permissible uncertainty

Note 1 to entry: For the EU Directives [1], [2] and [3] it is the daily emission limit value that relates to the uncertainty requirement.



### 3.10

#### **maximum permissible uncertainty**

uncertainty requirement on AMS measured values given by legislation or competent authorities

### 3.11

#### **legislation**

directives, acts, ordinances or regulations

### 3.12

#### **competent authority**

organization or organizations which implement the requirements of EU Directives and regulate installations which shall comply with the requirements of this European Standard

### 3.13

#### **calibration function**

linear relationship between the values of the SRM and the AMS with the assumption of a constant residual standard deviation

Note 1 to entry: For dust measuring AMS, a quadratic calibration function can be used as described in EN 13284-2.

### 3.14

#### **standard deviation**

positive square root of the mean squared deviation from the arithmetic mean divided by the number of degrees of freedom

Note 1 to entry: The number of degrees of freedom is the number of measurements minus 1.

### 3.15

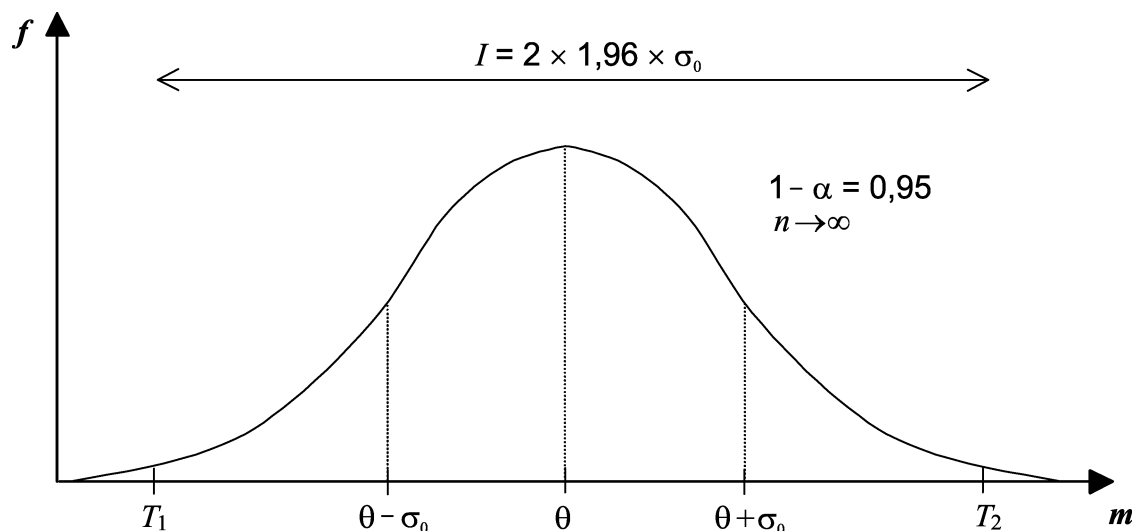
#### **confidence interval**

interval estimator ( $T_1, T_2$ ) for the parameter  $\theta$  with the statistics  $T_1$  and  $T_2$  as interval limits and for which it holds that  $P[T_1 < \theta < T_2] \geq (1 - \alpha)$

[SOURCE: ISO 3534-1:2006]

Note 1 to entry: The two-sided 95 % confidence interval of a normal distribution is illustrated in Figure 1, where:

$T_1 = \Theta - 1,96 \sigma_0$	is the lower 95 % confidence limit;
$T_2 = \Theta + 1,96 \sigma_0$	is the upper 95 % confidence limit;
$I = T_2 - T_1 = 2 \times 1,96 \times \sigma_0$	is the length of the 95 % confidence interval;
$\sigma_0 = I / (2 \times 1,96)$	is the standard deviation associated with a 95 % confidence interval;
$n$	is the number of observed values;
$f$	is the frequency;
$m$	is the measured value.



**Figure 1 — Illustration of the 95 % confidence interval of a normal distribution**

In this European Standard, the standard deviation  $\sigma_0$  is estimated in QAL2 by parallel measurements with the SRM. It is assumed that the requirement for  $\sigma_0$ , presented in terms of a maximum permissible uncertainty, is provided by the regulators (e.g. in some EU Directives). In the procedures of this standard, the premise is that the maximum permissible uncertainty is given as  $\sigma_0$  itself, or as a quarter of the length of the full 95 % confidence interval.

Note 2 to entry: In some EU Directives (see [1], [2], [3]) the uncertainty of the AMS measured values is expressed as half of the length of a 95 % confidence interval as a percentage  $P$  of the emission limit value  $E$ . Then, in order to convert this uncertainty to a standard deviation, the appropriate conversion factor is  $\sigma_0 = P E / 1,96$ .

### 3.16 variability

standard deviation of the differences of parallel measurements between the SRM and AMS

### 3.17 uncertainty

parameter associated with the result of a measurement that characterises the dispersion of the values that could reasonably be attributed to the measurand

[SOURCE: ISO/IEC Guide 98-3:2008]

### 3.18 measurand

particular quantity subject to measurement

[SOURCE: ISO/IEC Guide 98-3:2008]

Note 1 to entry: A measurand can be e.g. the mass concentration of a measured component or the waste gas velocity, pressure or temperature.

### 3.19 measured component

constituent of the waste gas for which a defined measurand is to be determined by measurement

[SOURCE: EN 15259:2007]

### 3.20

#### **peripheral parameter**

specified physical or chemical quantity which is needed for conversion of measured values to specified conditions

### 3.21

#### **measured value**

estimated value of the measurand derived from a measured signal

Note 1 to entry: This usually involves calculations related to the calibration process and conversion to required quantities.

Note 2 to entry: A measured value is a short-term average. The averaging time can be e.g. 10 min, 30 min or 1 h.

### 3.22

#### **instrument reading**

measured signal directly provided by the AMS without using the calibration function

### 3.23

#### **zero reading**

instrument reading on simulation of the input parameter at zero concentration

### 3.24

#### **span reading**

instrument reading for a simulation of the input parameter at a fixed elevated concentration.

### 3.25

#### **instability**

change in the measured signal comprised of drift and dispersion over a stated maintenance interval

Note 1 to entry: Drift and dispersion specify the monotonic and stochastic change with time of the measured signal, respectively.

### 3.26

#### **drift**

monotonic change of the calibration function over stated maintenance interval, which results in a change of the measured signal

### 3.27

#### **precision**

closeness of agreement of results obtained from the AMS for successive zero readings and successive span readings at defined time intervals

### 3.28

#### **response time**

##### **$t_{90}$**

time interval between the instant of a sudden change in the value of the input quantity to an AMS and the time as from which the value of the output quantity is reliably maintained above 90 % of the correct value of the input quantity

Note 1 to entry: The response time is also referred to as the 90 % time.

### 3.29

#### **maintenance interval**

maximum admissible interval of time for which the performance characteristics will remain within a predefined range without external servicing, e.g. refill, calibration, adjustment

### 3.30

#### reference material

substance or mixture of substances, with a known concentration within specified limits, or a device of known characteristics

### 3.31

#### CUSUM chart

calculation procedure in which the amount of drift and change in precision is compared to the corresponding uncertainty components which are obtained during QAL1

### 3.32

#### EWMA chart

calculation procedure in which the combined amount of drift and change in precision is compared to the corresponding uncertainty components which are obtained during QAL1

Note 1 to entry: The EWMA chart averages the data in a way that gives less and less weight to data as they are further removed in time.

## 4 Symbols and abbreviations

### 4.1 Symbols

$a$	intercept of the calibration function
$\hat{a}$	best estimate of $a$
$b$	slope of the calibration function
$\hat{b}$	best estimate of $b$
$D_i$	difference between SRM measured value $y_i$ and calibrated AMS measured value $\hat{y}_i$
$\bar{D}$	average of $D_i$
$E$	emission limit value
$k_v$	test value for variability (based on a $\chi^2$ -test, with a $\beta$ -value of 50 %, for $N$ numbers of paired measurements)
$N$	number of paired samples in parallel measurements
$P$	percentage value
$s_{\text{AMS}}$	standard deviation of the AMS used in QAL3
$s_D$	standard deviation of the differences $D_i$ in parallel measurements
$t_{0,95; N-1}$	value of the $t$ distribution for a significance level of 95 % and a number of degrees of freedom of $N - 1$
$u_{\text{inst}}$	uncertainty due to instability (expressed as a standard deviation)
$u_{\text{temp}}$	uncertainty due to influence of temperature (expressed as a standard deviation)
$u_{\text{pres}}$	uncertainty due to influence of pressure (expressed as a standard deviation)
$u_{\text{voltage}}$	uncertainty due to influence of voltage (expressed as a standard deviation)
$u_{\text{others}}$	any other uncertainty that may influence the zero and span reading (expressed as a standard deviation)
$x_i$	$i^{\text{th}}$ measured signal obtained with the AMS at AMS measuring conditions

$\bar{x}$	average of AMS measured signals $x_i$
$y_i$	$i^{\text{th}}$ measured value obtained with the SRM
$\bar{y}$	average of the SRM measured values $y_i$
$y_{i,s}$	SRM measured value $y_i$ at standard conditions
$y_{s,\min}$	lowest SRM measured value at standard conditions
$y_{s,\max}$	highest SRM measured value at standard conditions
$\hat{y}_i$	best estimate for the "true value", calculated from the AMS measured signal $x_i$ by means of the calibration function
$\hat{y}_{i,s}$	best estimate for the "true value", calculated from the AMS measured signal $x_i$ at standard conditions
$\hat{y}_{s,\max}$	best estimate for the "true value", calculated from the maximum value of the AMS measured signals $x_i$ at standard conditions
$Z$	offset (the difference between the AMS zero reading and the zero)
$\alpha$	significance level
$\varepsilon_i$	deviation between $y_i$ and the expected value
$\sigma_0$	standard deviation associated with the uncertainty derived from requirements of legislation

## 4.2 Abbreviations

AMS	automated measuring system
AST	annual surveillance test
CUSUM	cumulative sum
DAHS	data acquisition and handling system
ELV	emission limit value
EWMA	exponentially weighted moving-average
QA	quality assurance
QAL	quality assurance level
QAL1	first quality assurance level
QAL2	second quality assurance level
QAL3	third quality assurance level
QC	quality control
SRM	standard reference method

## 5 Principle

### 5.1 General

An AMS to be used at installations shall have been proven suitable for its measuring task (parameter and composition of the flue gas) by use of the QAL1 procedure, as specified by EN 15267-1 EN 15267-2, EN 15267-3 and EN ISO 14956. Using these standards, it shall be proven that the total uncertainty of the results obtained from the AMS meets the specification for uncertainty stated in the applicable regulations. In

QAL1 the total uncertainty required by the applicable regulation is calculated by summing in an appropriate manner all the relevant uncertainty components arising from the individual performance characteristics.

In case of new installations of AMS, the AMS shall have been certified in accordance with EN 15267-1, EN 15267-2, and EN 15267-3.

In case of AMS already installed at plants which have not been certified according to EN 15267-1, EN 15267-2, and EN 15267-3, or AMS already installed at plants which were certified according to EN 15267-1, EN 15267-2, and EN 15267-3 but where the ELV and the uncertainty requirement have subsequently changed, the procedure described in H.2 may be applied. However, H.2 does not apply to new installations of old AMS which have not been certified according to EN 15267-1, EN 15267-2 and EN 15267-3.

NOTE 1 SRM measurements, influences by peripheral parameters and the sampling site can contribute to the uncertainty of the AMS measured values determined in QAL2.

NOTE 2 EN 15267-3 requires that the total uncertainty of the AMS measured values determined in the performance test should be at least 25 % below the maximum permissible uncertainty specified e.g. in applicable regulations to provide a sufficient margin for the uncertainty contributions from the individual installation of the AMS to pass QAL2 and QAL3 successfully.

The QAL2 and AST procedures involve testing laboratories, whereas the QAL3 procedures involve the plant operators.

QAL2 is a procedure for the determination of the calibration function and its variability, and a test of the variability of the measured values of the AMS compared with the maximum permissible uncertainty given by legislation. The QAL2 tests are performed on suitable AMS that have been correctly installed and commissioned. A calibration function is established from the results of a number of parallel measurements performed with the standard reference method (SRM). The variability of the measured values obtained with the AMS is then evaluated against the maximum permissible uncertainty.

The QAL2 procedures are repeated periodically, after a major change of plant operation, after a failure of the AMS or as required by legislation.

QAL3 is a procedure which is used to check drift and precision in order to demonstrate that the AMS is in control during its operation so that it continues to function within the required specifications for uncertainty. This is achieved by conducting periodic zero and span checks on the AMS – based on those used in the procedure for zero and span repeatability tests carried out in QAL1 – and then evaluating the results obtained using control charts. Zero and span adjustments or maintenance of the AMS, may be necessary depending on the results of this evaluation.

The AST is a procedure which is used to evaluate whether the uncertainty of the measured values obtained from the AMS still meet the uncertainty criteria – as demonstrated in the previous QAL2 test. It also determines whether the calibration function obtained during the previous QAL2 test is still valid. The validity of the measured values obtained with the AMS is checked by means of a series of functional tests as well as by the performance of a limited number of parallel measurements using an appropriate SRM.

NOTE 3 There are several concentration ranges relevant to the application of this European Standard:

- certification range

This is the range over which the AMS has been certified. It is generally recommended that this range be related to the ELV given in relevant EU Directives of the processes under which the AMS will be used. EN 15267-3 requires that the certification range be no greater than 1,5 times the daily ELV for waste incineration plants and 2,5 times the daily ELV for large combustion plants. Where there is a choice, the daily ELV is used.

- calibration range

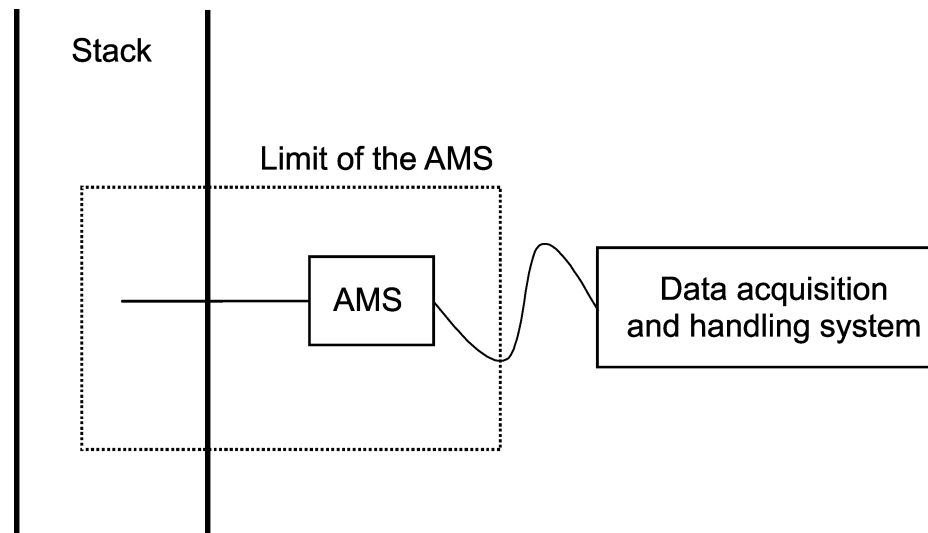
This is the range over which the AMS has been calibrated under the QAL2 procedure.

- measuring range

This is the range at which the AMS is set to operate during use. There are usually requirements from national competent authorities that the range encompasses the maximum short-term ELV. The measuring range can be greater than the certification range.

## 5.2 Limitations

Figure 2 illustrates the components of the AMS covered by this standard.



**Figure 2 — Limits for the QA of the AMS excluding the data acquisition and handling system**

**NOTE 1** The influence of the uncertainty of the measurement results, which arise from the data acquisition and handling system of the AMS or of the plant system, and its determination, are not covered by this standard.

**NOTE 2** The performance of the data acquisition and handling system (DAHS) can be as influential as the AMS performance in determining the quality of the results obtained from the whole measuring system/process. There are different requirements for data collection, recording and presentation in different countries. A European Standard on quality assurance of DAHS is currently under preparation.

When conducting parallel measurements, the measured signals from the AMS 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 e.g. for temperature and oxygen). A plant data collection system with ongoing quality control can alternatively be used to collect the measured signal from the AMS.

## 5.3 Measurement site and installation

The AMS shall be installed in accordance with the requirements of the relevant European and/or international standards. Special attention shall be given to ensure that the AMS is readily accessible for regular maintenance and other necessary activities.

The AMS should be positioned as far as practical in a position where it measures a sample that is representative of the stack gas composition. EN 15259 describes a procedure to identify the best sampling location for the AMS, in order to provide representative measurements. It also defines the optimum location for undertaking parallel SRM measurements for the QAL2.

All measurements shall be carried out on a suitable AMS and peripheral AMS installed within an appropriate working environment.

The working platform used to access the AMS and the working platform used to perform the SRM measurements shall be in accordance with the requirements of EN 15259. The sampling ports for measurements with the SRM shall be placed in such a location to avoid mutual interference between SRM and AMS in order to achieve comparable measurements between AMS and SRM.

**NOTE** Lack in the fulfilment of these conditions can result in higher measurement uncertainties, potentially resulting in nonconformity with the requirements given by EU Directives.

It is necessary to have good access to the AMS to enable inspections to take place and also to minimize the time taken to implement the quality assurance procedures of this standard. A clean, well-ventilated and well-lit working space around the AMS is required to enable the staff to perform this work effectively. Suitable protection is required for the personnel and the equipment, if the working platform is exposed to the weather.

#### **5.4 Testing laboratories performing SRM measurements**

The testing laboratories performing the measurements with the SRM shall be accredited for this task according to EN ISO/IEC 17025, or shall be approved directly by the relevant competent authority.

**NOTE** CEN/TS 15675 provides clarification and additional information on the application of EN ISO/IEC 17025 to periodic measurements used e.g. for the calibration of AMS.

## **6 Calibration and validation of the AMS (QAL2)**

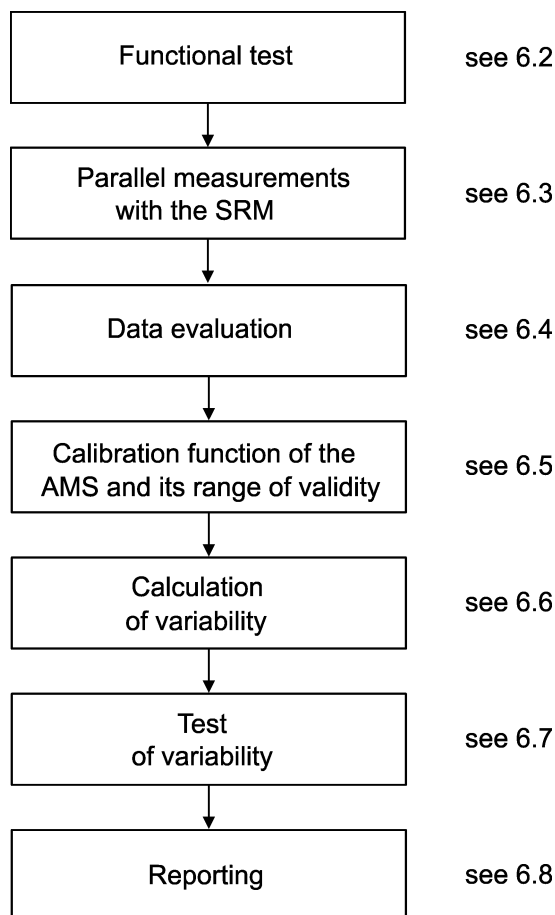
### **6.1 General**

QAL2 covers the following items:

- functional test of the AMS including check of correct installation;
- parallel measurements with the SRM;
- data evaluation;
- determination of the calibration function of the AMS and its range of validity;
- calculation of variability of the AMS measured values;
- test of variability of the AMS measured values;
- reporting.

The sequence of the combined tests is shown in Figure 3.





**Figure 3 — Flow diagram for the calibration and variability tests**

A QAL2 procedure shall be performed for all measurands:

- at least every 5 years for every AMS or more frequently if so required by legislation or by the competent authority;

Furthermore, a QAL2 shall be performed for all the measurands influenced by:

- any major change in plant operation (e.g. change in flue gas abatement system or change of fuel), or
- any major changes or repairs to the AMS, which will influence the results obtained significantly.

The results of QAL2 shall be implemented within six months after the changes. During the period before a new calibration function has been established the previous calibration function (where necessary with extrapolation) shall be used.

**NOTE** In some EU member countries the local authorities allow in individual cases the continued use of the previous calibration function if it can be proven by use of a specified statistical procedure that the new calibration function does not significantly differ from the previous one.

Examples of calculation of the calibration function and of the variability test are given in Annex E.

## 6.2 Functional test

The requirements for installation and the measurement site as specified in 5.3 shall be fulfilled.

Before calibration (see 6.3 and 6.5) and the test for variability (see 6.6 and 6.7) are performed, it shall be proven that the AMS is commissioned satisfactorily, e.g. as specified by the AMS supplier and/or manufacturer. It shall also be shown and documented that the AMS gives a zero reading on a zero concentration.

**NOTE** For some AMS it is difficult to achieve a zero reading. In those situations, the AMS can be removed from the stack, and zeroed using a test bench or similar. As an alternative, a measuring path, which enables this zero test to be carried out, can be installed in the stack.

The functional test before calibration shall be performed according to Annex A. It is recommended to perform the functional test not more than one month before parallel measurements are started. The functional test shall be performed by an experienced testing laboratory, which has been recognised by the competent authority.

The specific precautions to be taken should depend on the individual location. Special attention should be made for particulate measurements.

Since the AMS and SRM measured values are converted to standard conditions by independently determined data sets of the peripheral parameters, the uncertainties in the peripheral parameters are attributed to the AMS of the air pollutant in the variability test. Therefore, it is recommended to perform the relevant steps of the functional test specified in Annex A for measuring systems of the peripheral parameters to minimize uncertainties caused by the peripheral parameters.

### 6.3 Parallel measurements with the SRM

Parallel measurements shall be performed with the AMS and SRM in order to calibrate and validate the AMS by use of an independent method.

It is not sufficient to use reference materials alone to obtain the calibration functions and this is therefore not permitted. This is because these reference materials do not replicate sufficiently the matrix stack gas, they cannot be used to establish that the sampling point(s) of the AMS are representative, and they are not used with the sampling system in all cases. However, if there are limited variations in the results obtained in the AMS/SRM tests, and the measured concentrations are well below the ELV, an extrapolation of the calibration function to the ELV may be verified by the use of appropriate reference materials, taking into account the effects of interfering substances on the AMS, where appropriate.

If clear and distinct operating modes of the plant process are part of its normal operation (for example changes of fuel), additional calibrations shall be performed and a calibration function established for each operational mode.

**NOTE 1** It can be possible to establish one calibration function fulfilling the variability requirements that covers the range of conditions within which the plant operates.

In order to ensure that the calibration function is valid for the range of conditions within which the plant will operate, the concentrations during the calibration shall be varied as much as possible within the normal operations of the plant. This shall ensure that the calibration of the AMS is valid over as large a range as possible, and also that it covers most operational situations.

**NOTE 2** Careful measurement planning can identify the optimum time for the parallel measurements, when the emissions are at their highest or most varied.

The test for variability shall be performed (see 6.7) for each calibration function, i.e. for each operating mode of the plant.

The SRM shall be used to sample the emissions at a sampling plane in the duct, which fulfils the requirements of EN 15259, and is as close as possible to the AMS.

The presence of the SRM equipment shall not influence or disturb the AMS measurements and vice versa.

**NOTE 3** Although EN 15259 allows simplified sampling of gaseous components in cases of homogeneous flue gas or negligible concentration variations, grid measurements can improve the quality of the calibration curve.

For each calibration a minimum of 15 valid parallel measurements shall be made with the plant operating normally. These measurements shall be uniformly spread both over at least three days and over each of the measuring days of normally 8 h to 10 h (e.g. not five measurements in the morning and none in the afternoon) and be performed within a period of four weeks.

**NOTE 4** The required spread of a minimum of 15 valid measurements over three days is essential in minimizing the effect of influences of the subsequent measurement results (i.e. to avoid auto-correlation between the calculated differences in the results of the AMS and SRM). The alternative of performing more measurements within a shorter time interval can lead to the establishment of an invalid calibration function.

**NOTE 5** A minimum of 15 valid measurements can in practice require that more than 15 samples be taken, since some samples may be deemed to be invalid during subsequent analysis because of inadequate quality.

**NOTE 6** The requirement that the measurements need to be uniformly spread over at least three days does not imply that the measurements need to be performed within three consecutive days.

If the QAL2 is not the first QAL2 being carried out on the AMS, then an AST may be performed instead of a QAL2 provided that the SRM measured values obtained in the AST and at least 95 % of the AMS measured values at standard conditions obtained since the last AST are less than the maximum permissible uncertainty specified e.g. in the relevant EU Directive.

A set of measurements is valid when all of the requirements below are fulfilled:

- the SRM measurements are performed according to the accepted standard;
- the time period of each AMS measured signal is larger than 90 % of the averaging time (excluding all of the measured signals which are above 100 % or below 0 % of the measuring range of the AMS, signals obtained during internal checks (auto calibration), and signals obtained during any other malfunctioning of the AMS).

During the parallel measurements with the AMS and SRM, each result is considered as a measurement pair (one AMS measured signal and one SRM measured value) and these shall cover the same time period.

The sampling time for each of the parallel measurements shall be at least 30 min, or at least four times the response time of the AMS, including the sampling system (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. The recording system shall have an averaging time significantly shorter than the response time of the AMS.

**NOTE 7** If the emissions are at low levels the SRM measured values can be improved for manual SRM by extending the sampling time.

The time interval between the start of each sample shall be at least 1 h.

The results obtained from the SRM shall be expressed under the same conditions as those measured by the AMS (e.g. conditions of pressure, temperature, etc.). In order to establish the calibration function and perform the variability test all additional parameters and values included in the corrections to AMS conditions and standard conditions shall be obtained for each measurement pair.

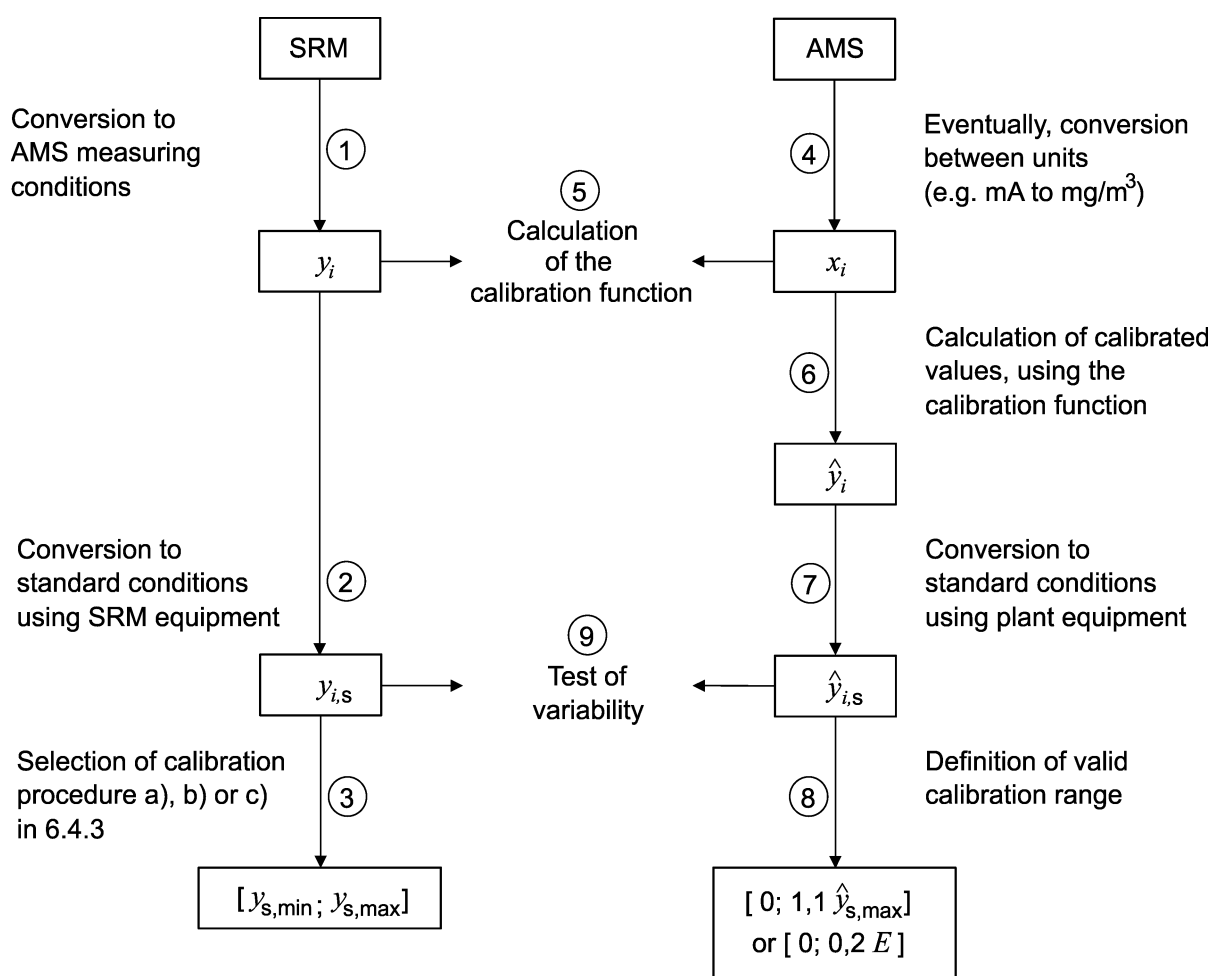
**EXAMPLE** If the AMS measures gaseous HCl in units of  $\text{mg}/\text{m}^3$  in stack gas containing water vapour, then the SRM measured values are expressed in the same units (e.g.  $\text{mg}/\text{m}^3$  in the stack gas with the same water vapour concentration).

In order to fulfil the requirement that the calibration of the AMS is valid over as large a range as possible, and that it covers most operational situations, parallel measurements over three days are required. However, this requires several manual SRM measurements of the water vapour concentration. If calibrated AMS measured values for water vapour are available, these may be used to convert the SRM data to dry or wet basis. When wet abatement techniques are used, the exhaust gas is saturated and therefore the water vapour concentration is often nearly constant. In such cases an extended measurement of the water vapour concentration is of little purpose. In those situations, conversion of SRM data to dry or wet basis may be carried out using calculated water vapour values.

## 6.4 Data evaluation

### 6.4.1 Preparation of data

The steps for providing data required for establishing the calibration function and performing the test of variability are illustrated in Figure 4.



The figure in the circles indicates the sequence of the steps.

**Figure 4 — Flow chart describing the steps in calibration procedure and test for variability**

The AMS shall be calibrated at the condition of the flue gas as measured by the AMS. Therefore, the SRM measured values shall be converted to AMS measuring conditions, if necessary, giving SRM measured values  $y_i$  to be expressed in concentration units (e.g.  $\text{mg}/\text{m}^3$ ).

The measured signals from the AMS  $x_i$  can be either a signal in an electrical unit (e.g. mA or Volt) or in a concentration unit (e.g. mg/m<sup>3</sup>).

**NOTE** For in-situ AMS, that measure the gas directly, the calibration function is reported at the operating conditions. For extractive AMS measuring at specified conditions, the calibration function is reported at these specified conditions.

The data sets obtained in the parallel measurements shall be checked for possible outliers. The method used to assess outliers and reasons for excluding outliers shall be given in the QAL2 report. Outliers shall be reported and identified in the calibration data tables and diagrams.

This standard requires at least 15 valid data points for a QAL2 calibration function. If points are excluded e.g. through the use of outlier tests, this requirement can be failed. It is therefore recommended that additional data points be taken, to allow for the exclusion of outliers. If this is not done the QAL2 can be invalid. All data points shall be used to form the calibration function, unless excluded through the use of outlier tests or have been shown to be invalid.

#### 6.4.2 Selection of data points from automated SRM

In the case of data sets produced from an automated SRM, which may produce a high number of data points, any selection of points shall be justified and documented.

#### 6.4.3 Establishing the calibration function

It is presupposed in the standard that the calibration function is linear and has a constant residual standard deviation. The calibration function shall be described by the model below (see ISO 11095):

$$y_i = a + b x_i + \varepsilon_i \quad (1)$$

where

- $x_i$  is the  $i^{\text{th}}$  AMS measured signal;  $i = 1$  to  $N$ ;  $N \geq 15$ ;
- $y_i$  is the  $i^{\text{th}}$  SRM measured value;  $i = 1$  to  $N$ ;  $N \geq 15$ ;
- $\varepsilon_i$  is the deviation between  $y_i$  and the expected value;
- $a$  is the intercept of the calibration function;
- $b$  is the slope of the calibration function.

The general procedure requires a sufficient range of the measured concentrations to give a valid calibration of the AMS for the complete range of concentrations encountered during normal operations. As stated in 6.3 it is essential that the concentration range is as large as possible within the normal operation of the plant to allow for a valid calibration function to be obtained. However, at a large number of plants, it can be difficult under normal operating conditions to achieve a sufficiently large concentration range. In such cases, in which the concentration range (measured with the SRM) is less than the maximum permissible uncertainty, other (similar) procedures are given below for high level clusters (procedure b) and for low level clusters (procedure c).

**NOTE 1** In some EU Directives (see [1], [2], [3]) the maximum permissible uncertainty of the AMS measured values is expressed as half of the length of a 95 % confidence interval as a percentage  $P$  of the emission limit value  $E$ . In this case the maximum permissible uncertainty corresponds to an expanded uncertainty.

If the concentration range is slightly bigger than the maximum permissible uncertainty, and if procedure a) results in an inadequate calibration function (e.g. a function with negative slope), procedure b) or c) may be used instead. The justification shall be given in the QAL2 report.

The following quantities shall be calculated:

$$\bar{x} = \frac{1}{N} \sum_{i=1}^N x_i \quad (2)$$

$$\bar{y} = \frac{1}{N} \sum_{i=1}^N y_i \quad (3)$$

The difference ( $y_{s,max} - y_{s,min}$ ) between the highest and lowest measured SRM concentration at standard conditions shall be calculated.

- a) If ( $y_{s,max} - y_{s,min}$ ) is greater than or equal to the maximum permissible uncertainty, the parameters of the calibration function shall be calculated according to Formula (4) and Formula (5):

$$\hat{b} = \frac{\sum_{i=1}^N (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^N (x_i - \bar{x})^2} \quad (4)$$

$$\hat{a} = \bar{y} - \hat{b} \bar{x} \quad (5)$$

- b) If ( $y_{s,max} - y_{s,min}$ ) is smaller than the maximum permissible uncertainty and  $y_{s,min}$  is greater than or equal to 15 % of the ELV, the parameters of the calibration function shall be calculated according to Formula (6) and Formula (7):

$$\hat{b} = \frac{\bar{y}}{\bar{x} - Z} \quad (6)$$

$$\hat{a} = -\hat{b} Z \quad (7)$$

where the offset  $Z$  is the difference between the AMS zero reading and zero.

NOTE 2 For several AMS the offset is 4 mA.

For procedure b) it is essential that, prior to the parallel measurements, it is proven that the AMS gives a reading at or below detection limit (as demonstrated in QAL1) at a zero concentration (as stated in 6.2).

- c) If ( $y_{s,max} - y_{s,min}$ ) is smaller than the maximum permissible uncertainty and  $y_{s,min}$  is smaller than 15 % of the ELV, the parameters of the calibration function shall be determined as follows:

If appropriate reference materials at zero and close to the ELV are available, these shall be used to obtain two data pairs (AMS measured signal and reference value) one at zero and one close to the ELV. The data pairs shall be converted to AMS measuring conditions by use of the average of the AMS measuring conditions in the parallel measurements with the SRM. A combined data set consisting of the results of the parallel measurements and of the data pairs obtained by use of the reference materials shall be formed. The combined data set shall be used to calculate the quantities according to Formula (2)

and Formula (3) as well as the parameters of the calibration function according to Formula (4) and Formula (5).

NOTE 3 If appropriate data pairs are available from the functional test they can be used.

If appropriate reference materials at zero and close to ELV are not available, alternative procedures for the establishment of calibration function can be used, subject to approval by the competent authority. The procedure applied shall be agreed by both the plant operator and the competent authority and be completely documented in the QAL2 report.

The results shall be plotted on an x-y graph in order to show explicitly the calibration function and the valid calibration range.

## 6.5 Calibration function of the AMS and its validity

The calibration function is given by Formula (8):

$$\hat{y}_i = \hat{a} + \hat{b} x_i \quad (8)$$

where

$\hat{y}_i$  is the calibrated AMS measured value;

$x_i$  is the AMS measured signal.

Each AMS measured signal  $x_i$  shall be converted to a calibrated value  $\hat{y}_i$  by means of the above calibration function.

It is recommended that this calibration function is incorporated into the data processing system of the plant.

NOTE  $\hat{y}_i$  is the calibrated measurement result obtained from the AMS. According to certain EU Directives (see [1], [2], [3]) the maximum permissible uncertainty should be subtracted from that result before comparisons are made with the emission limit value. That procedure is outside the scope of this standard. The calibrated result  $\hat{y}_i$  of the AMS is without subtraction of the maximum permissible uncertainty.

The calibration function is valid when the plant is operated within the valid calibration range. This valid calibration range is either the calibration range from zero to the maximum value  $\hat{y}_{s,max}$  of the calibrated AMS measured values at standard conditions, determined during the QAL2 procedure, plus an extension of 10 % of  $\hat{y}_{s,max}$ , or to 20 % of ELV, whichever is greater.

For measurements outside the valid calibration range, however, the calibration curve shall be extrapolated in order to determine the concentration values, which exceed the valid calibration range.

If greater confidence in the performance of the AMS at ELV is required when the plant is emitting outside its calibration range determined above, reference materials at zero and at a concentration close to 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 SRM measured values. The deviation at ELV should be less than the maximum permissible uncertainty specified by legislation. The deviation at zero should be less than 10 % of the ELV. If these criteria are not fulfilled then further investigations shall be performed to establish the reasons for this.

The validity of the valid calibration range shall be evaluated by the plant owner on a weekly basis (Monday to Sunday). A full new calibration (QAL2) shall be performed, reported and implemented within 6 months, if any of the following conditions occur:



- more than 5 % of the number of AMS measured values calculated over this weekly period (based on standardized calibrated values) are outside the valid calibration range for more than 5 weeks in the period between two AST;
- more than 40 % of the number of AMS measured values calculated over this weekly period (based on standardized calibrated values) are outside the valid calibration range for one or more weeks.

If the plant is not operated continuously then the percentage values may be calculated from the last 168 operational hours (representing one week in operation).

If exceedances of the valid calibration range are caused by plant failures, a full new calibration (QAL2) is not needed after fixing the plant failure.

If the best estimate of the true value  $\hat{y}_{i,s}$  is outside the valid calibration range but below 50 % of ELV, then the competent authority can allow the plant to perform an AST instead of the QAL2. If the AST demonstrates that the existing calibration function is valid beyond the existing valid calibration range, the competent authority can allow the plant to extend the valid calibration range up to the maximum measured concentration determined during the AST plus an extension of 10 % of this value, but the valid calibration range shall not exceed 50 % of ELV.

The existing calibration function shall be used until the new calibration function has been implemented.

Data from previous calibrations shall not be combined with data from a new calibration exercise when calculating the calibration function.

Only calibrated values should be used when reporting to the authorities.

## 6.6 Calculation of variability

Identify the stated maximum permissible uncertainty for the AMS measured values. Verify the exact definition of this uncertainty (e.g. is it expressed as a 95 % confidence interval, an expanded uncertainty, a standard deviation, or any other statistical formulation). If necessary, convert the maximum permissible uncertainty in terms of an absolute standard deviation  $\sigma_0$ .

In the case where the expanded uncertainty is expressed at a level of confidence of 95 %, the value of an absolute standard deviation shall be determined by using a factor of 1,96 as the value for the coverage factor.

**EXAMPLE** In some EU Directives (see [1], [2], [3]) the maximum permissible uncertainty of the AMS measured values is expressed as half of the length of a 95 % confidence interval as a percentage  $P$  of the emission limit value  $E$ . Then, in order to convert this uncertainty to a standard deviation, the appropriate conversion factor is  $\sigma_0 = P E / 1,96$ .

The variability test shall be based on the results of the parallel measurements and shall not include data obtained by use of reference materials or alternative procedures for the determination of the calibration function.

The variability test shall be performed on the measured values (calibrated values) of the AMS. Hence, for every parallel measurement the AMS measured value  $\hat{y}_i$  shall be calculated using the calibration function (see 6.5).

Where the requirements on the data quality are specified under standard conditions (as e.g. in the relevant EU Directives [1], [2] and [3]), the variability test shall be performed using concentrations under these conditions.

The AMS measured values should be standardized by use of the calibrated measured values of the peripheral AMS for oxygen and water vapour. These peripheral AMS can be calibrated by use of the data sets obtained in the parallel measurements according to 6.3. The calibration function of the peripheral AMS can be established in line with 6.4.3.



NOTE 1 Since the AMS and SRM measured values are converted to standard conditions by independently determined data sets of the peripheral parameters, the uncertainties in the peripheral parameters are attributed to the AMS of the air pollutant in the variability test.

When calculating the variability, the peripheral parameters (e.g. water vapour content, temperature and oxygen concentration) used to standardize the measurements shall be taken from:

- a) the SRM instrumentation for standardizing the SRM measured values;
- b) the plant instrumentation for standardizing the AMS measured values, or in case these do not exist, the default values used by the plant.

NOTE 2 The purpose of this procedure is to ensure that the standardization procedure carried out in the plant's data recording and processing system is included in the variability test.

Examples of Formulae for the conversion of values are given in Annex E.

If the AMS fails the variability test due to error arising from measurements in the peripheral parameters obtained from the plant instrumentation, it is permissible to repeat the variability test using the parameters obtained by the test laboratory from their peripheral SRM. This is only permitted if measures are taken to correct the faulty plant instrumentation.

For each data set (minimum 15 pairs) for a given calibration function, the following parameters shall be calculated, where  $y_{i,s}$  is the SRM measured value at standard conditions and  $\hat{y}_{i,s}$  the calibrated AMS measured value (the best estimate for the "true value"), calculated from the AMS measured signal  $x_i$  at standard conditions:

$$D_i = y_{i,s} - \hat{y}_{i,s} \quad (9)$$

$$\bar{D} = \frac{1}{N} \sum_{i=1}^N D_i \quad (10)$$

$$s_D = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (D_i - \bar{D})^2} \quad (11)$$

## 6.7 Test of variability

The AMS passes the variability test when:

$$s_D \leq \sigma_0 k_v \quad (12)$$

Values for  $k_v$  which shall be applied for different number of parallel measurements are given in Annex I.

NOTE 1 The  $k_v$  values are the test values from a  $\chi^2$ -test, with a  $\beta$ -value of 50 %.

NOTE 2 The variability obtained includes uncertainty components associated with the repeatabilities of both the AMS and the SRM, but not the overall uncertainty of the SRM (therefore an imprecise implementation of the SRM can result in an apparent poorer variability of the AMS and could result in its false rejection during the variability test). The procedure for determination of variability is not in accordance with GUM (ISO/IEC Guide 98-3).

NOTE 3 This method implies that the quality of the application of the SRM will influence the result of the test. It will be noted, however, that it is the result, which determines a pass or failure and that in some cases a better application of the SRM could change the result from fail to pass.

The measured values of the AMS may be used to demonstrate compliance with the emission limit value only if the AMS has passed the variability test.

When the AMS passes the variability test, for compliance with legislation, the AMS then complies with the uncertainty requirement at the emission limit value, since the variability is deemed as constant throughout the range.

## 6.8 QAL2 report

The QAL2 report shall contain at least the following information:

- a) a description of the plant and its sampling location(s);
- b) a description of the operating condition of the plant, and the fuel(s) used at the plant during the tests;
- c) the names of the testing laboratory and of the personnel conducting the tests;
- d) details of the EN ISO/IEC 17025 accreditation of the testing laboratory, or details of approval by the relevant competent authority;
- e) a description of the AMS used – including the measurands covered, its principle, type, operating range, and its location;
- f) a description of the SRM used: its principle, type, operating range, repeatability and/or measurement uncertainty, and its EN or ISO reference number where appropriate;
- g) dates and times of the parallel measurements;
- h) detailed data of all the measured values obtained from the AMS and the SRM, averaged over relevant periods;
- i) method used to assess outliers and reasons for excluding outliers;
- j) the calibration function and the valid calibration range including the procedure for the determination of the calibration function and all data used for calculating the calibration function and performing the variability test;
- k) the x-y plot of parallel measurements, including the valid calibration range;
- l) any deviation from the procedures described in this European Standard, and their possible influence on the results obtained presented;
- m) the results of the last functional test (see Annex A).

## 7 Ongoing quality assurance during operation (QAL3)

### 7.1 General

AMS can drift or become less precise during routine operation. Drift can be due to, for example, changes in the AMS, such as contamination of an optical surface, gradual failure of a component or blockage in a filter. Such changes can cause systematic deviations in the AMS data. On the other hand, AMS are also subject to short-term variations due to influence factors such as changes in ambient temperature. These variations can cause random deviations. The magnitude of the random deviations is assessed during the certification process of the AMS (QAL1).

After the acceptance and calibration of the AMS, further quality assurance and quality control procedures shall be followed so as to ensure that the measured values obtained with the AMS meet the maximum permissible uncertainty on a continuous basis (also described as *ongoing quality control*). The implementation and performance of the QAL3 procedures given in this standard are the responsibility of the plant owner (i.e. the owner of the AMS). It is also the responsibility of the plant owner to assure that the AMS is operating inside the valid calibration range (see 6.5). The procedures shall be implemented and be in place at the same time that the collection of emission data by means of the AMS is mandatory for reporting to the authorities. It is recommended, however, that these procedures commence as soon as possible after the installation of the AMS in order to gain as much information on the performance of the AMS as possible. This may begin before the AMS has to be calibrated with the SRM in order to fulfil the QAL2 procedure requirements.

A special case may be applied if the plant is operating two independent parallel AMS, measuring the same measured component, standardizing and registering the two outputs independently in the DAHS of the plant, a situation commonly known as a hot spare. In this case if the measurement quality is monitored by an online continuous monitoring of the difference between the output of the two AMS, giving alarm if the difference between the two independent AMS measured values exceeds 5 % of the short-term ELV for more than five consecutive measurements, then the intervals for QAL3 procedures may be extended to one year. If, for whatever reason, the redundant AMS is not working for more than half of the maintenance period of the AMS in question, a QAL3 procedure shall be implemented again immediately after this point in time. In order to control the entire sampling system the two independent AMS should have separate extraction systems and separate zero and span gas supplies for automatic control cycles. It is also recommended that they use separate instruments for monitoring of all peripheral parameters.

## 7.2 Procedures to maintain ongoing quality

The aim of the procedure is to maintain and demonstrate the quality of the AMS, so that requirement for the stated zero and span repeatability and drift values are met during ongoing operation and the AMS is maintained in the same operational condition as when installed and calibrated in QAL2. This shall be achieved by confirming that the drift and precision determined during the QAL1 remain under control. A suitable methodology shall either:

- a) determine the combined drift and precision of the AMS, or
- b) separately determine the drift and precision.

Both procedures shall identify when an adjustment or maintenance (e.g. by the manufacturer) is necessary.

These operations shall be achieved by the use of control charts which plot the drifts (zero and span) against the time. In both procedures reference materials of known quantity and quality are needed.

In case a), the combined drift and precision obtained in the field shall be compared against specified control limits. This method (e.g. Shewhart control chart) is simple, but does not have the benefit of allowing the AMS to be externally adjusted when it is demonstrated to be out of control.

In case b), a more sophisticated method (e.g. CUSUM control chart) shall be used, which allows separate determination of drift and precision and gives more flexibility by determining if and by how much the zero and span of the AMS need to be externally adjusted.

Control charts require regular and ideally frequent measurements at zero and span points. The needed frequency of the QAL3 is at least once within the period of the maintenance interval, which is defined during the certification process of the AMS in accordance with EN 15267-3. Control charts show trends in the zero and span point measurements and can help the operator by making adjustments to the AMS only when required.

Therefore, QAL3 requires plant operators to have a procedure which describes the requirements for

- measuring zero and span values,

- plotting these values by use of control charts and
- using the control charts to determine whether there are systematic deviations, whether the random deviations become too large, and to ignore the random deviations if they lie between defined control chart limits.

### 7.3 Choosing control charts

Any type of manual or automated control chart, which allows separate or combined determination of drift and precision may be used. Different control charts have different advantages and can be more or less complicated to use, depending on the type of control chart chosen. Three examples of control charts (Shewhart, EMWA and CUSUM) are described in Annex C.

An alternative to an external control chart is to use AMS built-in procedures. AMS may include internal checks for zero and span points, which can be used to compensate for drift and to warn for instrument problems. Certain internal checks are referred to as zero and span checks. If these internal zero and span checks are certified in a QAL1 test report according to EN 15267-3 as QAL3 compliant, they may be used for QAL3 purpose and are no longer treated as an integral part of the AMS only.

In order to fulfil the QAL3 requirements, the data from the zero and span checks shall be available to the operator. Alarms to the operator have to be output when the control chart limits are exceeded.

To carry out zero and span checks internally in the AMS, the AMS has to be able to record both positive and negative values and record zero and span data for a time period longer than one year to enable auditing of the data during the periodic check of the AST or during a new QAL2.

**NOTE** In order to ensure appropriate measurements, some AMS perform automatic checks with or without automatic adjustments at a very high frequency, e.g. every 2 h. These automatic checks and/or adjustments are integral parts of the AMS. They are not QAL3 substitutes.

The plant quality management system shall include a description how to respond to exceeding of control chart limits. If the control chart limit is exceeded, the AMS is regarded as out of order and shall be rectified.

### 7.4 Control chart limits

#### 7.4.1 General

The control chart limits may be determined by use of performance data of the AMS obtained during QAL1, or may be determined on the basis of the maximum permissible uncertainty specified e.g. in EU Directives.

#### 7.4.2 Calculation of control chart limits using performance data

Determination of the control chart limits by use of performance data of the AMS requires the calculation of the standard deviation  $s_{AMS}$  which includes the influence factors likely to have the most significant influence on zero and span results.

This approach requires the following:

- understanding of the main influence factors which can cause random variations in zero and span readings;
- performance data for the AMS for each of the influence factors in the calculation.

The performance data are typically available from test reports for AMS tested according to EN 15267-3, or from test reports for performance testing schemes which preceded EN 15267-3.

Whilst this calculation uses performance data derived from QAL1, plant operators shall consider the actual conditions at the plant. For example, testing to EN 15267-3 for QAL1 tests the influence of ambient temperature on the AMS over defined ranges such as 5 °C to 40 °C. However, if the AMS is kept in a climate-controlled enclosure where the temperature varies from 18 °C to 23 °C, then the operator uses a temperature variation of 5 °C in the calculation of  $s_{AMS}$ . If any of the influences are time-dependent, this shall be taken into account. For example, if the instability is given as a percentage value  $\pm p$  per  $q$  days, then  $q$  equals the time between two readings for the control charts.

The standard deviation  $s_{AMS}$  shall be calculated according to Formula (13):

$$s_{AMS} = \sqrt{u_{inst}^2 + u_{temp}^2 + u_{volt}^2 + u_{pres}^2 + u_{others}^2} \quad (13)$$

where

- $u_{inst}$  is the uncertainty from instability;
- $u_{temp}$  is the uncertainty relating from variations in ambient temperature;
- $u_{volt}$  is the uncertainty relating from variations in voltage;
- $u_{pres}$  is the uncertainty relating from variations in ambient pressure;
- $u_{others}$  is any other uncertainty that may influence the reading on zero and span reference material (e.g. dilution).

**NOTE**  $s_{AMS}$  is expressed as a standard deviation; therefore all above uncertainties are expressed as standard deviations. E.g. if the uncertainties are given as values at 95 % confidence it is divided by the coverage factor ( $k_s = 2$ ), for the correct calculation of  $s_{AMS}$ .

A calculation of  $s_{AMS}$  is an uncertainty calculation and therefore an estimate. Over time, a plant operator could find that the value of  $s_{AMS}$  is set too high or too low, and therefore needs optimizing. Therefore, setting control chart limits is an iterative process.

Examples of calculation of the standard deviation of the AMS at zero and span level are given in Annex F.

In case of Shewhart control charts which determine the combined drift and precision of the AMS,  $\pm 2 s_{AMS}$  shall be used to establish the alarm limits. In addition, warning limits may be established by use of  $\pm s_{AMS}$  to provide early information on necessary adjustment or maintenance of the AMS.

In case of more sophisticated methods (e.g. EWMA or CUSUM) the control chart limits shall be calculated by use of the specific control chart parameters and  $s_{AMS}$ . The control chart parameters shall be chosen to ensure early information on necessary adjustment or maintenance of the AMS.

### 7.4.3 Calculation of control chart limits using the maximum permissible uncertainty

Site data are necessary to calculate  $s_{AMS}$ . However, the collection of site data is sometimes complicated and several assumptions have to be made. Therefore, a simpler and more pragmatic approach is a determination of the control chart limits on the basis of the maximum permissible uncertainty specified e.g. in EU Directives.

In case of Shewhart control charts which determine the combined drift and precision of the AMS,  $\pm 50$  % of the maximum permissible uncertainty shall be used to establish the alarm limits of the control chart. In addition, warning limits may be established e.g. at  $\pm 25$  % of the maximum permissible uncertainty to provide early information on necessary adjustment or maintenance of the AMS.

In case of more sophisticated methods (e.g. EWMA or CUSUM) the control chart limits shall be calculated by use of the specific control chart parameters and 50 % of the maximum permissible uncertainty. The control

chart parameters shall be chosen to ensure early information on necessary adjustment or maintenance of the AMS.

NOTE It can be necessary to convert the maximum permissible uncertainty to AMS measuring conditions.

## 7.5 Zero and span measurements

### 7.5.1 General

QAL3 requires the AMS to have a means to perform zero and span measurements. Negative values shall be recorded as such and not forced to zero.

Some AMS use reference materials other than test gases. In this case, the reference material and the QAL3 procedure developed by the AMS manufacturer may be used, provided they are validated according to EN 15267-3 during the QAL1 certification process.

NOTE In the case of test gases, there can be a change in the expected concentration value when the reference gas cylinder is changed. This can require the establishment of a new QAL3 base-line following adjustment of the AMS to account for previous drift and checking of the gas quality.

### 7.5.2 Frequency of zero and span measurements

Operators have to plot zero and span data using control charts. The application of control charts require regular and ideally frequent zero and span measurements. The maintenance interval defined during the performance testing of the AMS shall be used as the minimum frequency of zero and span checks. However, the plant operator may perform more frequent zero and span checks.

For AMS without certification according to EN 15267-1, EN 15267-2 and EN 15267-3, the frequency of zero and span checks should be at least every four weeks unless there are reasons to extend the period between testing. Reasons for extending the test frequency to the maintenance interval of the instrument are:

- If there are more frequent internal checks within the analyser which warn of the most likely instrument or component failure between QAL3 tests (including sampling system).
- In multi-component analysers which monitor all measured components using one device like FTIR a QAL3 test for one pollutant gas is made at least every four weeks.

NOTE The maintenance interval is determined during performance testing for approval to the requirements of standards such as EN 15267-3 or for the schemes and programmes which preceded EN 15267-3. In most AMS, the maintenance interval is typically between eight days and one month. Some AMS have much longer maintenance intervals; for example, from three to six months. The benefit of such AMS is that they have a proven long-term stability. Furthermore, as they do not require frequent span measurements, this means that the AMS have a higher availability for monitoring, as span measurements can be time consuming. This is most of the time achieved thanks to appropriate internal checks and adjustments during normal operation. When generating appropriate alarms it can avoid the risk related to infrequent zero and span measurements of not detecting a systematic deviation in the AMS, or an increase in random deviations.

The CUSUM procedure defined in C.3 requires frequent zero and span checks recommended to be weekly.

The operator shall ensure the correct operation of the AMS and should ascertain that any internal checks or compensation systems are operational and that plant personnel are aware of the status of any AMS instrument alarm. This is to ensure that attention is taken in the case of instrument malfunction between QAL3 tests.

### 7.5.3 Extractive gas analysis systems

For AMS with extractive sampling systems, the following options for performing zero and span checks may be applied:

a) use of test gases

The exact concentration is not as important as the stability of the test gas. Nitrogen or ambient air without measured component can be used as zero gas. To perform QAL3, it is not always necessary to inject the test gas through the complete sampling line. If the sampling line serving the extractive AMS is relatively long, then the zero and span procedures can be time consuming, can consume relatively large amounts of gas and reduce the availability of the AMS. The test gas can be injected directly in front of the analyser, but should be injected preferably in front of the sampling conditioning system.

b) use of reference materials other than test gases

Use of reference materials other than test gases to perform QAL3 for extractive AMS is possible, provided it was certified in QAL1 according to EN 15267-3 as QAL3 compliant.

### 7.5.4 In-situ gas-monitoring AMS

For in-situ gas-monitoring AMS, the following options for performing zero and span checks may be applied:

a) Use of test-gases:

Some in-situ AMS include a sintered tube allowing the injection of test gases. This can be used to perform zero and span checks.

b) Use of reference materials other than external test gases:

For some in-situ AMS it is not possible to inject test gases. Use of reference materials other than test gases to perform QAL3 for in-situ AMS is possible, provided it was certified in QAL1 according to EN 15267-3 as QAL3 compliant.

### 7.5.5 Particulate-monitoring AMS

There are several varieties of particulate-monitoring AMS, using a variety of techniques which respond to variations in concentrations of particulate matter. Regardless of the technique employed, zero and span readings are typically carried out using reference materials consisting of e.g. optical filters with a varying density.

Use of these reference materials to perform QAL3 for particulate monitoring AMS is possible, provided it was certified in QAL1 according to EN 15267-3 as QAL3 compliant.

## 7.6 Documentation of control charts

The control chart calculations shall be performed according to the requirements of this standard and fully documented. The history of the checks and appropriate actions in case of exceeding the control limits shall be available for auditing during the AST or during a new QAL2. This is specifically important, if the QAL3 is performed automatically or internally in the AMS. The control charts should be stored for at least five years.

**NOTE** The use of a spreadsheet is very suitable for the control chart calculations. At the same time the sheet can be used for providing traceable documentation on the performance of the AMS (see Clause 9).



## 8 Annual Surveillance Test (AST)

### 8.1 General

AST covers the following items:

- functional test of the AMS;
- parallel measurements with the SRM;
- data evaluation;
- calculation of variability of the AMS measured values;
- test of variability of the AMS measured values and validity of the calibration function;
- reporting.

The sequence of the AST is shown in Figure 5.

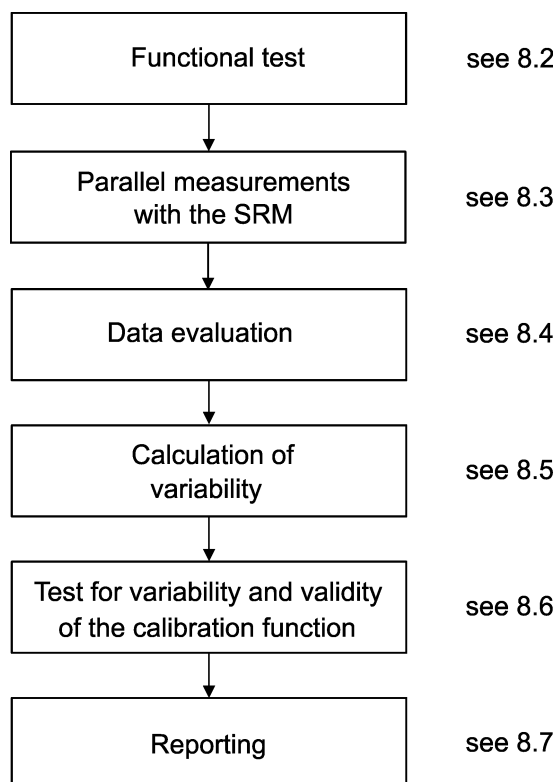


Figure 5 — Flow diagram for the AST

Examples of using the calibration function and testing the variability and the validity of the calibration function in the AST are given in Annex G.

### 8.2 Functional test

The first part of the AST is the functional test, which shall be performed according to Annex A. The functional test shall be performed by an experienced testing laboratory, which has been recognised by the competent authority.



### 8.3 Parallel measurements with the SRM

During AST at least five parallel measurements with the SRM shall be performed. This shall be carried out according to the procedure described in 6.3. The testing laboratory performing the parallel measurements shall meet the requirements in 5.4.

The purpose of comparison measurements is to verify if the calibration function of the AMS is still valid and if the precision of the AMS is still within the required limits. If this is the case, and if these measurements include results outside the valid calibration range, the valid calibration range may be increased with use of these results.

The evaluation shall be based on minimum five valid measurements within the calibration range. These measurements shall be uniformly spread over the whole measuring day (as described in 6.3).

A set of measurements is valid when all the requirements below are fulfilled:

- the SRM measurements are performed according to the appropriate standard;
- the SRM measurements fulfil all the requirements given in the appropriate standard;
- the time period of each AMS measured signal, is larger than 90 % of the averaging time (excluding the signals which are above 100 % or below 0 % of the measuring range of the AMS, signals obtained during internal checks (auto calibration), and signals obtained during any other malfunctioning of the AMS).

The sampling time per measurement shall be the same as used during the initial calibration (QAL2) as described in 6.3.

The sampling time for the parallel measurements shall be at least 30 min or at least 4 times the response time of the AMS, including the sampling system (as determined in QAL1), whichever is the greater. In general it is recommended that the sampling time used be the shortest averaging time, which is related to an ELV.

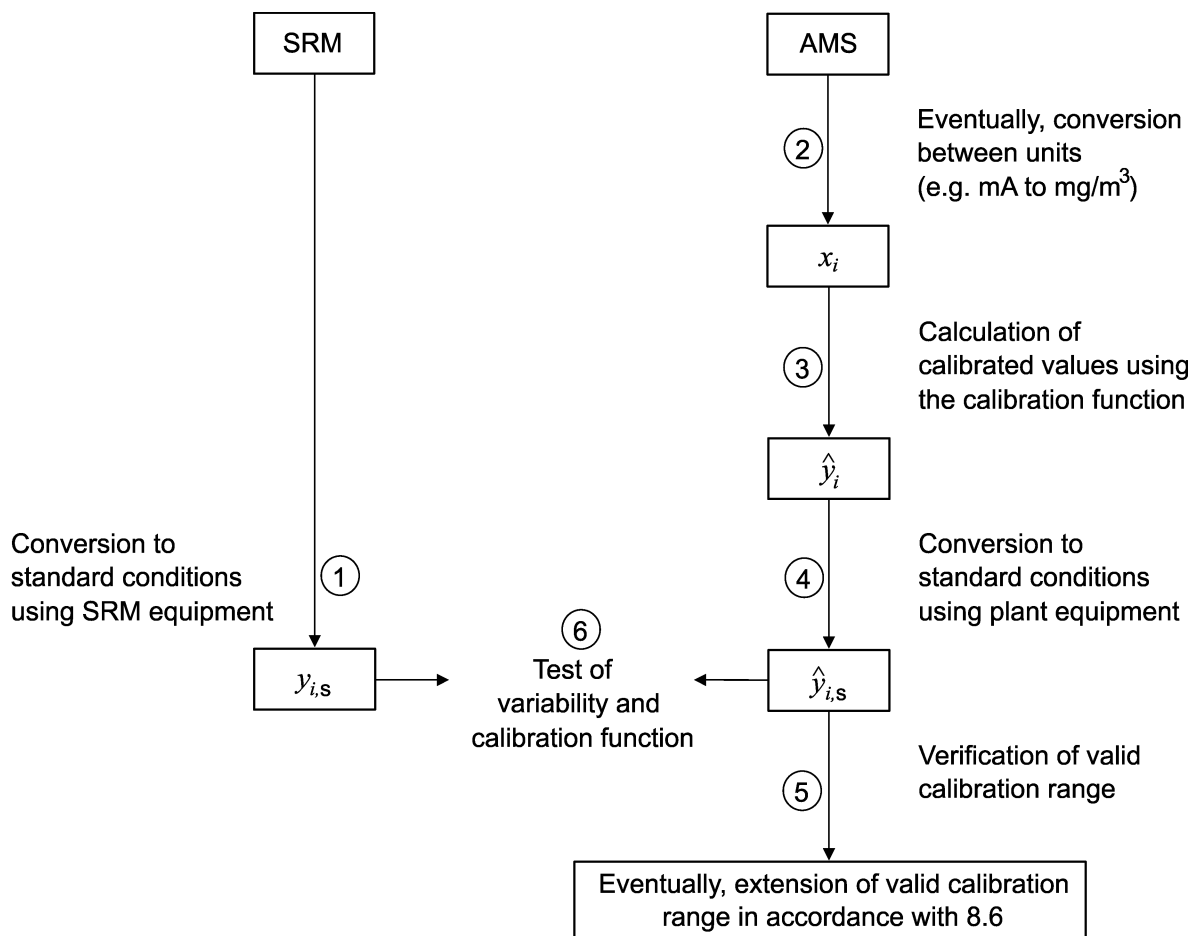
If the sampling time is shorter than one hour, the time interval between the start of each sample shall be longer than one hour.

During the performance of the parallel measurements with the AMS and SRM each result is a measurement pair (one AMS measured signal and one SRM measured value) and these shall cover the same time period.

The results obtained from the SRM shall be expressed in the same conditions as the uncorrected results obtained from the AMS. For example, if the AMS measures HCl in  $\text{mg/m}^3$  in wet gas, the SRM measured values shall be given in that unit ( $\text{mg/m}^3$  in wet gas).

### 8.4 Data evaluation

The steps for providing data required for performing the variability test and to test the calibration function are illustrated in Figure 6.



The figure in the circles indicates the sequence of the steps.

**Figure 6 — Flow chart describing the steps in the test for variability and calibration function and verification of the valid calibration range**

The data sets obtained in the parallel measurements shall be checked for possible outliers. The method used to assess outliers and reasons for excluding outliers shall be given in the AST report. Outliers shall be reported and identified in the calibration data tables and diagrams.

This standard requires at least five valid data points for an AST. If points are excluded e.g. through the use of outlier tests, this requirement can be failed. It is therefore recommended that additional data points be taken, to allow for the exclusion of outliers. If this is not done the AST can be invalid. All data points shall be used in the test of variability and in the assessment of the validity of the calibration function, unless excluded through the use of outlier tests or have been shown to be invalid.

Calculate the AMS measured values  $\hat{y}_i$ , (calibrated values) from the AMS measured signals  $x_i$  using the established calibration function (calculated according to 6.5) and use the peripheral AMS equipment to convert  $\hat{y}_i$  to standard conditions and to calculate the standardised measured values  $\hat{y}_{i,s}$ .

The results from the comparative measurements (AST) shall not be used together with the measurements from the most recent calibration to determine a new calibration function (QAL2), but they may be used to extend the valid calibration range.

## 8.5 Calculation of variability

Identify the maximum permissible uncertainty specified by the legislation,  $\sigma_0$ , using the same procedure as in 6.6.

Calculate for all data sets:

$$D_i = y_{i,s} - \hat{y}_{i,s} \quad (14)$$

$$\bar{D} = \frac{1}{N} \sum_{i=1}^N D_i \quad (15)$$

$$s_D = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (D_i - \bar{D})^2} \quad (16)$$

## 8.6 Test of variability and validity of the calibration function

The variability of the measured values of the AMS is accepted if the following inequality is fulfilled:

$$s_D \leq 1,5 \sigma_0 k_v \quad (17)$$

Values of  $k_v$  for different numbers of parallel measurements  $N$  are given in Annex I.

NOTE 1 The  $k_v$  values are the test values from a  $\chi^2$ -test, with a  $\beta$ -value of 50 %.

NOTE 2 The variability obtained includes uncertainty components associated with the repeatabilities of both the AMS and the SRM, but not the overall uncertainty of the SRM (therefore an imprecise implementation of the SRM can result in an apparent poorer variability of the AMS and could result in a false failure of the variability test). The procedure for determination of uncertainty is not in accordance with GUM (ISO/IEC Guide 98-3).

NOTE 3 This method implies that the quality of the application of the SRM influences the result of the test. It will be noted, however, that it is the result that determines a pass or failure and that in some cases a better application of the SRM could change the result from fail to pass.

The calibration of the AMS is accepted if:

$$|\bar{D}| \leq t_{0,95; N-1} \frac{s_D}{\sqrt{N}} + \sigma_0 \quad (18)$$

Values of  $t_{0,95; N-1}$  for different numbers of parallel measurements  $N$  are given in Annex I.

If either of the two above tests fails, the causes shall be identified and rectified. Subsequently new parallel measurements according to QAL2 shall be performed, reported and implemented within six months. If necessary the supplier shall be contacted, in order to maintain the AMS before the next calibration.

If the AST demonstrates that the existing calibration function is valid beyond the existing valid calibration range, the competent authority can allow the plant to extend the valid calibration range up to the maximum measured concentration of the calibrated AMS measured values at standard conditions, determined during the AST, plus an extension of 10 % of this value, but the valid calibration range shall not exceed 50 % of ELV.

## 8.7 AST report

The AST report shall contain at least the following information:

- a) a description of the plant and sampling location;
- b) a description of the AMS used – including the measurands covered, its principle, type, operational range, and its location;
- c) a description of the SRM used – its principle, type, operational range, repeatability and/or measurement uncertainty, and its EN or ISO reference number where appropriate;
- d) the dates and times of the parallel measurements;
- e) detailed data of all the measured values obtained from the AMS and the SRM, averaged over the relevant periods;
- f) method used to assess outliers and reasons for excluding outliers;
- g) actual AMS calibration function and valid calibration range;
- h) the x-y plot of parallel measurements, including the calibration function and valid calibration range;
- i) the test results for validity of the precision and calibration;
- j) any deviation from the procedures described in this European Standard, and the possible influence on the obtained result(s);
- k) the results of the AST functional test (Annex A).

## 9 Documentation

Every occurrence significantly affecting the AMS during its life span shall be documented (see Annex D). The AMS shall be assigned a registration number and a file specific to the AMS containing all the relevant information, which shall be drawn up and updated by the person in charge of the AMS.

The AMS documentation shall include all relevant diagrams and can include photographs of the sampling system and AMS, when they were installed and commissioned.

## Annex A (normative)

### QAL2 and AST functional test of AMS

#### A.1 General

Table A.1 specifies the individual steps of the functional test of AMS to be performed during QAL2 and AST for extractive and in-situ AMS.

**Table A.1 – Specification of individual steps of the functional test to be performed during QAL2 and AST**

Activity	Extractive AMS	In-situ AMS
Alignment and cleanliness		X
Sampling system	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 & span drift (QAL3 audit)	X	X
Response time	X	X
Report	X	X

#### A.2 Alignment and cleanliness

A visual inspection, with reference to the AMS manuals, shall be carried out on the following when applicable:

- internal check of the analyser;
- cleanliness of the optical components;
- flushing air supply;
- obstructions in the optical path.

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

- alignment of the measuring system;
- contamination control (internal check of optical surfaces);
- flushing air supply.

### A.3 Sampling system

A visual inspection of the sampling system shall be performed, noting the condition of the following components, when fitted:

- sampling probe;
- gas conditioning systems;
- pumps;
- all connections;
- sample lines;
- power supplies;
- filters.

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

### A.4 Documentation and records

The following documentation shall be controlled, readily accessible and up to date:

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

### A.5 Serviceability

There shall be provisions for the effective management and maintenance of the AMS, in order to ensure the maintenance of the quality of data. Such provisions include at least the following:

- safe and clean working environment with sufficient space and weather protections;
- easy and safe access to the AMS;

- adequate supplies of reference materials, tools and spare parts.

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

## A.6 Leak test

Leak testing shall be performed according to the AMS manuals. The test shall cover the entire sampling system.

## A.7 Zero and span check

Reference zero and span materials shall be used to verify the corresponding readings of the AMS.

In case of non-extractive AMS, zero and span checks shall be performed using a reference-path free of flue gas.

**NOTE** For some AMS it is difficult to achieve a zero reading. In those situations, the AMS can be removed from the stack, and zeroed using a test bench or similar. As an alternative, a measuring path, which enables this zero test to be carried out, can be installed in the stack.

## A.8 Linearity

The linearity of the analyser's response shall be checked using five different reference materials, including a zero concentration.

The reference material with zero concentration, as well as the reference materials with four different concentrations, shall have a verifiable quantity and quality.

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

The reference material concentrations shall be selected such that the measured values are at approximately 20 %, 40 %, 60 % and 80 % of a range which is at least the short-term ELV. It is necessary to know the values of the ratios of their concentrations precisely enough so that an incorrect failure of the linearity test does not occur. The dry test reference material shall be applied to the inlet of the AMS.

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

- reference material with zero concentration;
- reference material concentration approximately 20 % of 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.

After each change in concentration, the first instrument reading shall be taken after a time period equal to at least three times the response time of the AMS. At each reference material concentration, at least three readings shall be made. The time period between the start of each of the three readings shall be separated by at least four times the response time.

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

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

**NOTE 2** Where no other method is possible, the linearity can also be performed with the aid of reference materials such as grating filters or gas filters.

The linearity shall be calculated and tested using the procedure as given in Annex B. If the AMS does not pass this test, then the problem shall be identified and rectified.

## **A.9 Interferences**

A test shall be undertaken if the process gases to be monitored contain components that are known interferences, as identified during QAL1.

## **A.10 Zero & span drift (audit)**

The zero point and span drift shall be obtained from and evaluated on the basis of the records of QAL3.

## **A.11 Response time**

The response time of the AMS shall be checked. This can be performed, if appropriate, by feeding of the reference material at the end of the sampling probe. The response time shall not exceed the performance criterion specified for QAL1.

## **A.12 Report**

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



## Annex B (normative)

### Test of linearity

#### B.1 Description of the test procedure

In this test procedure, a regression line is established between the instrument readings of the AMS ( $x$ -values) and the reference material values ( $y$ -values) during the linearity test performed in A.8 In the next step, the average of AMS readings at each concentration level is calculated. Then the deviation (residual) of this average to the regression line is calculated.

#### B.2 Establishment of the regression line

A linear regression for the function in Formula (B.1) is established:

$$x_i = A' + B(y_i - y_z) \quad (\text{B.1})$$

For the calculation, all measurement points are taken into account. The total number of measuring points  $n$  is equal to the number of concentration levels (of which there are five, including zero) times the number of repetitions (these are the results of the at least three readings) at a particular concentration level. In total,  $n$  is at least 18 as at zero in total at least six repetitions are made.

The coefficient  $A'$  is obtained by Formula (B.2):

$$A' = \frac{1}{n} \sum_{i=1}^n x_i \quad (\text{B.2})$$

where

- $A'$  is the average value of the  $x$ -values, i.e. the average of the AMS instrument readings;
- $x_i$  is the individual AMS instrument reading;
- $n$  is the number of measuring points (at least 18).

The coefficient  $B$  is obtained by Formula (B.3):

$$B = \frac{\sum_{i=1}^n x_i (y_i - y_z)}{\sum_{i=1}^n (y_i - y_z)^2} \quad (\text{B.3})$$

where

- $y_z$  is the average of the  $y$ -values, i.e. the average of the reference material concentrations;
- $y_i$  is the individual value of the reference material concentration.

Secondly the function  $x_i = A + B(y_i - y_z)$  is converted to  $x_i = A + B y_i$  through the calculation of  $A$  according to Formula (B.4):

$$A = A' - B y_z \quad (\text{B.4})$$

### B.3 Calculation of the residuals of the average concentrations

The residuals of the average concentration at each concentration level to the regression line are calculated as follows:

Calculate at each concentration level the average of the AMS readings at one and the same concentration level  $c$  according to Formula (B.5):

$$\bar{x}_c = \frac{1}{m_c} \sum_{i=1}^{m_c} x_{c,i} \quad (\text{B.5})$$

where

- $\bar{x}_c$  is the average  $x$ -value (AMS reading) at concentration level  $c$ ;
- $x_{c,i}$  is the individual  $x$ -value (AMS reading) at concentration level  $c$ ;
- $m_c$  is the number of repetitions at one and the same concentration level  $c$ .

Calculate the residual  $d_c$  of each average according to Formula (B.6):

$$d_c = \bar{x}_c - (A + Bc) \quad (\text{B.6})$$

where

- $c$  is the concentration level.

Convert  $d_c$  in concentration units to a relative unit  $d_{c,rel}$  by dividing  $d_c$  by the upper limit  $c_u$  of the range used in the linearity test (see A.8) according to Formula (B.7):

$$d_{c,rel} = \frac{d_c}{c_u} 100 \% \quad (\text{B.7})$$

### B.4 Test of the residuals

Test each residual according to Formula (B.8):

$$d_{c,rel} < 5 \% \quad (\text{B.8})$$

All residuals shall pass this test.

## Annex C (informative)

### Control charts

#### C.1 Shewhart control charts

Shewhart control charts are the simplest types of control charts, and can either plot the recorded span value, or the actual difference between the original span value and subsequent span values, i.e. the drift, whether this drift consists of random variations, or systematic changes. Shewhart control charts contain a centre line which is equal to the target value and lower and upper control limits, as determined according to 7.4.

Once the control chart limits have been determined (one for zero and one for the span of the reference material), the results from the AMS readings are indicated on each control chart to detect drift and/or change in accuracy requiring the operator to take action. Such action can include AMS adjustment or maintenance, and potential elimination of the AMS measurements since the previous QAL3 test.

When using Shewhart control charts, the decision is taken based on the last result. This chart rapidly detects drift which is large, but is less efficient at detecting small amounts of drift.

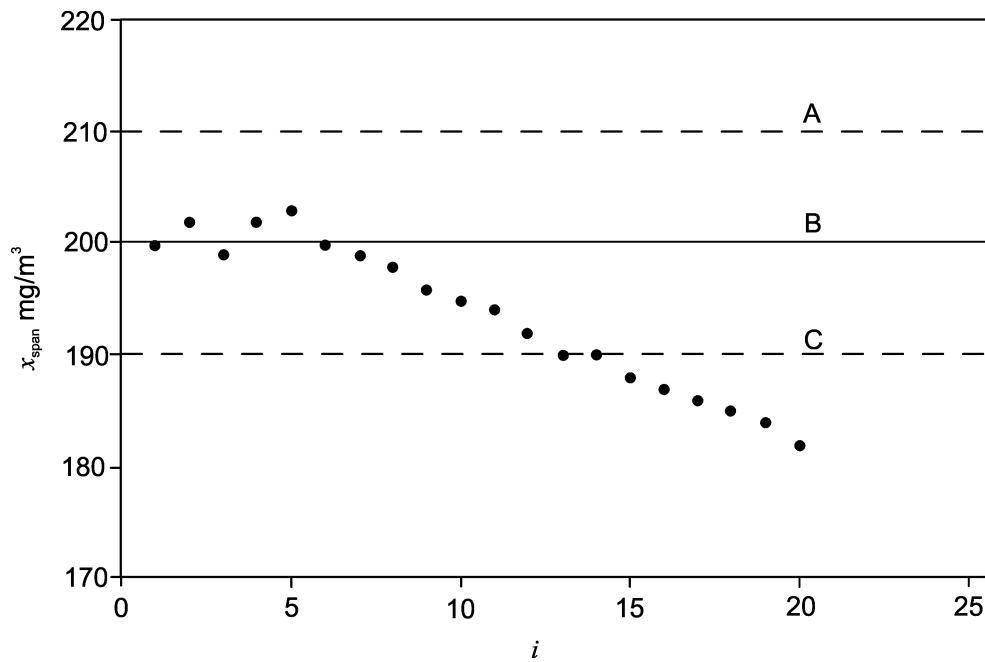
The following example shows a series of span measurements for NO, with 20 checks for the span value at regular intervals (see Table C.1). Absolute values and relative values with the target value are shown, whilst in this example,  $s_{AMS}$  would be calculated according to 7.4.2. For the sake of example, the value of  $s_{AMS}$  is given as  $5 \text{ mg/m}^3$ .

**Table C.1 — Raw and relative data for Shewhart control charts**

Span-point number	Span value $\text{mg/m}^3$	Deviation from the center line $\text{mg/m}^3$
1	200	0
2	202	2
3	199	-1
4	202	2
5	203	3
6	200	0
7	199	-1
8	198	-2
9	196	-4
10	195	-5
11	194	-6
12	192	-8
13	190	-10

Span-point number	Span value mg/m <sup>3</sup>	Deviation from the center line mg/m <sup>3</sup>
14	190	-10
15	188	-12
16	187	-13
17	186	-14
18	185	-15
19	184	-16
20	182	-18

Figure C.1 shows a plot of the span measurements in sequence, together with the deviation from the baseline. The results show the random variations quite clearly over the first ten measurements, although it is not clear whether there is a systematic change until over 15 measurements have been taken, even though there appears to be a trend of drift.



- Key**
- $x_{span}$  span value, in milligrams per cubic metre (mg/m<sup>3</sup>)
  - $i$  number of span check, with  $i = 1$  to  $n$
  - A upper control limit
  - B centre line
  - C lower control limit

Figure C.1 — Example of a Shewhart control chart

## C.2 Exponentially weighted moving average control charts

Two solutions are possible to improve the efficiency in detecting slow and gradual changes in the precision and accuracy of the AMS, due to drift. The options are to:

- increasing the number of checks  $n$ , since efficiency increases with  $\sqrt{n}$ , but this produces a cost that increases proportionally to  $n$ ; however, increasing the number of checks also decreases the availability of the AMS;
- taking previous results into account.

Exponential weighted moving average (EWMA) control charts improve the efficiency of detection by using results of measurements previous to the last check, whereas Shewhart control charts do not.

Compared with the Shewhart and CUSUM control charts, the EWMA control chart:

- is more appropriate for early detection of small or medium-sized drift than the Shewhart control chart;
- is simpler and easier to use than the CUSUM control chart;
- is easier to set up and keeps the graphical format of the Shewhart control chart;
- implements only one decision rule.

The EMWA control chart requires three preparatory steps:

- selecting the control chart parameters:
  - $m_0$  the centre line;
  - $s_0 = s_{AMS}$  the process standard deviation;
  - $n$  the number of checks ( $n = 1$  for one zero or span check);
  - $\delta$  the shift to be detected as soon as possible as a multiple of  $s_0$ ;
  - $ARL(0)$  the average run length corresponding to a risk of a false alarm;
  - $ARL(\delta)$  the average run length to detect a shift  $\delta$ ;
  - $\lambda$  the smoothing parameter that determines the depth of memory of the EWMA;
  - $K$  a constant for setting the control limits.
- determining weighting of the past values with the last reading:

$$z_i = \lambda x_i + (1 - \lambda) z_{i-1} \tag{C.1}$$

where

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

and  $0 < \lambda < 1$ ;

— determining the upper control limit (UCL) and the lower control limit (LCL):

$$UCL = m_0 + K \frac{s_0}{\sqrt{n}} \sqrt{\frac{\lambda}{2-\lambda}} \quad (C.2)$$

$$LCL = m_0 - K \frac{s_0}{\sqrt{n}} \sqrt{\frac{\lambda}{2-\lambda}} \quad (C.3)$$

The optimum values of the smoothing parameter  $\lambda$  and the constant  $K$  depend on the shift  $\delta$  to be detected and the average run length ARL(0) that are set as quality objectives.

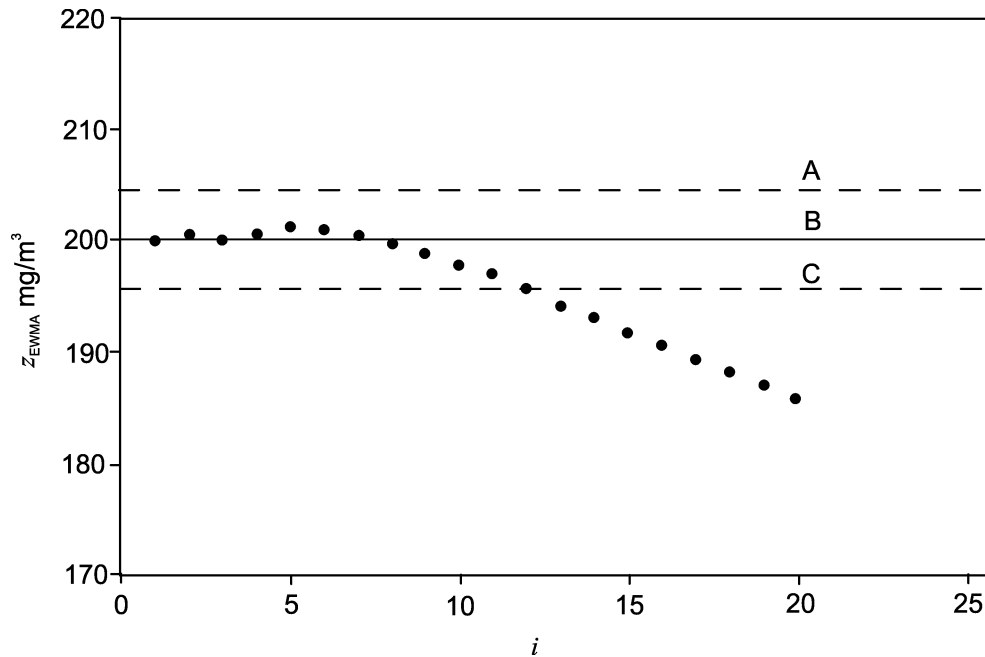
If  $\lambda$  nears 0, this will take the past more into account and detect small drifts, but sudden major drifts are less easily detected. If  $\lambda$  nears 1, this will take the past less into account and responsiveness to sudden major drifts are greater, but small drifts will be less easily detected.

Table C.2 shows the values of the span checks which were used in the example of a Shewhart control chart, together with the weighted, smoothed values calculated for  $s_{AMS} = 5 \text{ mg/m}^3$ ,  $n = 1$ ,  $\delta = 1$ ,  $\lambda = 0,25$  and  $K = 2,0$ .

**Table C.2 — Raw and calculated EWMA data**

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

Figure C.2 shows the EWMA control chart. When compared to the Shewhart control chart, acceptable random variations are smoothed, whilst the systematic changes are much clearer to see.



**Key**

- $z_{EWMA}$  EWMA value, in milligrams per cubic metre (mg/m<sup>3</sup>)
- $i$  number of span check, with  $i = 1$  to  $n$
- A upper control limit
- B centre line
- C lower control limit

**Figure C.2 — Example of an EWMA control chart**

**C.3 CUSUM control charts**

**C.3.1 Design and use of CUSUM control charts for detection of drift and precision**

This annex provides detailed procedures for the design and use of CUSUM control charts for the detection of drift and decrease of precision of an AMS during operation.

CUSUM control charts are more complex to understand and set up. However, the benefit of this approach is that CUSUM control charts can help distinguish between drift, and loss of precision. This means that the approach is better for predictive maintenance and for planning of the service work. It is mathematically more complex, and therefore mostly suited for automatic systems run on a personal computer. If combined with automatic logging of data from the instruments the whole process can be automated with considerable reduction in costs as a consequent.

The flow charts shown in Figure C.3 and C.4 describe the design and use of CUSUM control charts.

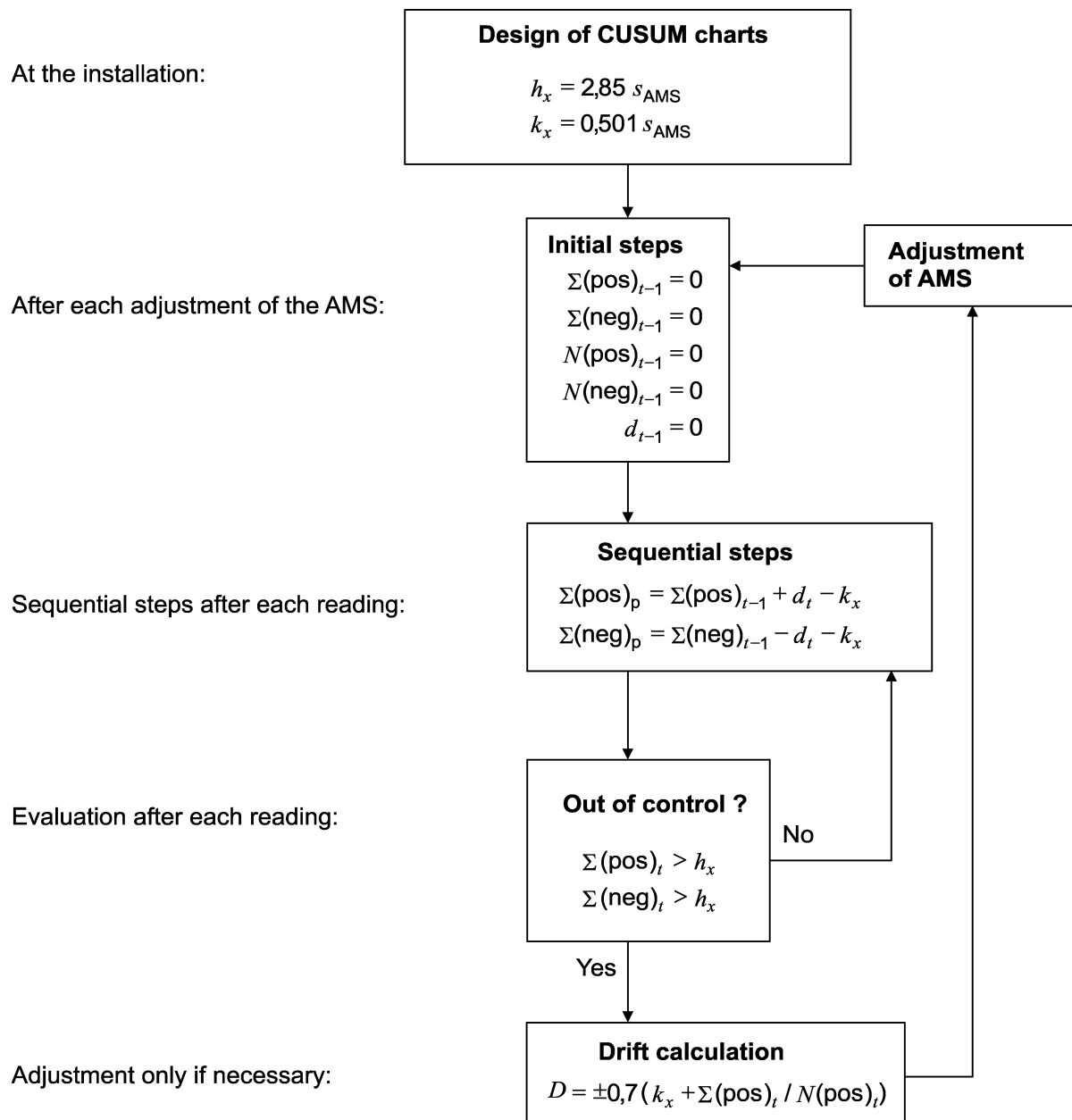


Figure C.3 — Flow chart for design and use of CUSUM Control charts for drift



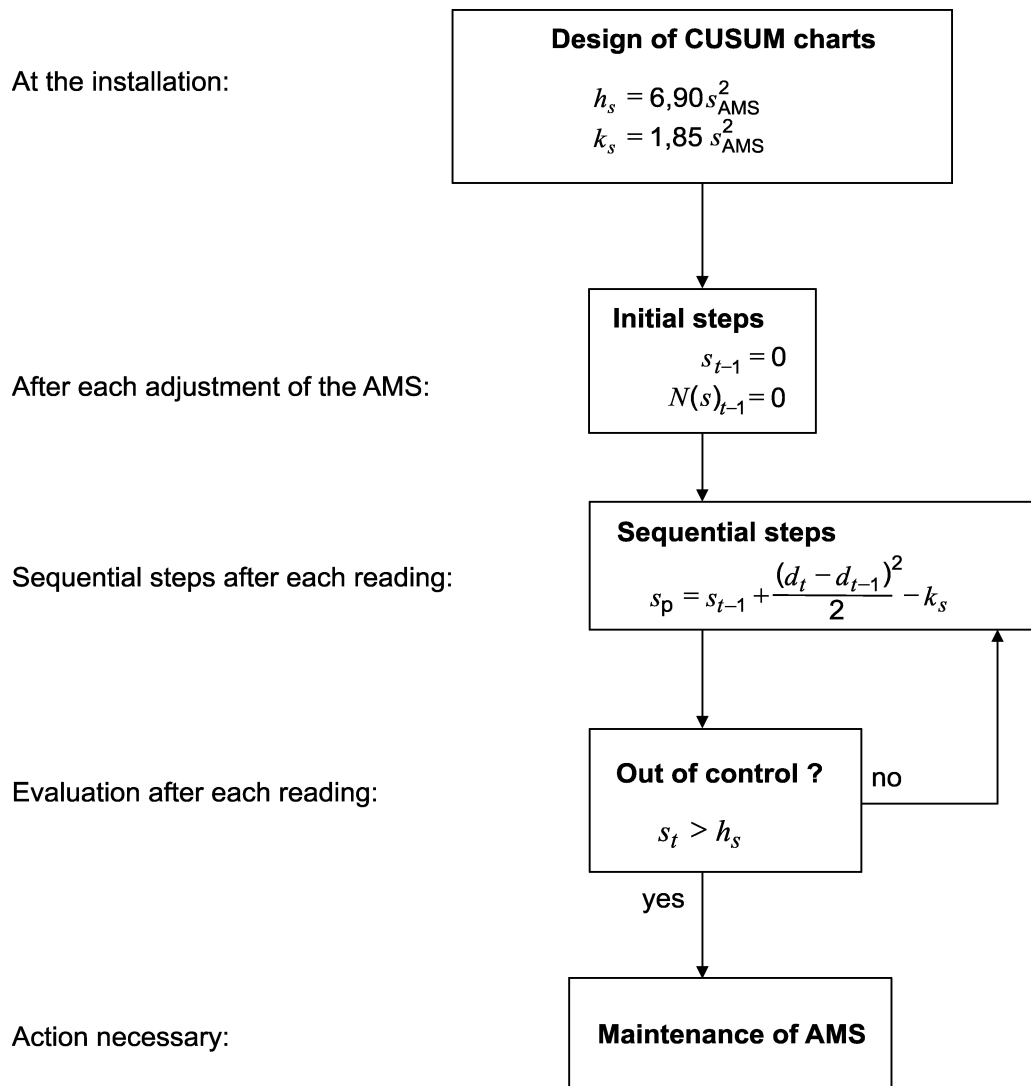


Figure C.4 — Flow chart for design and use of CUSUM Control charts for precision

### C.3.2 Default values for the CUSUM control charts

In the CUSUM control charts, the amount of drift and decrease in precision is compared to the uncertainty of the measured value itself. For this comparison, the standard deviation derived from the uncertainties sources applicable to zero and span readings as determined in QAL1 is taken.

The standard deviation  $s_{AMS}$  shall be derived from the information obtained for the QAL1 calculations.  $s_{AMS}$  shall be calculated according to 7.4.1 considering plant conditions and not the test conditions during QAL1, for example to calculate  $u_{temp}$ .

a) CUSUM charts for drift:

calculate the default values for  $h_x$  and  $k_x$ :

$$h_x = 2,85 s_{AMS} \tag{C.4}$$

$$k_x = 0,501 s_{AMS} \tag{C.5}$$

NOTE The values in the formulae above are calculated so the average number of readings between two false alarms equals 50, and so  $s_{AMS}$  is just detected.

b) CUSUM charts for precision:

calculate the default values for  $h_s$  and  $k_s$ :

$$h_s = 6,90 s_{AMS}^2 \quad (C.6)$$

$$k_s = 1,85 s_{AMS}^2 \quad (C.7)$$

NOTE The values in the formulae above are calculated so the average number of readings between two false alarms equals 100, and so two times  $s_{AMS}$  is just detected.

### C.3.3 Initialising the calculation procedure

This procedure initialises or resets the “operating” parameters of a CUSUM control chart. This shall be carried out in the following cases:

- at the first use of the control chart;
- after each adjustment of the AMS.

In the following, three essential types of quantities are introduced. The first quantity is the normalised sum of the precision  $s$  of the AMS, the second is the normalized sum  $\Sigma$  of the drift of the AMS, the last is the number of samples  $N$  since the sums were equal to zero.

NOTE The term *normalised sums* used in this section is chosen because the calculations involve both a summation of the history of the AMS, and a normalisation of the new reading with respect to the history.

Since the drift can be both positive and negative, it is necessary to have quantities for both kinds of drift of the AMS (difference to the reference value). The precision has no sign. Therefore, six quantities have to be reset (to be set equal to zero):

- a) number of samples since standard deviation different from zero:  $N(s)_{t-1} = 0$
- b) normalized sum for positive difference:  $\Sigma(\text{pos})_{t-1} = 0$
- c) normalized sum for negative difference:  $\Sigma(\text{neg})_{t-1} = 0$
- d) number of samples since positive difference:  $N(\text{pos})_{t-1} = 0$
- e) number of samples since negative difference:  $N(\text{neg})_{t-1} = 0$
- f) difference between actual instrument reading of the AMS and the reference value:  $d_{t-1} = 0$
- g) provisional sum of the standard deviation:  $s_{t-1} = 0$

### C.3.4 Calculation procedure

A spreadsheet is suitable for the calculation procedure given below. However, in order to avoid the use of a computer at the measuring site, manual calculations may be performed on site. At the same time the sheet can be used for the documentation of the AMS (see Clause 9).

This procedure has to be performed at each reading of the zero and span values from the AMS.

Calculate the provisional sum for standard deviation, and the provisional sums for positive and negative difference:

$$s_p = s_{t-1} + \frac{(d_t - d_{t-1})^2}{2} - k_s \quad (\text{C.8})$$

$$\Sigma(\text{pos})_p = \Sigma(\text{pos})_{t-1} + d_t - k_x \quad (\text{C.9})$$

$$\Sigma(\text{neg})_p = \Sigma(\text{neg})_{t-1} - d_t - k_x \quad (\text{C.10})$$

where

$d_t = x_t - y_t$  is the difference between the actual instrument reading  $x_t$  and the reference value  $y_t$ ; notice the sign!

$p$  indicates the provisional value of the normalised sums;

$t$  indicates the actual instrument reading;

$t - 1$  indicates the previous instrument reading.

Calculate the test values, and add up the number of instrument readings since the standard deviation and the (positive or negative) difference occurred as follows:

- |    |                                    |   |     |   |
|----|------------------------------------|---|-----|---|
| a) | If $s_p > 0$ :                     | $s_t = s_p$                                   | and | $N(s)_t = N(s)_{t-1} + 1$                   |
|    | If $s_p \leq 0$ :                  | $s_t = 0$                                     | and | $N(s)_t = 0$                                |
| b) | If $\Sigma(\text{pos})_p > 0$ :    | $\Sigma(\text{pos})_t = \Sigma(\text{pos})_p$ | and | $N(\text{pos})_t = N(\text{pos})_{t-1} + 1$ |
|    | If $\Sigma(\text{pos})_p \leq 0$ : | $\Sigma(\text{pos})_t = 0$                    | and | $N(\text{pos})_t = 0$                       |
| c) | If $\Sigma(\text{neg})_p > 0$ :    | $\Sigma(\text{neg})_t = \Sigma(\text{neg})_p$ | and | $N(\text{neg})_t = N(\text{neg})_{t-1} + 1$ |
|    | If $\Sigma(\text{neg})_p \leq 0$ : | $\Sigma(\text{neg})_t = 0$                    | and | $N(\text{neg})_t = 0$                       |

### C.3.5 Test for a decrease of precision

Test the precision of the AMS:

- if  $s_t > h_s$  then a decrease in precision of the AMS has been established.

If this inequality is *false* for both zero and span precision then these components of the AMS are in control, and the test for zero and span drift shall be performed. However, if the above inequality is true for either zero or span precision, the manufacturer shall be contacted. In this latter case it is unnecessary to perform the drift tests at this time.

### C.3.6 Test for drift and the need for adjustment

Test for positive or negative drift of the AMS:

- if  $\Sigma(\text{pos})_t > h_x$ , then a positive drift is detected;
- if  $\Sigma(\text{neg})_t > h_x$ , then a negative drift is detected.

If both of the two inequalities above are false for both zero and span, then the AMS is in control and no action is required. However, if one value is true for either zero or span, then an adjustment of the AMS is required, and thereafter the calculations continue from C.3.2.

a) For AMS without automatic internal adjustment:

In the case of a detected drift the value of the drift can be estimated, and shall be used for the adjustment of the AMS.

If a drift is detected of either zero value or span value, this shall be adjusted and the other value shall be checked and may be adjusted.

If a positive drift is detected, then the value of the necessary adjustment can be estimated. This estimate is calculated as:

$$D_{\text{adjust}} = 0,7 (k_x + \Sigma(\text{pos})_t / N(\text{pos})_t) \quad (\text{C.11})$$

If a negative drift is detected, then the value of the necessary adjustment can be estimated. This estimate is calculated as:

$$D_{\text{adjust}} = -0,7 (k_x + \Sigma(\text{neg})_t / N(\text{neg})_t) \quad (\text{C.12})$$

If the AMS, after the above correction, still gives a signal that result in a detectable drift, the AMS is regarded as out of order and shall be rectified.

b) For AMS with automatic internal adjustment:

If a drift is detected, the AMS is regarded as out of order and shall be rectified.

## **Annex D (normative)**

### **Documentation**

#### **D.1 Principle**

Every event significantly affecting the AMS during its life span should be documented. A file specific to the AMS and containing all the relevant information should be drawn up and updated, under the responsibility of the person in charge of the AMS.

#### **D.2 Setting-up of the AMS file**

The file should be set up as soon as the AMS has been received. It should contain at least the following elements, for example, in the form of sheets:

- an identification sheet;
- a follow-up sheet;
- a procedure for calibration and verification: It can be the manufacturer's instructions in the national language or a specific internal procedure;
- reports for all verifications, calibrations and interventions.

The following elements can also be included in the file:

- certificate of delivery;
- manufacturer's instructions for operation and maintenance.

A registration number should be assigned to the AMS, indicated in the identification attached to the analyser itself, in order to identify it more easily.

#### **D.3 Management of the AMS file**

Proof of the qualification of the person in charge of the AMS should be given (initial training, professional training or on-the-job training). The person in charge of the AMS should make sure that the file is kept up to date and that calibration and maintenance operations are carried out when necessary. Record of the maintenance operations should be kept. After the AMS is decommissioned, it can be necessary, according to national legislation, to retain the records for a given period of time, in order to ensure the documentation of past results.

#### **D.4 Composition of the AMS file**

##### **D.4.1 Identification record**

This record should be produced after the delivery of the AMS and should indicate:

- the type and designation of the AMS and its identification;
- the name of the manufacturer and if applicable, the supplier;
- the location;
- the expiry date of the guarantee;
- the date of delivery and of putting into service, optionally the date and number of the order form;
- references for the operation, calibration, verification and preventive maintenance procedures.

#### **D.4.2 Follow-up record**

The follow-up record should be kept up to date by the person in charge of the AMS. Every event affecting the AMS should be recorded, indicating the date, the nature of the event, the element of the AMS concerned, observations and/or results, the name of the intervening person and his/her identification (signature or initials). Examples of events, which affect the AMS, include: installation and commissioning, calibration, verification, preventive maintenance, malfunction, corrective maintenance, modification, and decommissioning.

#### **D.4.3 Verification report**

The verification report or form should be completed by the user of the AMS or a designated individual, following each verification, according to the procedure and to a frequency specified beforehand.

#### **D.4.4 Calibration report**

The individual responsible for this task should complete the report following each calibration, following routine calibrations according to the relevant procedure and to a frequency specified beforehand, and when an applicable non-conformity has been identified, following a verification or an intervention. The calibration procedure ensures that the result is linked to a certified standard.

#### **D.4.5 Intervention report**

Any intervention should be documented and filed under the responsibility of the person in charge of the AMS. The intervention can be carried out, for example, by the manufacturer, by the user or by the maintenance department.

## Annex E (informative)

### Examples of calculation of the calibration function and of the variability test

#### E.1 General

The purpose of QAL2 is to perform a calibration, determine the variability and determine compliance with legal requirements. The procedures of QAL2 are carried out as described in Clause 6.

The following examples illustrate how to perform the tests in QAL2.

#### E.2 Example of QAL2 for a particulate AMS and a high level cluster

##### E.2.1 General

Table E.1 lists the measurement methods and requirements used in this example.

**Table E.1 — Measurement methods and requirements**

Parameter	Particulate emission
AMS method	Opacity, continuous
Offset for AMS	4 mA
SRM method	Manual gravimetric method – EN 13284-1
Emission limit value (ELV) for the daily average at standard conditions (0 °C, 1013 hPa, dry gas, 11 % O <sub>2</sub> )	60 mg/m <sup>3</sup>
Maximum permissible uncertainty as a percentage related to ELV	30 % of ELV = 18,0 mg/m <sup>3</sup>
Standard deviation $\sigma_0$ at standard conditions (0 °C, 1013 hPa, dry gas, 11 % O <sub>2</sub> )	9 mg/m <sup>3</sup>

In this example, 15 parallel measurements have been taken over three days, evenly distributed. The results are given in Table E.2:

Table E.2 — Measurements for the QAL2 test

Sample number <i>i</i>	SRM measured value at AMS conditions $y_i$ mg/m <sup>3</sup>	AMS measured signal at AMS conditions $x_i$ mA
1	8,4	8,31
2	9,1	8,81
3	8,7	8,32
4	9,0	9,00
5	8,3	8,82
6	8,5	8,28
7	10,8	8,79
8	10,0	9,25
9	10,6	8,48
10	10,6	9,28
11	11,6	9,30
12	12,0	8,51
13	13,5	8,47
14	12,2	9,02
15	9,4	8,25
Sum	152,7	130,89

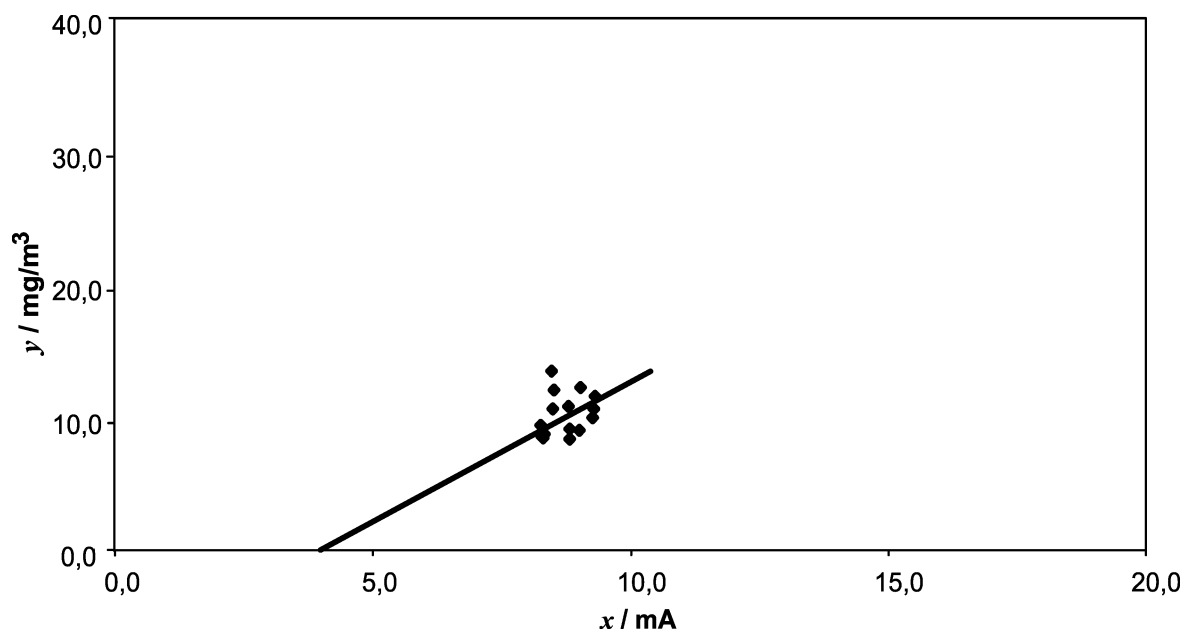


Figure E.1 — Plot of SRM measured values  $y$  versus AMS measured signals  $x$  and the calibration function determined in E.2.3



First the SRM measured values are plotted against the AMS measured signals (see Figure E.1). A plot of the SRM measured values against the AMS measured signals is recommended, to visualise the data and to help understand the results obtained by the statistical procedures.

Afterwards the calculations and tests are performed.

## E.2.2 Calculation of measured values of the SRM at standard conditions

The requirement on the measurement uncertainty of the AMS measured values is expressed as 30 % of the daily ELV, which is given at standard conditions (0 °C, 1013 hPa, dry flue gas with an oxygen content of 11 %).

To decide whether procedure a), b) or c) of 6.4.3 is used for calibrating the AMS, it is essential to calculate the SRM measured values at standard conditions. The measured values  $y$  of the SRM should therefore be converted to standard conditions in accordance with the Formula (E.1) by using the appropriate parts:

$$y_s = y \times \frac{t + 273,15\text{K}}{273,15\text{K}} \times \frac{1013\text{hPa}}{1013\text{hPa} + p} \times \frac{100\%}{100\% - h} \times \frac{21\% - o_s}{21\% - o} \quad (\text{E.1})$$

where

- $t$  is the Celsius temperature;
- $p$  is the difference between the static pressure of the sample gas and the standard pressure;
- $h$  is the absolute water vapour content (by volume);
- $o$  is the oxygen content in dry gas (by volume);
- $o_s$  is the oxygen standard condition.

The peripheral measurements used to perform the conversion of the SRM measured values and the results are given in Table E.3.

Table E.3 — QAL2 measurements by the SRM

Sample number	SRM measured value at AMS conditions	Temperature	Water vapour content	O <sub>2</sub> -content in dry flue gas	SRM measured value at standard conditions
<i>i</i>	$y_i$ mg/m <sup>3</sup>	$t_i$ °C	$h_i$ %	$o_i$ %	$y_{i,s}$ mg/m <sup>3</sup>
1	8,4	85	15,4	10,7	12,6
2	9,1	85	15,8	10,7	13,8
3	8,7	85	15,8	10,7	13,2
4	9,0	86	14,8	10,8	13,6
5	8,3	86	13,9	10,8	12,4
6	8,5	85	15,3	10,7	12,8
7	10,8	86	14,3	10,7	16,1
8	10,0	87	16,3	9,8	14,1
9	10,6	86	15,5	9,7	14,6
10	10,6	86	15,1	10,8	16,1
11	11,6	80	14,5	9,8	15,7
12	12,0	81	16,8	9,7	16,6
13	13,5	79	15,0	10,9	20,3
14	12,2	79	14,4	9,9	16,6
15	9,4	84	15,8	9,9	13,2

### E.2.3 Calibration function

The calibration function is described by Formula (E.2):

$$y_i = a + b x_i \quad (\text{E.2})$$

where

- $x_i$  is the result from the AMS;
- $y_i$  is the result from the SRM;
- $a$  is the intercept;
- $b$  is the slope.

From Table E.3 it can be seen for the maximum and minimum value at standard conditions that

$$y_{s,\max} = 20,3 \text{ mg/m}^3$$

$$y_{s,\min} = 12,4 \text{ mg/m}^3$$

The difference between the maximum and minimum value at standard conditions is given by:

$$\begin{aligned}\Delta y_{\max} &= (y_{s,\max} - y_{s,\min}) \\ &= 20,3 \text{ mg/m}^3 - 12,4 \text{ mg/m}^3 \\ &= 7,9 \text{ mg/m}^3\end{aligned}$$

The maximum permissible uncertainty  $U_{\max}$  is given by:

$$\begin{aligned}U_{\max} &= 0,30 E \\ &= 0,30 \times 60 \text{ mg/m}^3 \\ &= 18,0 \text{ mg/m}^3\end{aligned}$$

The criterion for the distance from zero for the minimum value is given by 15 % of ELV:

$$\begin{aligned}\Delta y_{\min} &= 0,15 E \\ &= 0,15 \times 60 \text{ mg/m}^3 \\ &= 9 \text{ mg/m}^3\end{aligned}$$

Since the maximum difference of the measured values is smaller than the maximum permissible uncertainty, and the minimum value at standard conditions is greater than the criterion for the distance from zero, the parameters  $a$  and  $b$  are calculated according to procedure b) by:

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

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

where

$$\bar{x} = \frac{1}{N} \sum_{i=1}^N x_i = \frac{1}{15} \times 130,89 \text{ mA} = 8,72 \text{ mA}$$

$$\bar{y} = \frac{1}{N} \sum_{i=1}^N y_i = \frac{1}{15} \times 152,7 \frac{\text{mg}}{\text{m}^3} = 10,2 \frac{\text{mg}}{\text{m}^3}$$

The slope and intercept are calculated by:

$$\hat{b} = \frac{\bar{y}}{\bar{x} - Z} = \frac{10,2 \text{ mg/m}^3}{(8,72 - 4) \text{ mA}} = 2,15 \frac{\text{mg/m}^3}{\text{mA}}$$

$$\hat{a} = -\hat{b} Z = -2,15 \frac{\text{mg/m}^3}{\text{mA}} \times 4 \text{ mA} = -8,61 \frac{\text{mg}}{\text{m}^3}$$

The calibration function then becomes (see Figure E.1):

$$\hat{y}_i = \hat{a} + \hat{b} x_i = -8,61 \frac{\text{mg}}{\text{m}^3} + 2,15 \frac{\text{mg/m}^3}{\text{mA}} x_i \quad (\text{E.3})$$

### E.2.4 Calibrated values of AMS

The results listed in Table E.4 are obtained by using the calibration function given by Formula (E.3) on the AMS measured signals:

**Table E.4 — Calibration of AMS**

Number <i>i</i>	AMS measured signal at AMS conditions  <i>x<sub>i</sub></i>  mA	SRM measured value at AMS conditions  <i>y<sub>i</sub></i>  mg/m <sup>3</sup>	AMS measured value at AMS conditions  <i>y<sub>i</sub></i>  mg/m <sup>3</sup>
1	8,31	8,4	9,28
2	8,81	9,1	10,36
3	8,32	8,7	9,31
4	9,00	9,0	10,77
5	8,82	8,3	10,38
6	8,28	8,5	9,22
7	8,79	10,8	10,32
8	9,25	10,0	11,31
9	8,48	10,6	9,65
10	9,28	10,6	11,37
11	9,30	11,6	11,42
12	8,51	12,0	9,71
13	8,47	13,5	9,63
14	9,02	12,2	10,81
15	8,25	9,4	9,15
Sum	130,9	152,7	152,7

### E.2.5 Conversion of data to standard conditions

The requirements on the quality of the AMS is expressed as 30 % of the daily ELV, which is given at standard conditions (0 °C, 1013 hPa, dry flue gas with an oxygen content of 11 %). The values of the SRM and the calibrated AMS should therefore be converted to these standard conditions. Formula (E.1) is used for the conversion of SRM measured values. The conversion of AMS measured values is carried out by application of the corresponding Formula (E.4) by:

$$\hat{y}_s = \hat{y} \times \frac{t + 273,15K}{273,15K} \times \frac{1013hPa}{1013hPa + p} \times \frac{100\%}{100\% - h} \times \frac{21\% - o_s}{21\% - o} \quad (E.4)$$

where

- t* is the Celsius temperature;
- p* is the difference between the static pressure of the sample gas and the standard pressure;
- h* is the absolute water vapour content (by volume);

- $o$  is the oxygen content in dry gas (by volume);
- $o_s$  is the oxygen standard condition.

The peripheral measurements used to perform the conversion of the AMS values and the results are given in Table E.5:

**Table E.5 — QAL2 measurements by AMS**

Sample number	AMS measured signal	Calibrated AMS measured value	Temperature	Water vapour content	O <sub>2</sub> content in dry flue gas	Calibrated AMS measured value at standard conditions
$i$	$x_i$ mA	$\hat{y}_i$ mg/m <sup>3</sup>	$t_i$ °C	$h_i$ %	$o_i$ %	$\hat{y}_{i,s}$ mg/m <sup>3</sup>
1	8,31	9,3	82	15	10,7	13,8
2	8,81	10,4	83	15	10,6	15,3
3	8,32	9,3	82	14	10,3	13,1
4	9,00	10,8	82	15	10,2	15,3
5	8,82	10,4	84	13	10,3	14,6
6	8,28	9,2	84	15	10,4	13,4
7	8,79	10,3	82	14	9,9	14,0
8	9,25	11,3	83	16	10,2	16,2
9	8,48	9,7	85	14	10,1	13,6
10	9,28	11,4	81	13	10,0	15,4
11	9,30	11,4	77	13	10,0	15,3
12	8,51	9,7	77	13	10,1	13,1
13	8,47	9,6	77	14	9,9	12,9
14	9,02	10,8	82	15	9,7	14,6
15	8,25	9,2	80	15	9,5	12,2

### E.2.6 Valid calibration range

The calibration function of the AMS is valid between zero and the maximum value  $\hat{y}_{s,max}$  of the calibrated AMS measured values at standard conditions plus an extension of 10 % of  $\hat{y}_{s,max}$ , or 20 % of ELV, whichever is the greater.

For this AMS, the maximum value is  $\hat{y}_{s,max} = 16,2 \text{ mg/m}^3$ . Since  $1,10 \times \hat{y}_{s,max} = 17,8 \text{ mg/m}^3$  is greater than  $0,20 \times E = 12,0 \text{ mg/m}^3$ , the valid calibration range is given by:

$$0 \leq \hat{y}_s \leq 1,10 \times 16,2 \text{ mg/m}^3$$

$$0 \leq \hat{y}_s \leq 17,8 \text{ mg/m}^3$$

The valid calibration range is from 0,0 mg/m<sup>3</sup> to 17,8 mg/m<sup>3</sup> at standard conditions.

### E.2.7 Test of variability

The variability is accepted if:

$$s_D \leq \sigma_0 k_v \quad (\text{E.5})$$

where

$s_D$  is the standard deviation of the differences  $D_i$  ;

$\sigma_0$  is the standard deviation associated with the uncertainty laid down by the authorities;

$k_v$  is the test parameter.

The standard deviation  $s_D$  is calculated in accordance with Formula (E.6):

$$s_D = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (D_i - \bar{D})^2} \quad (\text{E.6})$$

where the difference  $D_i$  is:

$$D_i = y_{i,s} - \hat{y}_{i,s} \quad (\text{E.7})$$

The values used for the calculation of  $s_D$  are given in Table E.6:

**Table E.6 — Figures used for variability test at standard conditions <sup>a</sup>**

Sample number	Calibrated AMS measured value at standard conditions	SRM measured value at standard conditions	Difference	Difference	Squared difference
$i$	$\hat{y}_{i,s}$ mg/m <sup>3</sup>	$y_{i,s}$ mg/m <sup>3</sup>	$D_i = y_{i,s} - \hat{y}_{i,s}$ mg/m <sup>3</sup>	$D_i - \bar{D}$ mg/m <sup>3</sup>	$(D_i - \bar{D})^2$ (mg/m <sup>3</sup> ) <sup>2</sup>
1	13,8	12,6	-1,17	-1,74	3,02
2	15,3	13,8	-1,58	-2,15	4,62
3	13,1	13,2	0,01	-0,55	0,31
4	15,3	13,6	-1,68	-2,25	5,05
5	14,6	12,4	-2,18	-2,75	7,56
6	13,4	12,8	-0,58	-1,14	1,31
7	14,0	16,1	2,06	1,49	2,22
8	16,2	14,1	-2,18	-2,74	7,53
9	13,6	14,6	1,03	0,46	0,21
10	15,4	16,1	0,65	0,08	0,01
11	15,3	15,7	0,39	-0,18	0,03
12	13,1	16,6	3,44	2,87	8,23
13	12,9	20,3	7,38	6,82	46,45
14	14,6	16,6	1,93	1,37	1,87
15	12,2	13,2	0,98	0,42	0,17
Average			0,57		
Sum					88,59
<sup>a</sup> Standard conditions: 0 °C, 1013 hPa, dry gas, 11 % O <sub>2</sub>					

The standard deviation  $s_D$  is given by:

$$s_D = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (D_i - \bar{D})^2} = \sqrt{\frac{1}{15-1} 88,59 \left(\frac{\text{mg}}{\text{m}^3}\right)^2} = 2,52 \frac{\text{mg}}{\text{m}^3}$$

The maximum permissible uncertainty laid down by the authorities is 30 % of the ELV as half length of a 95 % confidence interval.  $\sigma_0$  is therefore calculated as:

$$\begin{aligned} \sigma_0 &= p E / 1,96 \\ &= \frac{0,30 \times 60 \text{ mg/m}^3}{1,96} \\ &= 9 \text{ mg/m}^3 \end{aligned}$$

For 15 measurements the  $k_v$  value is 0,9761 (see Table I.1). The test for variability then results in:

$$2,52 \text{ mg/m}^3 \leq 9 \text{ mg/m}^3 \times 0,9761$$

$$2,52 \text{ mg/m}^3 \leq 8,78 \text{ mg/m}^3$$

which is fulfilled. The AMS passes the test.

### E.3 Example of a QAL2 for a carbon monoxide AMS and a low level cluster

#### E.3.1 General

Table E.7 lists the measurement methods and requirements used in this example.

**Table E.7 — Measurement methods and requirements**

Parameter	Carbon monoxide
AMS method	continuous monitor
Offset for AMS	no offset
SRM method	EN 15058
Emission limit value (ELV) at the conditions defined in the IED for gas turbines and gas engines (273,15 K, 1013 hPa, dry gas, 15 % O <sub>2</sub> )	100 mg/m <sup>3</sup>
IED maximum permissible uncertainty as a percentage related to ELV	10 % of ELV = 10,0 mg/m <sup>3</sup>
Standard deviation $\sigma_0$	5,1 mg/m <sup>3</sup>

In this example, 18 parallel measurements have been taken over three days, evenly distributed. As all measurements were made at dry conditions reported at 273 K and 1013 hPa, there is no need to correct for these peripheral measurements. The measurement results are given in Table E.8:



Table E.8 — Measurements for the QAL2 test

Sample number	AMS measured signal	AMS oxygen content	SRM oxygen content	SRM measured value at AMS conditions
$i$	$x_i$ mg/m <sup>3</sup>	%	%	$y_i$ mg/m <sup>3</sup>
1	7,3	14,2	14,4	8,3
2	7,3	14,3	14,4	8,1
3	6,7	14,3	14,4	7,7
4	6,4	14,3	14,4	7,7
5	6,4	14,3	14,5	7,5
6	6,0	14,3	14,4	6,9
7	5,6	14,4	14,5	7,5
8	5,4	14,4	14,5	7,3
9	6,0	14,4	14,5	7,6
10	6,3	14,4	14,5	7,6
11	6,2	14,4	14,5	7,8
12	5,7	14,1	14,3	7,0
13	6,0	14,0	14,1	6,9
14	5,9	14,0	14,1	6,6
15	4,6	14,1	14,3	5,9
16	4,5	14,3	14,4	5,8
17	5,1	14,3	14,4	7,0
18	6,2	14,3	14,4	6,9

The standardized data for the QAL2 test are given by Table E.9.

**Table E.9 — Standardised data for the QAL2 test**

Sample number  <i>i</i>	SRM measured value at standard conditions  <i>y<sub>i</sub></i>  mg/m <sup>3</sup>	AMS measured signal at standard conditions  <i>x<sub>i</sub></i>  mg/m <sup>3</sup>
1	7,5	6,4
2	7,4	6,5
3	7,0	6,0
4	7,0	5,7
5	6,9	5,7
6	6,3	5,4
7	6,9	5,1
8	6,7	4,9
9	7,0	5,5
10	7,0	5,7
11	7,2	5,6
12	6,3	5,0
13	6,0	5,1
14	5,7	5,1
15	5,3	4,0
16	5,3	4,0
17	6,4	4,6
18	6,3	5,6
Average	6,57	5,33
Minimum	5,3	
Maximum	7,5	
Spread	2,2	

### E.3.2 Calculation of SRM measured values at standard conditions

The requirement on the measurement uncertainty of the AMS measured values is expressed as a percentage of the ELV, which is given at standard conditions.

To decide whether procedure a), b) or c) of 6.4.3 is used for calibrating the AMS the SRM measured values are expressed at standard conditions, see Table E.9.

### E.3.3 Calibration function

From Table E.9 it can be seen for the maximum and minimum value at standard conditions that

$$y_{s,\max} = 7,5 \text{ mg/m}^3$$

$$y_{s,\min} = 5,3 \text{ mg/m}^3$$

The difference between the maximum and minimum value at standard conditions is given by:

$$\begin{aligned} \Delta y_{\max} &= (y_{s,\max} - y_{s,\min}) \\ &= 7,5 \text{ mg/m}^3 - 5,3 \text{ mg/m}^3 \\ &= 2,2 \text{ mg/m}^3 \end{aligned}$$

The maximum permissible uncertainty  $U_{\max}$  is given by:

$$\begin{aligned} U_{\max} &= 0,10 E \\ &= 0,10 \times 100 \text{ mg/m}^3 \\ &= 10,0 \text{ mg/m}^3 \end{aligned}$$

The criterion for the distance from zero for the minimum value is given by 15 % of ELV:

$$\begin{aligned} \Delta y_{\min} &= 0,15 E \\ &= 0,15 \times 100 \text{ mg/m}^3 \\ &= 15,0 \text{ mg/m}^3 \end{aligned}$$

Since the maximum difference of the measured values is smaller than the maximum permissible uncertainty, and the minimum value at standard conditions is smaller than the criterion for the distance from zero, the parameters  $a$  and  $b$  are calculated according to procedure c). Table E.10 shows the complete dataset for the calculation of the calibration function

**Table E.10 — Complete dataset for the calculation of the calibration function**

Sample number  <i>i</i>	SRM measured value at AMS conditions  <i>y<sub>i</sub></i> mg/m <sup>3</sup>	AMS measured signal at AMS conditions  <i>x<sub>i</sub></i> mg/m <sup>3</sup>	Data type
1	8,3	7,3	SRM
2	8,1	7,3	SRM
3	7,7	6,7	SRM
4	7,7	6,4	SRM
5	7,5	6,4	SRM
6	6,9	6,0	SRM
7	7,5	5,6	SRM
8	7,3	5,4	SRM
9	7,6	6,0	SRM
10	7,6	6,3	SRM
11	7,8	6,2	SRM
12	7,0	5,7	SRM
13	6,9	6,0	SRM
14	6,6	5,9	SRM
15	5,9	4,6	SRM
16	5,8	4,5	SRM
17	7,0	5,1	SRM
18	6,9	6,2	SRM
19	0,0	0,1	surrogate
20	76,0	75,3	surrogate
Average	10,31	9,15	

The calibration function is described by Formula (E.8):

$$y_i = a + b x_i \tag{E.8}$$

where

- x<sub>i</sub>* is the AMS measured signal;
- y<sub>i</sub>* is the SRM measured value;
- a* is the intercept of the calibration function;
- b* is the slope of the calibration function.

For procedure c), the parameters *a* and *b* are calculated by:

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

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

where

$$\bar{x} = \frac{1}{N} \sum_{i=1}^N x_i = 9,15 \frac{\text{mg}}{\text{m}^3}$$

$$\bar{y} = \frac{1}{N} \sum_{i=1}^N y_i = 10,31 \frac{\text{mg}}{\text{m}^3}$$

With these values the slope and intercept are:

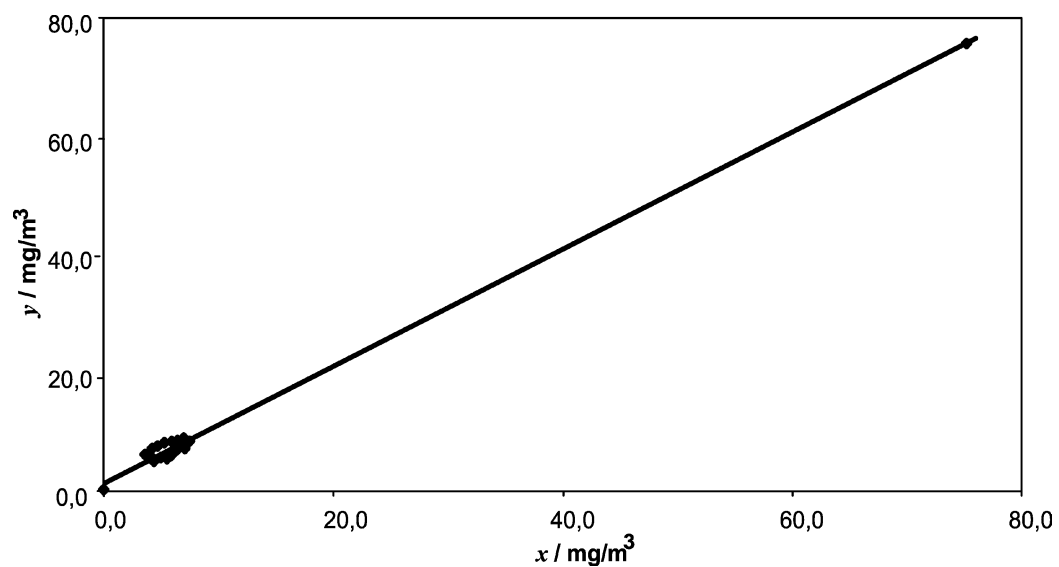
$$\hat{a} = 1,208 \frac{\text{mg}}{\text{m}^3}$$

$$\hat{b} = 0,994$$

The calibration function then becomes:

$$\hat{y}_i = \hat{a} + \hat{b} x_i = 1,208 \frac{\text{mg}}{\text{m}^3} + 0,994 x_i \quad (\text{E.9})$$

Figure E.2 shows a plot of the SRM measured values  $y$  versus the AMS measured signals  $x$  and the calibration function determined.



**Figure E.2 — Plot of SRM measured values  $y$  versus AMS measured signals  $x$  and the calibration function**

### E.3.4 Calibrated AMS measured values and conversion to standard conditions

The results listed in Table E.11 are obtained by using the calibration function given by Formula (E.9) on the AMS measured signals and conversion to standard conditions by use of Formula (E.10):

$$\hat{y}_s = \hat{y} \times \frac{21\% - o_s}{21\% - o} \quad (\text{E.10})$$

where

- $o$  is the oxygen content in dry gas (by volume);
- $o_s$  is the oxygen standard condition ( $o_s = 15\%$ ).

**Table E.11 — Calibration of AMS**

Number  $i$	AMS measured signal at AMS conditions  $x_i$  mg/m <sup>3</sup>	Calibrated AMS measured value at AMS conditions  $\hat{y}_i$  mg/m <sup>3</sup>	AMS oxygen content  $o_i$  %	Calibrated AMS measured value at standard conditions  $\hat{y}_{i,s}$  mg/m <sup>3</sup>
1	7,3	8,5	14,2	7,5
2	7,3	8,5	14,3	7,6
3	6,7	7,9	14,3	7,1
4	6,4	7,6	14,3	6,8
5	6,4	7,6	14,3	6,8
6	6,0	7,2	14,3	6,5
7	5,6	6,8	14,4	6,2
8	5,4	6,6	14,4	6,0
9	6,0	7,2	14,4	6,6
10	6,3	7,5	14,4	6,8
11	6,2	7,4	14,4	6,7
12	5,7	6,9	14,1	6,0
13	6,0	7,2	14,0	6,2
14	5,9	7,1	14,0	6,1
15	4,6	5,8	14,1	5,1
16	4,5	5,7	14,3	5,1
17	5,1	6,3	14,3	5,7
18	6,2	7,4	14,3	6,6

### E.3.5 Valid calibration range

The calibration function of the AMS is valid between zero and the maximum value  $\hat{y}_{s,\max}$  of the calibrated AMS measured values at standard conditions plus an extension of 10 % of  $\hat{y}_{s,\max}$ , or 20 % of ELV, whichever is the greater.

For this AMS, the maximum value is  $\hat{y}_{s,\max} = 7,6 \text{ mg/m}^3$ . Since  $1,10 \times \hat{y}_{s,\max} = 8,4 \text{ mg/m}^3$  is less than  $0,20 \times E = 20,0 \text{ mg/m}^3$ , the valid calibration range is from  $0,0 \text{ mg/m}^3$  to  $20,0 \text{ mg/m}^3$  at standard conditions.

### E.3.6 Test of variability

The variability is accepted if:

$$s_D \leq \sigma_0 k_v \quad (\text{E.11})$$

where

- $s_D$  is the standard deviation of the differences  $D_i$ ;
- $\sigma_0$  is the standard deviation associated with the uncertainty laid down by the authorities;
- $k_v$  is the test parameter.

The standard deviation  $s_D$  is calculated in accordance with Formula (E.12):

$$s_D = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (D_i - \bar{D})^2} \quad (\text{E.12})$$

where the difference  $D_i$  is:

$$D_i = y_{i,s} - \hat{y}_{i,s} \quad (\text{E.13})$$

The values used for the calculation of  $s_D$  are given in Table E.12:

Table E.12 — Figures used for variability test at standard conditions<sup>a</sup>

Sample number	Calibrated AMS measured value at standard conditions	SRM measured value at standard conditions	Difference	Difference	Squared difference
$i$	$\hat{y}_{i,s}$ mg/m <sup>3</sup>	$y_{i,s}$ mg/m <sup>3</sup>	$D_i = y_{i,s} - \hat{y}_{i,s}$ mg/m <sup>3</sup>	$D_i - \bar{D}$ mg/m <sup>3</sup>	$(D_i - \bar{D})^2$ (mg/m <sup>3</sup> ) <sup>2</sup>
1	7,5	7,5	0,0	-0,1	0,0
2	7,6	7,4	-0,3	-0,4	0,2
3	7,1	7,0	-0,1	-0,2	0,1
4	6,8	7,0	0,2	0,0	0,0
5	6,8	6,9	0,1	0,0	0,0
6	6,5	6,3	-0,2	-0,3	0,1
7	6,2	6,9	0,7	0,6	0,3
8	6,0	6,7	0,7	0,6	0,3
9	6,6	7,0	0,5	0,3	0,1
10	6,8	7,0	0,2	0,0	0,0
11	6,7	7,2	0,5	0,3	0,1
12	6,0	6,3	0,3	0,1	0,0
13	6,2	6,0	-0,2	-0,3	0,1
14	6,1	5,7	-0,4	-0,5	0,3
15	5,1	5,3	0,2	0,1	0,0
16	5,1	5,3	0,1	0,0	0,0
17	5,7	6,4	0,7	0,5	0,3
18	6,6	6,3	-0,4	-0,5	0,3
Average			0,16		
Sum					2,16

<sup>a</sup> Standard conditions: 0 °C, 1013 hPa, dry gas, 15 % O<sub>2</sub>

The standard deviation  $s_D$  is given by:

$$s_D = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (D_i - \bar{D})^2} = \sqrt{\frac{1}{18-1} 2,16 \left(\frac{\text{mg}}{\text{m}^3}\right)^2} = 0,36 \frac{\text{mg}}{\text{m}^3} \quad (\text{E.14})$$

The maximum permissible uncertainty laid down by the authorities is 10 % of the ELV as half length of a 95 % confidence interval.  $\sigma_0$  is therefore calculated as:



$$\begin{aligned}\sigma_0 &= p E / 1,96 \\ &= \frac{0,10 \times 100 \text{ mg/m}^3}{1,96} \\ &= 5,1 \text{ mg/m}^3\end{aligned}\tag{E.15}$$

For 18 measurements the  $k_v$  value is 0,9803 (see Annex I). The test for variability then results in:

$$\begin{aligned}0,36 \text{ mg/m}^3 &\leq 5,1 \text{ mg/m}^3 \times 0,9803 \\ 0,36 \text{ mg/m}^3 &\leq 5,00 \text{ mg/m}^3\end{aligned}$$

which is fulfilled. The AMS passes the test.

## Annex F (informative)

### Example of calculation of the standard deviation $s_{AMS}$ of the AMS at zero and span level

This example is given for an extractive SO<sub>2</sub>-monitor, range: 0 to 250 mg/m<sup>3</sup>, concentration of span reference material: 200 mg/m<sup>3</sup>.

The standard deviation  $s_{AMS}$  is calculated by:

$$s_{AMS} = \sqrt{(u_{inst})^2 + (u_{temp})^2 + (u_{volt})^2 + (u_{pres})^2 + (u_{other})^2}$$

where

- $u_{inst}$  is the uncertainty from instability (drift and dispersion) expressed as standard deviation;
- $u_{temp}$  is the uncertainty relating from variations in ambient temperature expressed as standard deviation;
- $u_{volt}$  is the uncertainty relating from variations in voltage expressed as standard deviation;
- $u_{pres}$  is the uncertainty relating from variations in ambient pressure expressed as standard deviation;
- $u_{others}$  is the uncertainty relating from other sources expressed as standard deviation.

The supplier has given the following specifications about this analyser (all refer to standard temperature and pressure):

a) Range:

Display: auto-ranging from 0 to 250 mg/m<sup>3</sup>, resolution 0,02 mg/m<sup>3</sup>

Analogue output: 0 to full scale from 0 mg/m<sup>3</sup> to 10 mg/m<sup>3</sup> to 0 mg/m<sup>3</sup> to 250 mg/m<sup>3</sup> with 0 %, 5 % and 10 % offset

b) Noise (RMS):

Measurement process: 0,005 mg/m<sup>3</sup> or 0,1 % of concentration range, whichever is greater

Analogue output: 0,005 mg/m<sup>3</sup> or 0,1 % of analogue output full scale, whichever is greater

c) Zero drift:

Temperature dependence: 0,025 mg/m<sup>3</sup> per K

Time dependent, at fixed temperature:

24 h: less than 0,25 mg/m<sup>3</sup>

30 days: less than 0,25 mg/m<sup>3</sup>

d) Span drift:

Temperature dependence: 0,1 % of measured concentration per K

Time dependence, at fixed temperature:

24 h: 1 % of instrument reading

30 days: 1 % of instrument reading

e) Sample pressure dependence:

A 5 % change in pressure produces less than 1 % change in instrument reading

f) Temperature range:

5 °C to 40 °C

US-EPA designated range: 15 °C to 35 °C

Type test range: 5 °C to 40 °C

**Table F.1 — Calculation of  $s_{AMS}$  for the zero point**

Parameter	Suppliers information	Contribution
$u_{inst}$ (noise)	0,005 mg/m <sup>3</sup> or 0,1 % of analogue output full scale (250 mg/m <sup>3</sup> )	0,25 mg/m <sup>3</sup>
$u_{inst}$ (drift)	0,25 mg/m <sup>3</sup>	0,25 mg/m <sup>3</sup>
$u_{temp}$	0,025 mg/m <sup>3</sup> / K (5 °C to 40 °C)	0,26 mg/m <sup>3</sup>
$u_{volt}$	no information	0 mg/m <sup>3</sup>
$u_{pres}$	$\Delta p < 5 \%$ , i.e. less than 1 % change in reading (0 mg/m <sup>3</sup> )	0 mg/m <sup>3</sup>
$s_{AMS}$		0,44 mg/m <sup>3</sup>

**Table F.2 — Calculation of  $s_{AMS}$  for the span point**

Parameter	Suppliers information	Contribution
$u_{inst}$ (noise)	0,005 mg/m <sup>3</sup> or 0,1 % of analogue output full scale (250 mg/m <sup>3</sup> )	0,25 mg/m <sup>3</sup>
$u_{inst}$ (drift)	1 % of reading (200 mg/m <sup>3</sup> )	2 mg/m <sup>3</sup>
$u_{temp}$	0,1 % / K (5 °C to 40 °C)	2,08 mg/m <sup>3</sup>
$u_{volt}$	no information	0 mg/m <sup>3</sup>
$u_{pres}$	$\Delta p < 5 \%$ , i.e. less than 1 % change in instrument reading (200 mg/m <sup>3</sup> )	0 mg/m <sup>3</sup> a
$s_{AMS}$		2,90 mg/m <sup>3</sup>
a contribution negligible because pressure seldom varies 5 %.		

The  $s_{AMS}$  value used as input in the QAL3 calculations are:

- at zero:  $s_{AMS} = 0,44 \text{ mg/m}^3$
- at span:  $s_{AMS} = 2,9 \text{ mg/m}^3$

Below the calculation of the contribution to  $s_{AMS}$  value due to changes in the temperature is given. The calculation is performed in accordance with the general formula presented in EN ISO 14956:

$$u_x = |I_x| \sqrt{\frac{i_{x+}^2 + i_{x+}i_{x-} + i_{x-}^2}{3}}$$

In case of temperature as influence quantity, this formula is transformed to:

$$u_{temp} = |I_{temp}| \sqrt{\frac{t_+^2 + t_+t_- + t_-^2}{3}}$$

$$t_{cal} = 20^\circ\text{C}$$

$$t_+ = t_{max} - t_{cal} = (40 - 20)^\circ\text{C} = 20\text{K}$$

$$t_- = t_{min} - t_{cal} = (5 - 20)^\circ\text{C} = -15\text{K}$$

$$u_{temp} = |I_{temp}| \sqrt{\frac{(20\text{K})^2 + (20\text{K})(-15\text{K}) + (-15\text{K})^2}{3}} = 10,41\text{K} |I_{temp}|$$

For the zero point:

$$I_{temp} = 0,025 \frac{\text{mg}}{\text{m}^3} / \text{K}$$

$$u_{temp} = 10,41\text{K} \times 0,025 \frac{\text{mg}}{\text{m}^3} / \text{K} = 0,26 \frac{\text{mg}}{\text{m}^3}$$

For the span point:

$$I_{temp} = 0,001 / \text{K} \times 200 \frac{\text{mg}}{\text{m}^3} = 0,2 \frac{\text{mg}}{\text{m}^3} / \text{K}$$

$$u_{temp} = 10,41\text{K} \times 0,2 \frac{\text{mg}}{\text{m}^3} / \text{K} = 2,08 \frac{\text{mg}}{\text{m}^3}$$

## Annex G (informative)

### Example of using the calibration function and testing the variability and validity of the calibration function in the AST

#### G.1 General

The AST is carried out to check that the variability of the measured values provided by the AMS still complies with legal requirements and the calibration function is still valid.

The following example illustrates how to perform the test.

#### G.2 Example – Particulate monitor

##### G.2.1 General

The particulate monitor in example E.1 is used in this example. Table G.1 lists the basic information about this AMS.

**Table G.1 — Basic information about the AMS**

Parameter	Particulate emission
AMS method	Opacity, continuous
Offset for AMS	4 mA
SRM method	Manual gravimetric method – EN 13284-1
Emission limit value (ELV) for for the daily average at standard conditions (0 °C, 1013 hPa, dry gas, 11 % O <sub>2</sub> )	60 mg/m <sup>3</sup>
Maximum permissible uncertainty as a percentage related to ELV	30 % of ELV = 18,0 mg/m <sup>3</sup>
Calibration function: $\hat{y}_i = \hat{a} + \hat{b} x_i$ <sup>a</sup>	$\hat{y}_i = \hat{a} + \hat{b} x_i = -8,61 \frac{\text{mg}}{\text{m}^3} + 2,15 \frac{\text{mg/m}^3}{\text{mA}} x_i$
Valid calibration range at standard conditions:	0 to 17,8 mg/m <sup>3</sup>
Standard deviation $\sigma_0$ at standard conditions (0 °C, 1013 hPa, dry gas, 11 % O <sub>2</sub> )	9 mg/m <sup>3</sup>
<sup>a</sup> $x_i$ is the result of the AMS; $\hat{y}_i$ is the calibrated result of the AMS (best estimate for true SRM-value); $\hat{a}$ is the intercept; $\hat{b}$ is the slope.	

As part of the AST, five parallel measurements with the AMS and SRM inclusive peripheral parameters to correct to standard conditions were taken over one day, evenly distributed. The results are presented in Tables G.2 and G.3.

## G.2.2 Calculation of measured values of the calibrated AMS

The calibrated AMS measured values are calculated by using the calibration function derived from the measured signals from the AMS. The calibration function was determined during the previous QAL2 test, and it is described by:

$$\hat{y}_i = \hat{a} + \hat{b} x_i$$

where

- $x_i$  is the AMS measured signal;
- $\hat{y}_i$  is the calibrated AMS measured value (the best estimate for the true SRM measured value);
- $\hat{a}$  is the intercept;
- $\hat{b}$  is the slope.

From Table G.1 it can be seen, that the calibration function is:

$$\hat{y}_i = \hat{a} + \hat{b} x_i = -8,61 \frac{\text{mg}}{\text{m}^3} + 2,15 \frac{\text{mg/m}^3}{\text{mA}} x_i$$

Application of the calibration function on the measured signals from the AMS provides the results shown in Table G.2. In order to perform the variability test, the results of the calibrated AMS and the SRM are converted to standard conditions in Tables G.2 and G.3 by using the relevant parts of Formulae (E.1) and (E.4):

**Table G.2 — AMS measurements for the AST test**

Sample number	AMS measured signal	Calibrated AMS measured value	Temperature	Water vapour content	O <sub>2</sub> content in dry flue gas	Calibrated AMS measured value at standard conditions
$i$	$x_i$ mA	$\hat{y}_i$ mg/m <sup>3</sup>	$t_i$ °C	$h_i$ %	$o_i$ %	$\hat{y}_{i,s}$ mg/m <sup>3</sup>
1	8,42	9,48	76	14	9,8	12,59
2	9,25	11,27	75	13	9,9	14,88
3	8,43	9,50	74	14	9,7	12,44
4	9,07	10,88	72	14	9,7	14,16
5	8,72	10,13	76	15	9,8	13,61

Table G.3 — SRM measurements for the AST test

Sample number	SRM measured value	Temperature	Water vapour content	O <sub>2</sub> content in dry flue gas	SRM measured value at standard conditions
<i>i</i>	<i>y<sub>i</sub></i> mg/m <sup>3</sup>	<i>t<sub>i</sub></i> °C	<i>h<sub>i</sub></i> %	<i>o<sub>i</sub></i> %	<i>y<sub>i,s</sub></i> mg/m <sup>3</sup>
1	8,9	80	16,2	10,5	13,08
2	9,8	81	15,8	10,6	14,52
3	9,1	80	15,7	10,9	13,83
4	9,3	79	16,0	10,5	13,60
5	8,2	80	15,8	10,2	11,66

### G.2.3 Test of variability

Then the variability  $s_D$  is calculated according to the following formula:

$$s_D = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (D_i - \bar{D})^2}$$

where

$$D_i = y_{i,s} - \hat{y}_{i,s}$$

$$\bar{D} = \frac{1}{N} \sum_{i=1}^N D_i$$

To calculate the variability, Table G.4 is used:

**Table G.4 — Figures used for variability test at standard conditions <sup>a</sup>**

Sample number <i>i</i>	Calibrated AMS measured value at standard conditions $\hat{y}_{i,s}$ mg/m <sup>3</sup>	SRM measured value at standard conditions $y_{i,s}$ mg/m <sup>3</sup>	Difference $D_i = y_{i,s} - \hat{y}_{i,s}$ mg/m <sup>3</sup>	Difference $D_i - \bar{D}$ mg/m <sup>3</sup>	Squared difference $(D_i - \bar{D})^2$ (mg/m <sup>3</sup> ) <sup>2</sup>
1	12,59	13,08	0,49	0,688	0,4733
2	14,88	14,52	-0,36	-0,162	0,0262
3	12,44	13,83	1,39	1,588	2,5218
4	14,16	13,60	-0,56	-0,362	0,1310
5	13,61	11,66	-1,95	-1,752	3,0695
Sum	67,68	66,69	-0,99	0,000	6,2218
Average			-0,198		

<sup>a</sup> Standard conditions: 0 °C, 1013 hPa, dry gas, 11 % O<sub>2</sub>

Inserting the values from Table G.4 gives:

$$s_D = \sqrt{\frac{1}{5-1} \times 6,2218 \left(\frac{\text{mg}}{\text{m}^3}\right)^2} = 1,25 \frac{\text{mg}}{\text{m}^3}$$

The variability is accepted if:

$$s_D \leq 1,5 \sigma_0 k_v$$

where

$s_D$  is the standard deviation of the values  $D_i$ ;

$\sigma_0$  is the maximum permissible uncertainty laid down by the authorities;

$k_v$  is the test parameter.

For five measurements the  $k_v$  value is 0,9161, see Annex I.

The test for variability then yields:

$$1,25 \text{ mg/m}^3 \leq 1,5 \times 9 \text{ mg/m}^3 \times 0,9161$$

$$1,25 \text{ mg/m}^3 \leq 12,37 \text{ mg/m}^3$$

The condition for acceptance is fulfilled. The variability of the AMS is thus accepted.

## G.2.4 Test of validity of the calibration function

Finally, the calibration function of the AMS is accepted if:



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

In this example the Student  $t$ -value for a number of degrees of freedom of four and a confidence level of 95 % (one-sided) is equal to 2,132. The following values are calculated:

$$|\bar{D}| = 0,198 \frac{\text{mg}}{\text{m}^3}$$

$$t_{0,95,N-1} = 2,132$$

$$s_D = 1,25 \frac{\text{mg}}{\text{m}^3}$$

$$\sigma_0 = 9,00 \frac{\text{mg}}{\text{m}^3}$$

$$\begin{aligned} t_{0,95,N-1} \frac{s_D}{\sqrt{N}} + \sigma_0 &= \left( 2,132 \frac{1,25}{\sqrt{5}} + 9,00 \right) \frac{\text{mg}}{\text{m}^3} \\ &= 10,2 \frac{\text{mg}}{\text{m}^3} \end{aligned}$$

The calibration function of the AMS is accepted, since the following inequality is fulfilled:

$$|\bar{D}| = 0,198 \frac{\text{mg}}{\text{m}^3} \leq 10,2 \frac{\text{mg}}{\text{m}^3}$$

## Annex H (informative)

### Implementation of QAL1

#### H.1 General

The requirements for demonstrating that an AMS is suitable for installation on a plant are described in 5.1. CEN has published EN 15267-3, which specifies the performance criteria and test procedures for AMS for monitoring emissions from stationary sources in the framework of certification of AMS. It is both an application of EN ISO 14956, and a means of demonstrating compliance with the requirements of QAL1. EN ISO 14956 describes a procedure to determine the uncertainty of the results of measurement, using performance criteria and test data for an AMS.

This means that, if AMS which have been tested to the requirements of EN 15267-3, and the results of these tests show that the uncertainty meets the requirements of the Directives, then the AMS meets the requirements for QAL1.

EN 15267-3 and national standards which preceded it make allowances for the uncertainty contributions of the installation. For example, EN 15267-3 recommends that the uncertainty of the AMS, estimated using the procedure in EN ISO 14956, is not be more than 75 % of the uncertainty allowance specified in the Directives. This allows a margin of error for factors such as the uncertainty contributions from peripheral measurements and stack gas inhomogeneity.

There are many AMS which have been tested and certified in accordance with national standards which preceded EN 15267-3. In such cases, operators of industrial plants are advised to contact the competent authorities for guidance.

EN 15267-3:2007, Annex D, provides an example of an uncertainty determination for an AMS by applying EN ISO 14956.

#### H.2 Treatment of existing AMS without certification according to EN 15267-3

According to 5.1, AMS installed on a plant shall have been proven suitable for the task prior to installation, in accordance with QAL1. This is now implemented in procedures defined in EN 15267-3. In the case where an AMS has already been installed on the plant prior to the implementation of this European Standard, then the AMS should be expected to fulfil all requirements of this European Standard. However, it is possible that the AMS do not meet all of the requirements of EN 15267-3. However, the performance criteria specified within EN 15267-3 are set at a level which provides a margin of safety. This means that AMS which meet the requirements of EN 15267-3 are very likely to meet the uncertainty allowances specified in the Directives. Therefore, an AMS which does not meet the performance requirements of EN 15267-3 might still meet the uncertainty allowances specified within the Directives. In such cases, the operator can minimize the effects of influence factors which increase the uncertainty of the AMS once it is installed at the plant. For example, the AMS could be contained within a climate-controlled chamber, which could minimize the influence of variations in ambient temperature on the AMS.

Therefore, if an AMS already installed at the plant does not meet the requirements of EN 15267-3, and hence the requirements of QAL1, the competent authority can decide what action is necessary. For example, the competent authority can state that if the AMS still meets the requirements of QAL2, QAL3 and the AST, then the operator may keep the AMS for the rest of its design life.

## Annex I (normative)

### $k_v$ and $t_{0,95; N-1}$ values

Table I.1 —  $k_v$  and  $t_{0,95; N-1}$  values [11]

Number of parallel measurements $N$	$k_v$	$t_{0,95; N-1}$
3	0,832 6	2,920
4	0,888 1	2,353
5	0,916 1	2,132
6	0,932 9	2,015
7	0,944 1	1,943
8	0,952 1	1,895
9	0,958 1	1,860
10	0,962 9	1,833
11	0,966 5	1,812
12	0,969 5	1,796
13	0,972 1	1,782
14	0,974 2	1,771
15	0,976 1	1,761
16	0,977 7	1,753
17	0,979 1	1,746
18	0,980 3	1,740
19	0,981 4	1,734
20	0,982 4	1,729
25	0,986 1	1,711
30	0,988 5	1,699

If there are more than 30 pairs of data, then the applicable  $k_v$  and  $t_{0,95; N-1}$  values should be chosen for the next lowest value. For example, if there are 37 pairs of data points, then  $k_v$  and  $t_{0,95; N-1}$  values for 30 data pairs can be safely used.

## Annex J (informative)

### Significant technical changes

Clause	Technical change
5.1	Requirement has been added that in case of new installations of AMS, the AMS shall have been certified in accordance with EN 15267-1, EN 15267-2 and EN 15267-3.  Description of treatment of AMS already installed at plants which have not been certified according to EN 15267-1, EN 15267-2 and EN 15267-3 has been added.
5.3	Normative reference to EN 15259 has been added.
6.2	Recommendation has been added to perform the functional test not more than one month before parallel measurements are started.
6.2	Recommendation has been added to perform the relevant steps of the functional test for measuring systems of the peripheral parameters.
6.3	If the QAL2 is not the first QAL2 being carried out on the AMS, then an AST may be performed instead of a QAL2 provided that the SRM measured values obtained in the AST and at least 95 % of the AMS measured values at standard conditions obtained since the last AST are less than the maximum permissible uncertainty specified e.g. in the relevant EU Directive.
6.3	If calibrated AMS measured values for water vapour are available, these may be used to convert the SRM data to dry or wet basis. In case of wet abatement techniques with nearly constant water vapour concentration, conversion to dry or wet basis may be carried out using calculated water vapour values.
6.4.1	Requirement has been added that outliers in data sets shall be identified and reported.
6.4.3	A new procedure for treatment of low level clusters has been added.
6.4.3	The criterion for the identification of a cluster has been changed from 15 % of ELV to the maximum permissible uncertainty.
6.5	A minimum upper limit of the valid calibration range of 20 % of ELV has been added.
6.5	Treatment of exceedances of the valid calibration range in case of discontinuous plant operation or plant failures has been added.
6.6	Procedure has been adapted to the new procedure for treatment of low level clusters in 6.4.3.
6.6	Recommendation has been added to calibrate the peripheral AMS for oxygen and water vapour.
6.8	The method used to assess outliers and reasons for excluding outliers has to be presented in the QAL2 report.
Clause 7	The ongoing quality assurance during operation (QAL3) has been editorially revised and amended. Selection and use of control charts as well as the zero and span measurements are described in much more detail.
7.1	If a plant is operating two independent parallel AMS then the intervals for QAL3 procedures may be extended under specified conditions to one year.

8.2	Clarification has been added that the testing laboratory performing the parallel measurements shall meet the requirements in 5.4.
8.3	Requirement has been added that outliers in data sets shall be identified and reported.
8.5	Table with k and t values has been moved to Annex I.
8.5	If the AST demonstrates that the existing calibration function is valid beyond the existing valid calibration range, the competent authority can allow the plant to extend the valid calibration range up to the maximum measured concentration of the calibrated AMS measured values at standard conditions, determined during the AST, plus an extension of 10 % of this value, but below 50 % of ELV.
8.6	The method used to assess outliers and reasons for excluding outliers has to be presented in the AST report.
A.1	Functional tests are identical now for QAL2 and AST.
C.1	Description of Shewhart control charts and an example have been added.
C.2	Description of exponentially weighted moving average control charts and an example have been added.
E.3	Example for the calibration of an AMS in case of a low level cluster has been added.
Annex H	Original Annex H has been deleted.
Annex H	New annex on implementation of QAL1 has been added.
Annex I	Table with $k_v$ and $t_{0,95; N-1}$ values has been amended and moved from 8.5 to Annex I.

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