QUALITY ASSURANCE OF AUTOMATED MEASURING SYSTEMS – BACKGROUND FOR A NEW EUROPEAN STANDARD

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ABSTRACT

The work carried out by Working Group 9 within Technical Committee 264 of CEN is concerned with the development and prescription of procedures for a European Standard titled “Stationary source emissions – Quality assurance of automated measuring systems”. This will be described.

The development of the standard has been an iterative process, where theoretical considerations, technical discussions, and data analysis have been carried out following practical work, which included field tests. This working process is described and the outcome of this, which has produced the draft Standard, is presented.

The philosophies behind the individual procedures within this Standard are also explained. It should be emphasised that well-known statistical procedures and national or international standards have been used as the basis for the Standard wherever possible.

Examples from field-tests will be used to demonstrate the use of the standard.

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1. INTRODUCTION

The aim of this paper is to describe the work done by Working Group 9 within Technical Committee (TC) 264 of CEN, and specifically to discuss how the procedures of the European Standard "Stationary source emissions – Quality assurance of automated measuring systems" were developed and laid down.

This paper is intended to give an overview of the steps involved and the work performed. These steps have included both theoretical considerations and practical work carried out in field tests. Furthermore the intention and the overall theme for the Working Group was to develop a standard which draws on existing standards and sound statistical methods. In addition, the methods used and results obtained should be as simple and easy to understand as possible.

2. THE SCOPE OF THE WORKING GROUP

The Working Group was established in 1994 as an ad-hoc group within TC 264. In 1995 the group was constituted as a full Working Group, i.e. WG 9 under CEN TC 264.

The terms of reference for the Group were to develop and prescribe a standard concerning the quality assurance of automated measuring systems for airborne emissions from industrial plants, and also to meet the obligations of Annex III in the Directive 2000/76/EC of the European Parliament and Council on the incineration of waste which states:

"At the daily emission limit value level, the values of the 95% confidence intervals of a single measured result shall not exceed the following percentages of the emission limit values:…" etc.

Similar requirements are to be introduced in other Directives eg a revision of Directive 88/609/EEC for large combustion plants.

The European Commission mandated the work , which should cover:

- Field applications;
- Basic principles of the procedures;
- Validation of the methodology in existing standards covering field tests, carried out according to preliminary CEN standards;
- Evaluation and interpretation of the results obtained by at least 2 – 3 different kinds of equipment using parallel measurements at a number of plants;
- Calculation of the results and the evaluation of their uncertainties.

3. THE WORKING PROCESS

From the beginning of the work of the Working Group there was the intention to develop a standard which is relatively simple to use, as easy to understand as possible, and using existing national or international standards as far as possible. It should also be based on sound statistical methods.

The working process has been iterative, with theoretical considerations and discussions carried out following practical work. A number of field tests have been carried out, and the results have been used in combination with other practical knowledge in developing the procedures laid down in the draft standard.

The Working Group began with a review of relevant national and international standards dealing with the topics relevant for this standard, i.e. quality assurance of automated measuring systems for airborne emissions. Then a number of statistical procedures e.g. VDI 3950, ISO 7935, ISO 10155 and ISO 13752 were identified as candidate methods. The next step was to carry out two initial sets of field tests, one performed at a municipal waste incineration plant in the United Kingdom and the other at a power plant in Spain. The results obtained from this work were used to test the candidate procedures and subsequently improve the statistical tools and the procedures , which had been drafted by the Working Group at that time.

After this a second set of field tests were carried out, one at an Italian power plant and the other at Danish municipal waste incineration plant. Further development of the methodology was carried out following these.

At around this point, in order to solve certain fundamental problems arising from a need to understand of the requirements of the Directives, a group of statistical experts were formed as an ad-hoc Group to advise the Working Group. The recommendations from this ad-hoc group on statistics were then implemented in the procedures of the Standard.

This process and the outcomes from the process are described in more detail in this paper.

4. SHORT DESCRIPTION OF THE STANDARD

At an early stage, before the working group officially started, it was decided to divide the quality assurance work with AMS into three parts, also called QAL1, QAL2 and QAL3, where QAL is an abbreviation for Quality Assurance Level.

The three levels are:

- QAL1- Suitability evaluation of the AMS and the measuring procedure
- QAL2 – Quality assurance of the installation
- QAL3 - Ongoing quality assurance during operation

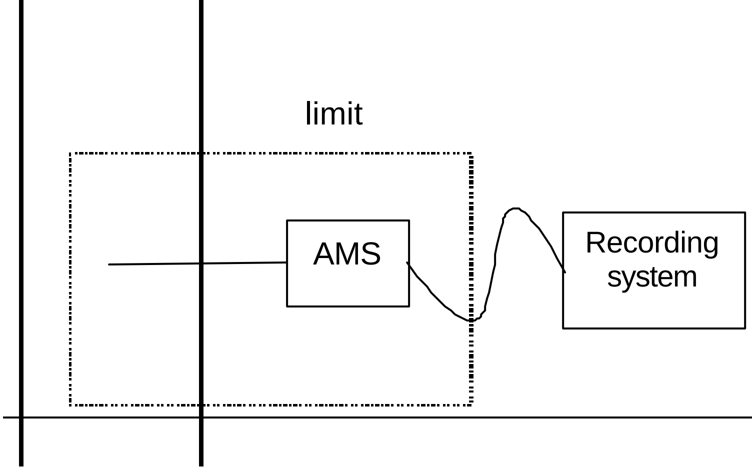
Later in the process a fourth level was introduced:

- AST – Annual surveillance test

Since such a procedure is required in the relevant directives.

It is important to note the limitation of this standard as regards the definition of an AMS. The AMS is limited to the measuring system itself. The recording system and the transmission of the signal are not included, as illustrated in Figure 4.1.

Figure 4.1 The Definition of the AMS as given in this Standard



The first level of quality-assurance (QAL1) is not included in the standard, since it is specified in EN-ISO 14956: “Air quality - Determination of minimum requirements of air quality measuring instruments”. The suitability of the AMS is evaluated at this level by means of the total uncertainty assigned to the AMS by a series of type-approval tests. This evaluation guarantee, in principle, that the AMS is capable of fulfilling a plant operator’s requirements, provided it is calibrated correctly.

The other three quality-assurance levels are contained in the EN Standard discussed in this paper, as follows:

The second level (QAL2) describes a procedure for the initial calibration of the AMS to provide the quality-assurance of the results correctly following its installation at the plant. This procedure shall be performed each time a new AMS is installed or whenever major modifications have been carried out on the AMS. The procedure is repeated each fifth year. This work shall be performed by an independent organisation.

The third level (QAL3) covers the ongoing quality–assurance and quality-control procedures, which must be performed on the AMS by the plant operator’s staff. Periodic checks of zero and span readings are made, and the correct operation of the AMS is evaluated from these measurement results. Furthermore, instructions for adjustments or maintenance are provided which must be implemented when drift or other problems occur.

The fourth level (AST) involves an annual test, which must be performed by an independent organisation, to ensure that proper functioning of the AMS. This test determines whether the AMS still operates with the same performance as it did during the last QAL2 test.

These last three quality levels were formulated in parallel during the process of developing the Standard.

5. PROGRESS ON THE QAL2 PROCEDURE

The main aim of this is to lay down procedures that ensures the quality-control of an AMS after installation, in order that it fulfils the requirements of Annex III of the Directive 2000/76/EC of the European Parliament and Council on the incineration of waste. This states:

At the daily emission limit value level, the values of the 95% confidence intervals of a single measured result shall not exceed the following percentages of the emission limit values:

Carbon monoxide	:	*10%*
Sulphur dioxide	:	*20%*
Nitrogen dioxide	:	*20%*
Total dust	:	*30%*
Total organic carbon	:	*30%*
Hydrogen chloride	:	*40%*
Hydrogen fluoride	:	*40%*

This wording is similar to the requirements of other directives eg Directive 88/609/EEC for large combustion plants

The procedure of QAL2 may be summarised as follows:

- Calibration of the AMS following installation;
- Demonstration that the AMS meets the requirements of Annex III of the Directive.

From its beginning the Working Group agreed to lay down a procedure which was as simple to use and to understand as possible. It should also be in line with other standards within this field, and be based on sound statistic methods. Furthermore the directive required, that the evaluations of the quality of an AMS and hereby its calibration should be based on parallel measurements carried out using an appropriate standard reference method (SRM).

One of the biggest problems was how to interpret the wording of this Annex III (quotations from the Annex are shown with italics):

- what is meant with *"the 95% confidence intervals of a single measured result";*
- how to compare results at *"the daily emission limit value level"* with *"the emission limit values";*
- how should the term *"shall not"* be interpreted in terms of a statistical test on uncertainties.

By way of introduction there was a review to determine which standards, European, national or international, already existed concerning quality assurance. (In this connection quality assurance of an AMS was defined as calibrating and controlling its performance). The group identified the standards listed below as relevant:

- ISO 7935 "Stationary source emissions – Determination of the mass concentration of sulphur dioxide – Performance characteristics of automated measuring methods"
- VDI 3950 – Part 1 "Calibration of automatic emission measuring instruments"
- ISO 10155 "Stationary source emissions – Automated monitoring of mass concentrations of particles – performance characteristics, test method and specifications"
- ISO 13752 "Air quality – Assessment of uncertainty of measurement methods under field conditions using a second method as reference"

Some of those standards are specific to one air quality parameter or one determinand. Some usean SRM to calibrate an AMS assuming a linear relation between the two. Others evaluate the quality of an AMS by means of an SRM.

The Working Group decided to use these four standards as the basis for all the air quality parameters to be studied. This decision enables the Group to evaluate the concepts and the statistics of methodologies within each of the standards.

Members of the Working Group also contributed with a large number (greater than 25) of parallel measurements between the AMS and an SRM in order to start the **initial** development of the standard. These measurements had been performed with the purpose of evaluating the quality of an AMS in accordance with one of the above-mentioned standards (depending of the scope of each task), rather than developing the new procedure. These parallel measurements covered the following determinands:

- Particulates
- Hydrogen chloride
- Sulphur dioxide
- Nitrogen dioxide
- Oxygen
- Carbon monoxide

The data obtained covered the more common situations, which occur in industrial plants as regards the relationship between the daily emission level and the emission limit values (ELV), which may be summarised as follows:

- The daily emission level is relatively constant and it might be close to or far below the ELV (also known colloquially as the 'cloud' situation);
- The daily emissions are distributed over a broad range compared to the ELV.

In the first case, it is difficult to establish a mathematical relation when comparing the results of parallel measurements between AMS and SRM, from a mathematical point of view (for an illustration see Figure 5.1). In the second case, it is easier to establish a linear relation between the two (for an illustration see Figure 5.2).

Figure 5.1 Small variations in the daily emission levels at an industrial plant.

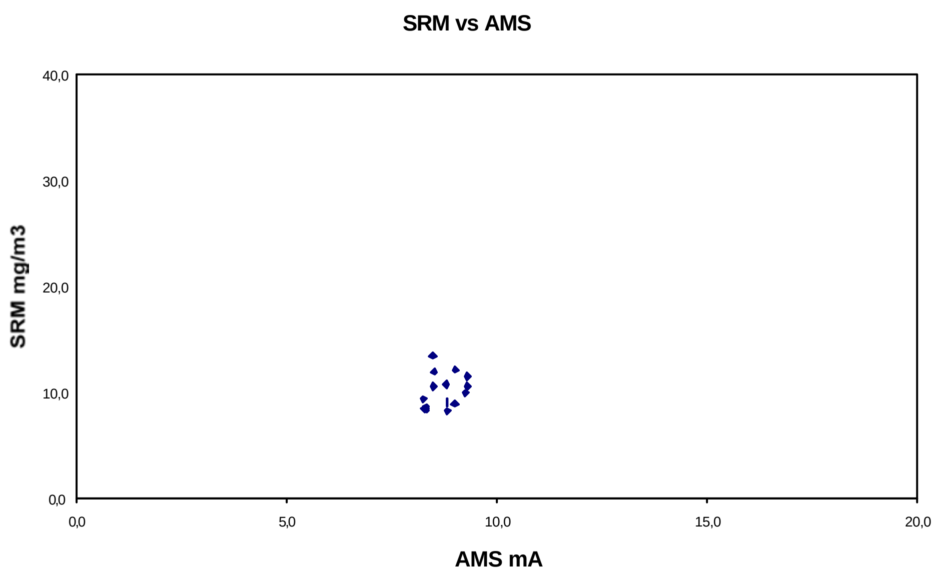
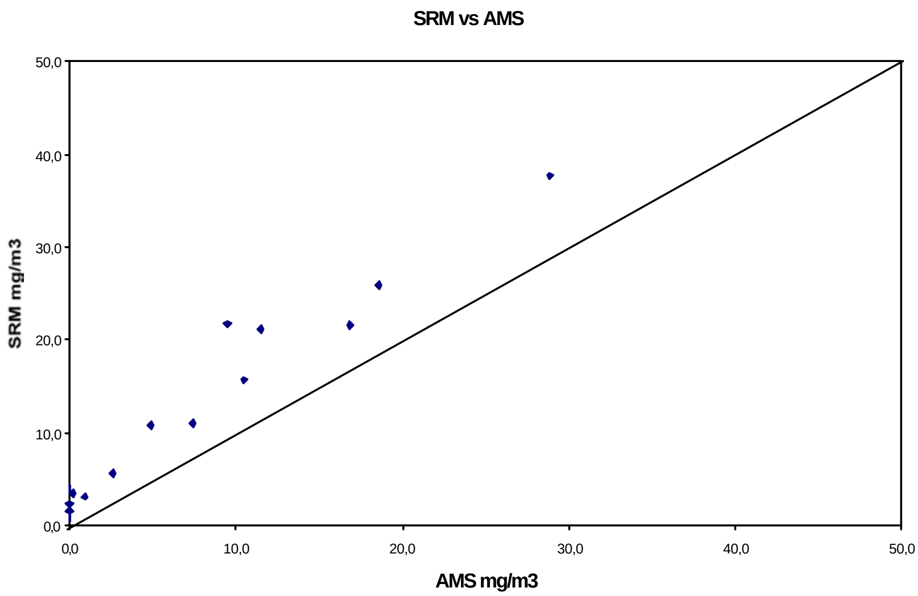


Figure 5.2 Broad variations in the daily emission levels at an industrial plant.



A large number of calculations were carried out using these 25 data sets according to the earlier mentioned four standards. The results obtained were disappointing, since none of the results were unambiguous. They were therefore deemed unsuitable for meeting the requirements of Annex III of the Directive.

It was therefore apparent that additional data was required, and the first sets of field tests were carried out to obtain these. It was decided to perform tests at a Spanish power plant (with high emission levels) and at an English municipal waste incineration plant (with low emission levels). The determinands to be measured are listed in Table 5.1:

Air quality determinands	Power plant	Municipal waste incineration
Carbon monoxide	+	+
Oxygen	+	+
Sulphur dioxide	+	+
Particulate	+	+
Total organic carbon	-	+
Hydrogen chloride	-	+
Nitrogen oxides	+	+

-: no measurement.

Table 5.1 Air quality parameters to be determined in the first field tests.

The measurements and data analyses were performed using appropriate selected CEN or ISO standards.

It was also required that the emissions from the plant were varied as much as possible within its normal operations during the measurements in order to achieve as wide a range of data as possible. The results were evaluated by means of the four standards noted above with the following conclusions:

Four international standards concerning quality assurance of AMS have been tested by means of results from field tests regarding their ability to fulfil the requirements in the draft EU Directive on the combustion of waste. No unambiguous results were obtained from these due partially at least to the issues listed below:

- *Two of the standards (VDI 3950 and ISO 10155) are primarily used to calibrate an AMS by means of reference method measurements, i.e.: SRM µ AMS + a constant. In these standards the objective is to evaluate the quality of the monitor and not to define a new calibration curve. To do this these two tests would have to be used in reverse, i.e.: AMS µ SRM – a constant. If this needs to be done, the concept of using an already well-established standard is invalidated.*
- *One standard (ISO 7935) is used to evaluate the quality of a calibrated AMS. However, the quality requirements in this standard are closely connected to the upper limit of detection of the AMS and the higher this value is, the easier it is for the AMS to pass the tests.*
- *The last standard (ISO 13752) is used to estimate the uncertainty of results obtained by an AMS. However, but it contains no specifications on the quality of the AMS.*

In addition, some of the four standards accepted results that clearly should be rejected and others rejected results that should be accepted, according to the experience of the Working Group.

Therefore it was recommended to that a new test method should be developed, which provides more realistic results, and which is not sensitive to the range of emissions present (eg whether at one level or over a broad interval), and which is able to meet the requirements of Annex III of the Directive, independently of whether the daily emission level is close to the emission limit value or far below it .

The Working Group had difficulties developing methods due to, for example, the following:

- It was difficult to transform the requirements of Annex III of the Directive (*the 95% confidence intervals of a single measured result)* to statistical sound and operational procedures of the AMS;
- The concentrations measured by an AMS are often at a low level compared to the ELV. In this case, the Group discussed candidate procedures on how to extrapolate downwards from the ELV to these lower emission levels.

A proposal was presented as to how to calculate when an AMS could be accepted according to the requirements of 95% confidence interval in Annex III. The group had serious considerations on whether the procedure should also involve the calibration of the AMS, at least to some extent.

It was, therefore, decided to (temporarily) establish an ad-hoc group of statistical experts and some members from the Working Group to address these problems. The ad-hoc group had the following terms of reference:

- to provide a procedure on how to check the suitability of the installation of an AMS and its compliance with Annex III of the Directive;
- to propose an interpretation of the text in Annex III.

The ad-hoc group recommended that a calibration function should be used to establish the relationship between the readings of the AMS and the SRM - in order to calibrate the measurements made by the AMS. This calibration function should be determined by an ordinary least-squares method (ISO 11095 or VDI 3950), and be based on data obtained during normal operations of the plant. Furthermore this calibration function should only be valid inside the range that calibration took pace (plus an extension of 10% relative beyond the highest and lowest values).

The ad-hoc group presented a method, where the following steps can be used to calibrate the AMS and to check the compliance of its measurements with the requirements of the Directive:

1. Carry out measurements simultaneously of the AMS versus SRM;
2. Calculate a calibration function for the AMS;
3. Calibrate the AMS using this function;
4. Test for variability (ie test compliance with Annex III of the Directive).

The calibration of the AMS removes any bias (also called systematic error) if present. (However, this is not normally the case, as the AMS will provide output readings in electrical units, which are converted by the calibration into concentration units). The test for variability is then a statistical test (ordinary χ^2-test) and not only a comparison of the results obtained using the AMS and the SRM. This χ^2-test is used in other standards, for example ISO 5725 “Accuracy (trueness and precision) of measurement methods and results” to control precision (with a β-value of 50%). This β-value means that the probability of accepting a poor AMS, close to the accepted quality, is 50%.

Defining this β-value provoked many discussions within the Working Group. On the one hand the smaller the β-value the more rigorous the test, but on the other hand, more experimental data is then required for the test. These discussions took place partly because everybody wanted the test to be as rigorous as possible but within practicality, and partly because this way of thinking was new to many of the members of the Working Group. This β-value is not used directly in any other known national or international standards. It is, however, included indirectly in other standards. However, by not specifically defining a β-value for a χ^2 test, this by default results in a value of 50%. For various reasons the Group therefore decided on a value of 50% for the β-value. Defining a lower β-value, e.g. 25% gives better possibility of finding bad performing AMS, whereas the requirement to a good performing AMS is not increased.

This new method for the test for variability was applied to the previous data obtained from the first field tests and the results were satisfactory. The method accepted an AMS that from experience should be accepted, and rejected similarly those, which it was felt, should be rejected. This new method therefore gave reasonable results, in comparison to the four standards previously mentioned. Examples from the comparison of results obtained by the selected standards (those having requirements to the quality of the result) and the new procedure is given in Table 5.2.

Plant	Determinand	ISO 7935[1]	ISO 10155[2]	"QAL 2 procedure"[3]	WG remarks
Power Plant	Particulate	Reject	Accept	Accept	Accept
	NO_x manual	Accept	Reject	Accept	Accept
	NO_x automated	Accept	Accept	Accept	Accept
	SO_2	Accept	Reject	Accept	Accept
Municipal Solid Waste Plant	NO_x manual	Reject	Accept	Reject	Reject
	$NO_x > 150$ mg/m^3	Reject	Reject	Reject	Reject
	SO_2		Reject	Reject	Reject
	HCl	Reject	Reject	Reject	Reject
	CO	Reject	Reject	Reject	Reject
	CO < 100 mg/m^3	Accept	Reject	Reject	Accept

1. Quality demands for integral performance and systematic error related to upper limit of AMS
2. Quality demand for correlation coefficient > 0,95 based linear regression by Least Squares Method
3. β-value of 25 and 50% (gives same result)

Table 5.2 Comparison of results obtained by selected standards and the new QAL2 procedure on data from first field tests.

The Working Group decided to begin a second set of field tests. The focus of these was on the validation of the QAL 2 procedure, i.e. the establishment of the calibration function and the performance of the variability test. This second set of field tests would again have to be carried out at normal operating conditions, but with as much variability in the measured results as possible.

The second set of field tests were therefore implemented so as to demonstrate the ability of the procedures in the standard to fulfil the required objectives. Measurements were performed at an Italian power plant and at a Danish municipal waste incineration plant. These measurements were performed in accordance with this newly developed procedure, which requires fifteen sets of parallel measurements evenly distributed over three working days. In addition, to obtain more information the second set of field tests were carried out with thirty sets (2 x 15) over those three days. The air quality determinands listed in Table 5.3 were measured:

Air quality determinand	Power plant	Municipal waste incineration
Carbon oxide	+	+
Oxygen	+	+
Sulphur dioxide	+	+
Particulate	+	+
Water vapour	-	+
Hydrogen chloride	-	+
Nitrogen oxides	+	+

-: no measurement.

Table 5.3 Air quality parameters to be determined in second field tests.

The results of these field tests were good and the specified procedure worked convincingly. For example, AMSs that performed well were accepted, and those which performed poorly were rejected. The Working Group therefore decided that the objectives required of this procedure were achieved.

The final QAL 2 procedure consists of the calibration of the AMS by 15 sets of parallel measurements with an SRM and subsequently a test for variability. The calibration function is linear and it has a constant residual deviation and it is calculated by:

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

where $\hat{y}_i$ is the calibrated value of the AMS, using the AMS signal, x_i.

α and β is calculated by means of the following relation:

$$y_i = a + b \cdot x_i + e_i$$

where

- x_i is the i^{th} result of the AMS; i=1, …, N; N ≥15
- y_i is the i^{th} result of the SRM; i=1, …, N; N ≥15
- ε_i is the deviation between y_i and the expected value
- α is the intercept of the calibration function
- β is the slope of the calibration function

$$\overline{AMS} = \bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$$

$$\overline{SRM} = \bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i$$

If $y_{max} - y_{min}$ is < 15% of the ELV, then:

$$\hat{a} = \frac{\overline{y}}{\overline{x}}$$

$$\hat{a} = 0$$

If $y_{max} - y_{min}$ is ≥ 15% of the ELV, then:

$$\hat{a} = \frac{\sum_{i=1}^{N}(x_i - \overline{x})(y_i - \overline{y})}{\sum_{n=1}^{N}(x_i - \overline{x})^2}$$

$$\hat{a} = \overline{y} - \hat{a} \cdot \overline{x}$$

The calibration shall be based on SRM results in a concentration unit (e.g. ppm or mg/m^3), while the results from the AMS can be either a signal (e.g. mA or Volt) or a concentration unit (e.g. ppm or mg/m^3).

The test for variability is performed on the calibrated AMS values. The AMS passes the variability test when:

$$s_D \leq \sigma_0 * k_v$$

σ_0 is given as the required uncertainty by the Authorities. The values of k_v depends on the number of parallel measurements.

And the variability s_D is given by:

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

$$D_i = y_i - \hat{y}_i$$

The QAL2 procedure should be carried out each time a (new or repaired) AMS is installed at a plant. It is also a requirement that it is repeated every five years. In the time between, provided the calibration function remains valid, it shall be used to calculate the emissions of the plant. The validity of this calibration function is checked each year using the AST procedure. A new QAL2 must, however, be performed if there are major changes in operation of the plant, or if the AST procedure results in a decision that the AMS is not performing satisfactorily.

The QAL2 procedure, as well as the AST procedure, is based on tests between an AMS and an SRM, which must be performed by an independent organisation.

6. PROGRESS ON THE QAL3 PROCEDURE

The procedures of QAL3 were defined in parallel with the development of the QAL2 procedure. The main aim of the QAL3 procedure is to ensure that the quality of the AMS remains without specifications during its ongoing operation between annual tests. The plant operators themselves will do this work. It is intended that this procedure should start after the installation of the AMS on the plant, and not later than when any reports to the authorities are required on measurements obtained by the AMS .

The quality assurance of the AMS during operations involves frequent automatic or manual checks of the signal at a zero level and a span level. The span level check is typically approximately 80% of the emission limit value (ELV). Where possible the plant operators should record the signals at those two levels in a logbook. This can clearly be done for a manually-controlled AMS, but not for those that are fully automatic. In connection with the manual control of zero and span, the plant operators may need to adjust the monitor to a correct level. Today the work done in connection with these controls is seldom used by the plant operator to evaluate the quality or any change in the quality of the AMS.

The Working Group needed to define a procedure, which provided data on the ongoing performance of the AMS. However, it was felt that this procedure should also be valuable to operators in optimising the quality assurance procedures at their plants. No national or international standards were found on this subject. From the beginning the Working Group therefore decided, that they wanted to develop a procedure that was based on valid statistical methods on quality assurance from the fields of chemical and laboratory analysis. It was also decided that the procedure should be fairly simple to use or, if that could not be fulfilled, that simple spreadsheets should be made available.

The scope of the QAL3 procedure is therefore in summary to:

- Perform quality assurance of the AMS during its ongoing operation;
- Control both the random error (the precision) and the systematic error (the drift);
- Decide when the AMS is outside its normal operating performance – i.e. it is out of control;
- Lay down rules for when and how to adjust an AMS when it is judged to be “out of control”.

The decision on when the AMS is ‘out of control’ will be derived from information obtained during the zero and span checks compared to that from the QAL1 procedure in order to assess the performance characteristics of the AMS at that time on the plant. It should be noted that the QAL1 procedure assesses the zero span repeatability by the use of repeated zero and span checks. As noted previously, the QAL1 procedure is not a part of this standard. It is described in EN-ISO 14956: “Air quality - Determination of minimum requirements of air quality measuring instruments”. The uncertainty of the AMS is determined by means of the standard deviation determined by tests performed on the AMS before it is supplied to the plant operator.

The Working Group discussed how to use this data. In analytical laboratories control charts are used regularly to quality-control of analyses, and to determine the uncertainty of the results obtained by those analyses. It was therefore an appropriate choice to review the possibility of using control charts for the QAL3 procedure.

Several types of statistical control charts exist. These are used to compare a measurable figure obtained at a given time in an analysis with stated control limits calculated with a specified probability. They are based on a number of independent samples. Certain control charts are very simple and test the result of an analysis of one parameter. An example of this involves the deviations of the samples from the mean value, and the control limits may then be defined as plus/minus the standard deviation multiplied by a factor of 2 or 3 to give an appropriate probability factor. Other control charts are more sophisticated and use information from previous samples. In these latter cases, it is possible to detect normal changes in the test parameter and to give estimates of when the changes occurred. Those control charts with built in memory are capable of determining, for instance, systematic deviations from the mean value.

The Working Group agreed upon that the QAL3 procedure should be based on an “intelligent” control chart, and that there would only be one sample for each measurement (i.e. the zero and span checks were not repeated for each sample). For this reason the CUSUM[3] MS[4]-chart procedure was selected. An important parameter of this control chart the average run length (ARL), which is the average number of samples, which are taken before an out-of-control signal can be detected.

The calculations involved in this procedure are, however, rather complex. To overcome this a spreadsheet was prepared for testing and for further development of the procedure, and the factors involved (ARL and others) were included in it. The Working Group decided to take certain fixed values for the ARL and other preset values in order to keep the procedures as simple as possible.

Some members from the Working Group provided data to assess the span and zero control of the AMS using the CUSUM procedure. However, this data was difficult to use since adjustments had been done each time the AMS was judged to be ‘out-of-control’ - in line with the normal operating procedures of some industrial plant.

Instead, therefore, when the first field tests were carried out, the Spanish power plant and the United Kingdom municipal waste incineration plant were asked to perform the CUSUM procedure for all the AMSs under evaluation. (Details of the air quality determinands included in these field tests are given in Section 7 of this paper).

These two sets of field tests revealed that there were certain problems with this new procedure as follows:

- It was difficult to persuade the staff on the plants to use the QAL3 procedure. This was because the procedure requires the use of a personal computer (PC) simultaneously with the tests of the zero and span of the AMS. However, this test of zero and span is typically performed on the stack, whereas a PC is normally held in an office. The operator could in principle bring a PC onto the stack or alternatively the operator could perform the zero and span check on the stack, and then move to the PC to calculate whether adjustments could be carried out;
- The QAL3 procedure is time consuming for plant operators;
- The UK plant was not able to adjust their AMS since they had contract with the instrument supplier to do this, which included maintenance.

However, the Working Group believe that these tests are important and thus it was proposed that:

- *The benefits of the QAL3 procedure should be stated in the standard so as to motivate the plant operators to use it;*
- *Paper forms would be made available based on the spreadsheets to be used on the stack, when a PC is not accessible. This form should be used in advance to calculate the upper and lower limits in order to define when to adjust the AMS;*
- *The instrument shall be checked for precision first and then for drift;*
- *If a drift is detected for the zero or for the span value both shall be adjusted due to their mutual influence;*
- *The QAL3 procedure was satisfactory in broad outline. However, minor details still need to be defined;*
- *Calculations of the influences of changes in the ARL and other factors in the procedure should be performed;*
- *The CUSUM MS-chart was suitable for detection of the precision of an AMS while only taking one sample at the time;*

[3] CUmulative SUM control charts
[4] MS means moving standard deviation

- *No further field tests were needed for the evaluation of this procedure. The CUSUM MS-chart fulfils the aims of the procedure.*

One of the most important constants in the CUSUM MS-chart is to determine the ARL for:

- Either false alarms, i.e. the average number of readings for which it is accepted that the AMS is judged out of control without being so, which equals the acceptable number of readings between a false alarm result;
- Or number of readings until it is detected that the AMS is "out of control", in the case that it is just "out of control".

The Working Group decided, that the first condition should be used, i.e. the false alarm, and that for the drift this ARL factor should be 50 readings and for the precision it should be 100 readings.

The second important factor to determine, before using the QAL3 procedure, is the uncertainty of the AMS under controlled conditions, expressed as the standard deviation. This preset value is neede to determine the "out-of-control" level. In this context, the procedure in the standard gives guidance on how to use the relevant information obtained during the QAL1 procedure.

In addition, besides giving a statistical procedure on how to ensure the quality of an AMS, based on regular readings of zero and span checks, it also gives instructions on how much to adjust an AMS that is judged "out of control". This adjustment is defined so that the correction factor of 0.7 of the drift is applied, in order not to over adjust the AMS.

7. PROGRESS ON THE AST PROCEDURE

When the Working Group begin its activities, this annual surveillance test (AST) procedure was not included in its terms of reference. However, as the Directive for the incineration of waste evolved, the requirement for a yearly procedure for the evaluation of the quality of the AMS became clear.

The main aims of the AST procedure is are therefore to:

- Verify that the AMS still operates in the same way as expected by the operator, to fulfil legislative or other requirements;
- Ensure that the calibration function determined in connection with the last QAL2 procedure remain valid;
- Ensure that no significant changes in performance had occurred since the last QAL2 validation.

The wording in the Draft to Directive of the European Parliament and Council on the incineration of waste has changed during the past years. When the AST-procedure was defined, the requirement to the AST in article 10.3 in the directive was:

"The appropriate installation and the functioning of the automated monitoring equipment for emissions into air shall be subject to control by means of parallel measurements with reference methods at least once a year"

When the Working Group included the AST procedure in the terms of reference it was initially decided to use existing international or national standards where possible, and at that time the requirement of parallel measurements with an SRM was not included.

The first requirement of an AST procedure in the Directive included, for example, visual inspection of the AMS, determination of interference from other emissions etc. Certain German standards include such a test, for instance VDI 3950. The Working Group therefore used part of this German procedure in the AST procedure.

When the first field tests were carried out, two test-houses were asked to perform the AST-procedure twice, once at the beginning and once at the end of the field tests. (The first set of field tests were carried out on a Spanish power plant and an UK municipal waste incineration plant and further details of the air quality determinands included in these field tests are given in Section 5.of this paper).

The conclusions from these field tests regarding the AST procedure were:

- *The AST procedure is essential, since it identifies features of the AMS which can influence the quality of the data produced;*
- *Long response times for some determinands resulted in long times required to carry out the procedure;*
- *The cost of an AST procedure could be reduced if an automatic gas concentration blender was to be authorised for use when carrying out linearity tests;*
- *The time for carrying out an AST procedure is longer than anticipated;*
- *Nevertheless, there is a need for this reduced QAL2 procedure to be applied each year.*

During this field-test the wordings in the draft Directive changed, which caused the requirement for parallel measurements with an SRM. Therefore, to some extent this new requirement of the parallel measurements with an SRM was included in the field tests.

Based on these experiences, and the extended requirements in the draft Directive the Working Group decided that:

- The parallel measurements with an SRM in the AST procedure shall be performed using appropriate selected CEN or ISO standards;
- The linearity shall be checked by means of test gasses;
- The parallel measurements with an SRM shall be a limited version of the QAL2 procedure.

The AST procedure was finally completed at the same time as the QAL2 procedure.

The AST procedure is carried out among other things to verify the calibration function is still valid and that the precision of the AMS is still within required limits. SRM and AMS base the verification on minimum 5 measurements. The calibrated AMS values are calculated from the AMS readings using the calculation function established by the latest QAL2 procedure. And the variability s_D is calculated by:

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

where

$$D_i = y_i - \hat{y}_i \quad \text{for all data sets}$$

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

The variability is accepted if:

$$s_D \leq 1.5 * \sigma_0 * k_v$$

σ_0 is given as the required uncertainty by the Authorities. The values of k_v depends on the number of parallel measurements.

8. SUMMARY

Working Group 9 within the CEN Technical Committee 264 developed a new standard on “Quality assurance of Automated measuring systems” for stationary emission sources. It is based on well-known and sound statistical methods, although some of these had not previously been used in the field of industrial emission measurements.

The standard covers the installation, calibration, and the ongoing maintenance and quality assurance of an AMS performed both by independent organisations and the plant owners. The standard will cover procedures that ensure compliance with Directives of the European Parliament and Council on emissions from waste incineration and combustion plants.

The working methodology, which led to the procedures now specified in the standard, involved theoretical considerations and experiences gained from field tests. The iterative procedure and the discussions carried out in the Working Group are described in this paper, and examples of the individual steps are also presented.

The standard is based on four quality levels (QAL):

1. QAL1- A Suitability evaluation of the AMS and its measuring procedure (not included in this CEN standard as it is being drafted separately as a dual ISO/EN Standard by ISO Technical Committee 146 Sub-committee 4).
2. QAL2 – Quality assurance of the installation. This entails validation of the AMS by means of linear calibration by using an SRM. The authorities’ requirements regarding variability are fulfilled are demonstrated using an ordinary χ^2-test.
3. QAL3 - Ongoing quality assurance during operation. This entails quality control of random errors (precision) and systematic errors (drift) using CUSUM MS (control) charts. Rules for when and how to adjust an AMS are also given.
4. AST – Annual surveillance test. This entails verification that no significant changes have occurred in the performance of the AMS, and by means of comparisons with results of the QAL2 procedure, this verifies that the calibration function is valid and that the AMS continues to fulfil the authorities’ requirements.

During spring 2001 the standard will be sent for voting on by national standardisation bodies in the European Union member states. The standard will, once adopted, be mandatory within the legislation of each member country.

9. REFERENCES

WI 00264014 “Stationary source emissions – Quality assurance of automated measuring systems.

10. BIOGRAFICAL DETAILS OF THE AUTHOR

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After graduating from the Technical University in Denmark in 1983 with a Master of Science degree in chemistry, Geertinger spent a couple of years carrying out scientific work on enhanced oil recovery at the Technical University in Denmark. Geertinger joined dk-TEKNIK in 1986 where she has been employed with air quality, emissions from combustion, quality assurance of manual and automated emission measuring systems. Geertinger has been a member of CEN TC 264/WG 9 since 1996, and she has performed the (mathematical) tests of the standards and procedures involved in the development of the procedures in the standard.