Agency Requirements for applying measurement uncertainty (MU) to periodic air monitoring

OVERVIEW

The aim of this short guidance is to outline how measurement uncertainty may be calculated and applied for periodic monitoring. The determination of measurement uncertainty (MU) involves a number of aspects:

1. Defining measurement uncertainty
2. The calculation of measurement uncertainty
3. The application of measurement uncertainty
4. Assessing compliance with the ELV

1. What is Measurement Uncertainty

All measurements, particularly those associated with dynamic processes such as stack emissions, are subject to an inherent doubt as to their absolute value due to the combination of individual factors associated with the many variables involved in the sampling and analysis procedure. This *Uncertainty of Measurement* may be defined as the range of values within which the "true" value of any measurement could be expected to lie with a given statistical confidence.

It should be stressed that the "true" value is a conceptual term, as it can never be exactly measured (without uncertainty) however the goal of any monitoring is to quantify any uncertainty such that the results can be properly interpreted. It is important to be able to show that the measured value is "fit for purpose" by taking account of the Uncertainty of Measurement and assessing its impact on the likelihood of non-compliance. A value of 6.5 mg/Nm^3 alone gives no indication of the range of possible concentrations. It is simply a number in isolation whereas 6.5 ± 0.5mg/Nm^3 clearly defines the range of possible concentrations. This latter value plus its uncertainty of measurement implies that the "true" concentration would be likely to lie within the range 6.0 – 7.0 mg/Nm^3 with a defined degree of confidence (typically 95%). The nature of the factors contributing to the uncertainty is such that it is not justifiable to say the concentration is certain to be in the range 6.0 – 7.0 mg/m^3. However if the uncertainty of 0.5 mg m^3 was calculated with a level of confidence of 95% then it can be assumed that 95 times out of 100 the result would be within those bounds. This enables regulatory bodies to interpret measurements and their uncertainties with respect to limit values and issues regarding demonstration of compliance.

2. The Calculation of Measurement Uncertainty

A generic approach to uncertainty calculation is described in the Guide to the Expression of Uncertainty in Measurement[1] (GUM). This document describes a procedure in which individual uncertainty sources are identified, quantified and combined to provide the measurement uncertainty. This approach is often described as a bottom-up approach. There is another technique for determining the uncertainty of a measurement, which is to repeat the measurement a number of times, compare with a SRM, and examine the spread of the results, known as a top-down approach. This has often been used to characterise measurement methods, by performing large-scale inter-laboratory studies to determine the repeatability and reproducibility of methods.

It is sometimes assumed that these two approaches are mutually exclusive. However, if the GUM approach is followed it is possible to include all significant component uncertainties. Additional uncertainty sources may be combined, for example those not covered in a method evaluation. The GUM approach should therefore be used as the most general method. The steps that should be taken are:

- review the measurement method and identify potential sources of uncertainty;
- quantify the significant sources of uncertainty;
- combine the uncertainty components and expand to give required level of confidence;
- report the measurement uncertainty with the measurement result.

Further information on the calculation of measurement uncertainty is outlined in the EA 'Technical Guidance Note (M2), available at http://publications.environment-agency.gov.uk/PDF/GEHO1211BVWU-E-E.pdf

In addition, the Source Testing Association (STA) has produced a guidance note for members 'Guidance on Assessing Measurement Uncertainty in Stack Monitoring' with associated excel spreadsheets for calculating uncertainty, available at www.s-t-a.org It is important that where this approach is used, that it should be consistent with the GUM approach outlined above.

3. The Application of Measurement Uncertainty

In the case of licences falling under the Waste Incineration Directive (WID), or the Large Combustion Plant Directive Directive (LCPD), the maximum allowable uncertainty for each parameter is set out in the IPPC license but this applies to continuous emission monitoring systems (CEMs) only (e.g. 30% uncertainty for particulate measurement, 20% for SO_2 and 40% for HCl). The EPA has a policy on the application of measurement uncertainty to CEMS which is available on the EPA website at: http://www.epa.ie/downloads/advice/air/emissions/name,33701,en.html

[1] Guide to the expression of uncertainty in analytical measurement, ISO, Geneva, 1995.

In the case of all periodic monitoring, results for measurement uncertainty should be included with the reported result. A list of maximum measurement uncertainties is outlined in Appendix 1. Uncertainty measurements are usually written in the form of +/- x mg/m^3 and should be reported at a 95% confidence level. This quantifies the probability that the true value lies within the region defined by the confidence interval.

95% Confidence Intervals: The uncertainty budget can be viewed as an allowable margin of error in the measurement, as a combination of the systematic and random errors. The systematic error is a measure of the 'bias' of the method used[2], whilst the random error can be seen as a measure of the precision of the measurements. The 95% confidence interval encompasses approximately two standard deviations of the measurement either side of the mean average value. This is known as the expanded uncertainty, whereas the standard uncertainty is one standard deviation.

4. Assessing compliance with the ELV

Air emission reports tend to report the monitoring result next to the appropriate ELV for comparison purposes. From this it can be determined if the ELV has been exceeded. However, the licensee should also check the ELV in the licence itself, including any technical amendments to the licence, together with any specific interpretation conditions. The results should always be reported as measured, i.e. without any subtraction of the measurement uncertainty, and where the measured value is above the ELV such occurrences should be reported to the EPA as an incident.

If a reported result is above the ELV, the Agency will assess the results for compliance and may take account of its measurement uncertainty. This is achieved by subtracting the measurement uncertainty from the measured value (as below).

1. Determine the measurement uncertainty:

    measurement uncertainty = (measured value x % uncertainty) / 100

Note: the measured value should be already corrected to the licence reporting conditions.

2. Adjust the measured result by subtracting the measurement uncertainty:

    Adjusted value = measured value – measurement uncertainty.

3. Compare the adjusted data versus the appropriate emission limit value to assess compliance.

[2] The terms repeatability and reproducibility may also be encountered as properties of a measurement method.

Example calculation:

Based on a measured value for particulates of 11 mg/m^3 (at STP corrected for O_2, and moisture) a measurement uncertainty of 15% and an ELV of 10mg/m^3.

Following the procedure above:

1. (11 x 15) / 100 = 1.65 mg/m^3 measurement uncertainty
2. 11 – 1.65 = 9.35 mg/m^3 adjusted value
3. Adjusted value is less than the ELV, therefore the measured value may be classified as an approach to limit rather than a breach.

Note 1: the measurement uncertainty is the expanded uncertainty at a 95% confidence interval.

Note 2: An 'approach to limit' is a value that on the initial assessment may be higher than the ELV, but following an adjustment for the measurement uncertainty the amended value is lower than the ELV. It should be reported as an incident, and the adjusted figure must then be assessed by the relevant OEE inspector (using the guidance above).

Appendix 1: Deriving Maximum Uncertainties

The following measurement uncertainties are the **maximum** uncertainties acceptable by the EPA to assess compliance of periodic measurement results against emission limit values specified in IPPC & Waste licences.

Normally the Agency will use the uncertainty values reported by the organisation that carried out the measurement. However, the quoted uncertainties should not be above the maximum values outlined below, as otherwise the result will not be accepted unless there is an adequate explanation provided. Measurement uncertainty calculations should be available for inspection if required.

Table 1: Maximum measurement uncertainties (MU) for periodic monitoring

Species	% uncertainty	MU source
TPM	±15	Measurement uncertainty half the value given in directives for continuous emissions monitoring systems.
TOC	±15	
HCl	±30	BS EN 1911
CO	±6	BS EN 15058
NOx	±10	BS EN 14792
SO_2	±20	BS EN 14791
HF	±30	Given the same uncertainty as HCl due to similar reactive nature and measurement technique
NH_3	±30	
Dioxins and furans / PCBs	±30	BS EN 1948
Speciated VOCs	±25	Value based on information in EN 13649 and a review of uncertainties applied by monitoring organisations
O_2	±6	BS EN 14789
H_2O	±20	BS EN 14790

Note: These figures are taken from the UK M2 Guidance Note ‘Monitoring of Stack emissions to Air’.

The values in Table 1 are the measurement uncertainties on the final result corrected to reference conditions (i.e. the reporting conditions required by the licence). These uncertainties therefore combine both the uncertainty from the measurement method, and any additional uncertainties from associated peripheral measurements used for correcting the result to reference conditions.

Appendix 2: Rounding and Significant Figures

Emission data should be interpreted to one digit more than the ELV value.

- For example an ELV of 20mg/m^3 would need reporting to 20.0mg/m^3 or an ELV of 0.1mg/m^3 would need reporting to at least 0.10mg/m^3.

The need to determine the correct rounded figure is a function of the monitoring programme and is required for all monitoring, but is particularly relevant where the monitoring result is very close to the ELV.

For example, where a monitoring result of 20.512 mg/m^3 is being compared to an ELV of 20 mg/m^3, the following will hold.

- The last significant figure of the monitoring result is the 5 (20.$\underline{5}$12 mg/m^3) and the first insignificant figure is 1 (20.5$\underline{1}$2 mg/m^3). As the first insignificant figure is 1 the monitoring result is rounded to 20.5mg/m$^{3.}$ The specified measurement uncertainty (ex. 15%) may then be taken account of, and in this particular case (20.5 – 3.1 = 17.4 mg/m^3) the ELV of 20mg/m^3 may not have been exceeded, but as the standard measured result exceeded the ELV it should be reported to the EPA for assessment as an incident.