Quality Assurance of Continuous Emission Monitoring Systems: A practitioner's guide/technical report

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Abstract

In 2004, the National Environmental Management Act (NEMA) and regulations were promulgated and by 2010 were gazetted into law for the first time in South Africa. Under the NEMA, the Air Quality Act 39 of 2004 (AQA) was promulgated and included priority pollutants identified by the Department of Environmental Affairs (DEA) as having or may have a significant detrimental effect on the environment, including health, social conditions, economic conditions, ecological conditions or cultural heritage. In this context continuous emission monitoring of emissions to air is a requirement under many of the operators as Air Emission Licenses (AEL) issued under section 21 of AQA. The quality of data obtained from continuous emission monitors is ensured by the inclusion of the BS EN14181:2004 (revised standard updated to current BS EN14181:2014) European standard which has been adopted into the South African legislation for this purpose.With this in mind the purpose of this technical paper is to provide an overview of the current status of automated measuring systems (AMS)/continuous emission monitors(CEMs) currently in use by industry to monitor emissions in South Africa, in terms of compliance with relevant emission limit values (ELVs) and the current challenges faced with ensuring the quality and reliability of the data obtained.

Keywords

CEMS/AMS, EN14181, TGN-M20, QAL1, 2 and 3

Introduction

In South Africa, there are currently no "South African" standards that have been developed for monitoring emissions to air. Instead the regulator has opted to adopt international best practise by utilising internationally recognised methods for air emissions monitoring and sampling.

Methods that have been adopted:

- European Committee for Standardization (CEN)
  - European EN Standards
- Environmental Protection Agency
  - USEPA Methods
- British Standards Institute (BSI)
  - British Standards
- International Standards Organization (ISO)
  - ISO Methods

Although these methods and standards have been adopted and widely utilised internationally the wholesale adoption of the standards without due consideration for the South African context is naïve and not without problems when it comes to the practical implementation of the standards or methods locally. It is for this reason that it is recommended that a review of the methods currently being utilised be conducted to ensure their relevance and applicability to the South African context.

One of the major shortcomings of the current legislation is the lack of a hierarchy of appropriate methods as per the United Kingdom Environment Agency Technical Guidance Note (TGN) M2 "Monitoring of stack emissions to air" This TGN describes the UK Environment agencies overall approach to stack-emission monitoring and provides guidance on methods used for regulatory purposes. It focuses on areas where practical guidance is necessary. This includes:

- The legislative framework
- The role of MCERTS (UK monitoring certification scheme for stack emission monitoring)
- Different approaches to stack emission monitoring
- Sampling strategy
- The hierarchy of different methods
- An index of monitoring methods

South Africa is currently in the unfortunate position that it has adopted many internationally recognized methods for sampling without any supplementary documentation with relevant practical guidance tailored to the South African context. The regulator will need to develop similar guidance as discussed here if it wishes to ensure quality and consistency of emission reporting throughout the country and across the industry as a whole.

When it comes to applying BS EN14181 the UK Environment agency has development TGN M20 “Quality assurance of continuous emission monitoring systems –application of EN14181 and BS EN 13284-2”. The primary role of this technical guidance note is to provide guidance on the application of European standard “BS EN14181:2014, Stationary source emissions – Quality assurance of automated measuring systems”.

It is important to note that the above standard utilises the term automated measuring systems (AMS) instead of continuous emission monitors (CEMs) however the terms are interchangeable and refer to the same concept. The guide summarizes the requirements of BS EN14181 and BS EN 13284-2 and provides guidance on how to perform each of the required tasks. It is important to remember that the TGN should always be read in conjunction with these standards and the relevant method implementation documentation. The development of equivalent South African TGN documents is therefore critical to ensure proper guidance and implementation is carried out where required.

Regulatory framework and standards for monitoring

It is important to note that up until June 2015 the BS EN14181 standard was applicable to all plants that fell under the European directives for the incineration of waste (WID) and large combustion plants (LCPD). Since June this year these two directives have been replaced by the Integrated Emission Directive (IED). Why is this important? It is important to note that these standards are not developed in a vacuum and supporting documentation such as the directives mentioned above are critical in assessing the applicability of methods and emission limit values etc. For example the monitoring of emissions to air for plants that fall under one of the directives need to be conducted according to the requirements of CEN, ISO or BS standards or applicable alternative method.

The TGN M2 document contains a table of approved methods with a hierarchy of methods that are applicable. In addition to the index of monitoring methods the directives specify the requirements for monitoring accuracy and precision through 95% confidence intervals. South Africa does not currently have any equivalent document. This needs to be developed in order to ensure that BS EN 14181 can be practically implemented in its entirety, without such guidance is a near impossible feat without adopting directives from other countries.

Scope and structure of BS EN14181

BS EN 14181 applies only to CEMs used for compliance monitoring and permanently installed IED installations. It does not apply to portable CEMs units or installations outside of the directives. South Africa needs its own similar directives for its industrial processes in order to ensure the correct applicability of EN14181. EN14181 specifies three quality assurance levels (QALs) and an annual surveillance test (AST) referred to as QAL1, QAL2, QAL3 and AST respectively (Figure 1).

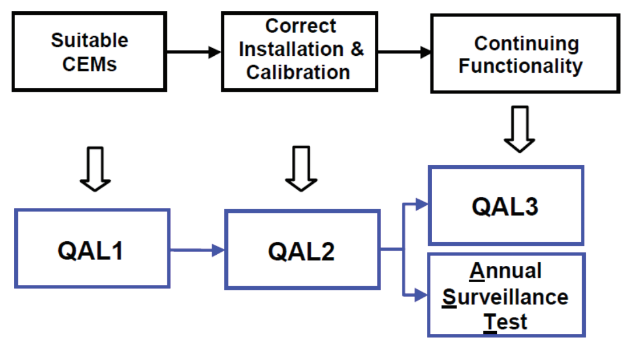

***Figure 1**: Schematic of Quality Assurance Levels*

QAL 1 – Specifies a procedure to demonstrate that the CEM is suitable for the intended purpose before installation, by meeting the required performance standards and the uncertainty allowances specified by the IED. This is difficult to demonstrate in South Africa without an equivalent directive being formally developed or adopted.

The first level of quality demonstrates the potential suitability of the CEM before it is installed on a stack. In England and Wales MCERTS product certification at an appropriate certification range is taken as evidence of compliance with the QAL 1 requirements. CEMs must meet certain performance requirements evaluated under the UK Environmental Agency’s monitoring certification scheme MCERTS. Once the CEM has been installed the unit must have means for tests for linearity, zero and span drift and leak checking the entire system. The IED also specifies uncertainty allowances expressed as 95% confidence intervals. Table 1 details Baseline Ranges, ELV’s and uncertainties.

Criteria in determining the suitability of CEMs:

- CEMs to be MCERTS certified for the determinants specified
- CEMs to be certified for the range it is to be utilised for
- Operator to ensure that the specific plant conditions will not reduce the performance of the CEM
- All CEMs must have provision that allow for zero, span and linearity checks to be performed
- Certification range is the lowest range over which MCERTS requirements are met
- The range would typically be set at a value at least twice the half hourly ELV of the intended application.

QAL 2 – Specifies a procedure to calibrate the CEM once it has been installed using standard reference methods (SRMs) and then verifying the required uncertainty allowances once installed. It is important to note that South Africa has not established its own uncertainty allowances as required by the standard or applicable directive.

The CEM instrument is calibrated using SRM parallel

***Table 1**: Selection of daily average ELV's including certification ranges and allowable uncertainties*

	ELV, $mg.m^3$	Certification range, $mg.m^{-3}$	Allowable uncertainty, %	Allowable uncertainty, $mg.m^{-3}$
NOx – incineration	200	300	20%	40
NOx – large combustion plant, solid/liquid fuel	200 - 600	500 - 1500	20%	40 – 120
NOx – large combustion plant, gaseous fuels	200 - 300	500 - 750	20%	40 – 60
NOx – large combustion plant, gas turbines	50 - 120	125 - 300	20%	10 – 24
SO_2 – large combustion plant, solid/liquid fuel	200 - 850	500 - 2125	20%	40 – 170
SO_2 – large combustion plant, gaseous fuels	35-800	88 - 2000	20%	7 – 160
SO_2 – incineration	50	75	20%	10
CO – incineration	50	75	10%	5
HCl – incineration	10	15	40%	4
Particulate matter, large combustion plant	30 - 50	75 - 125	30%	9 - 15
Particulate matter, incineration	10	15	30%	3
Particulate matter, co-incineration	30	45	30%	9
Total organic carbon, incineration	10	15	30%	3

measurements. The data obtained can then be utilised to calculate a calibration function for the CEM and determine it suitability for the specific application. The uncertainty for the CEM is then determined by calculating the variability of the calibration function.

It is important to note that the effectiveness of this test requires at least fifteen valid repetitions of each applicable SRM, over a three day period.

QAL 2 procedures are carried out when:

- Upon initial CEM installation
- At least every three to five years as per applicable directive
- Whenever there is a significant change in the plant operation which will have a change in the emissions
- After a failure of a CEM unit
- After a significant upgrade or other significant change to plant operations

QAL 3 – Specifies a procedure that ensures that the CEM remains within the required specifications during continued use. Drift and precision parameters are measured regularly by the plant operator. This data is then plotted utilising control charts such as CUSUM charts. The output of these charts will then determine the frequency of the CEM maintenance needed.

AST – The annual surveillance test is regarded as a mini QAL 2 test. The main objective of which is to determine whether the calibration function determined during QAL 2 tests is still valid. Functional tests need to be carried out. Once these have been conducted 3 – 5 parallel SRM measurements are conducted. If the AST shows the calibration is no longer valid then a full QAL 2 is required.

Calibration and Validation of the CEM according to QAL 2

The plant operators have the following responsibilities under QAL 2 to ensure valid data is obtained on a continual basis for reporting purposes:

- ensure the CEM is installed in the correcti location

Operators should follow the provisions for location and access described in TGN M1 and the method implementation document (MID) for EN15259 in order to determine the most representative location for the CEM according to the homogeneity test described in EN15259. The MID for EN15259 describes a procedure to determine whether the sample location will be representative or not. Grid measurements of the stack gas are conducted at centres of equal area across the sampling plane and comparing the results to a fixed reference point within the sampling plane.

- ensure sufficient access to the CEM to allow for regular maintenance, access and control of the unit
- ensure that the CEM is calibrated and operating correctly on a continual basis

To ensure that the CEMs are calibrated and operating correctly the following tasks need to be carried out. A set of functional tests and checks to ensure that the CEM has been installed correctly and is functioning at or better than the required performance levels required. A set of repeated parallel measurements to verify whether the readings from the CEM are reliable and to derive a calibration function if the SRM data shows that there is a bias in the CEMs readings. A set of statistical operations and tests following the parallel reference tests are conducted in order to verify whether the CEM meets the uncertainty budget as set out in the relevant directive. In Figures 2 and 3 the location of equal area points and sampling ports are shown. Figures 4 and 5 show examples of unsuitable and suitable sampling locations, respectively.

The test laboratory shall have overall responsibility for the functional tests, the checks may however be carried out by the operator, CEMs supplier or test laboratory and shall include the following checks, these checks are carried out prior to the parallel SRM measurements being conducted:

- Alignment and cleanliness
- Sampling system integrity
- Leak test
- Manual zero
- Span check
- Linearity
- Interferences
- Response time

EN14181 requires SRMs to be used to verify and calibrate CEMs. It is based on the following three premises for its effectiveness and accuracy. These are:

- There is a spread of data over the required range of the monitoring system
- There is a linear relationship between the CEM data and the SRM data when both sets of measurements are valid
- The SRM is linear, accurate and precise with an uncertainty no greater than half the maximum permissible uncertainty specified by the regulator.

Although EN14181 works best when there is good spread of data and the CEM has a linear response to increasing values of the target determinant, it is also common for emission results to be clustered, the most common patterns of emissions that test laboratories encounter are: linear (Figure 6), high level cluster (Figure 7) and low level cluster (Figure 8).

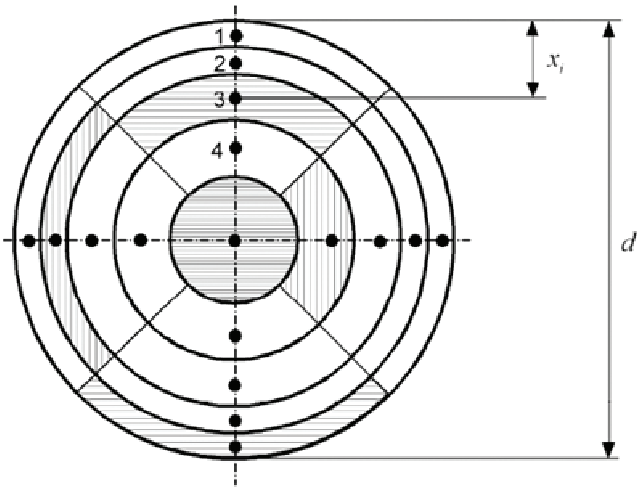

Figure D.1 — Sampling point positions in circular ducts - General method (showing positions for ducts over 2 m in diameter – The shaded positions are of equal area)

***Figure 2**: Location of equal area points*

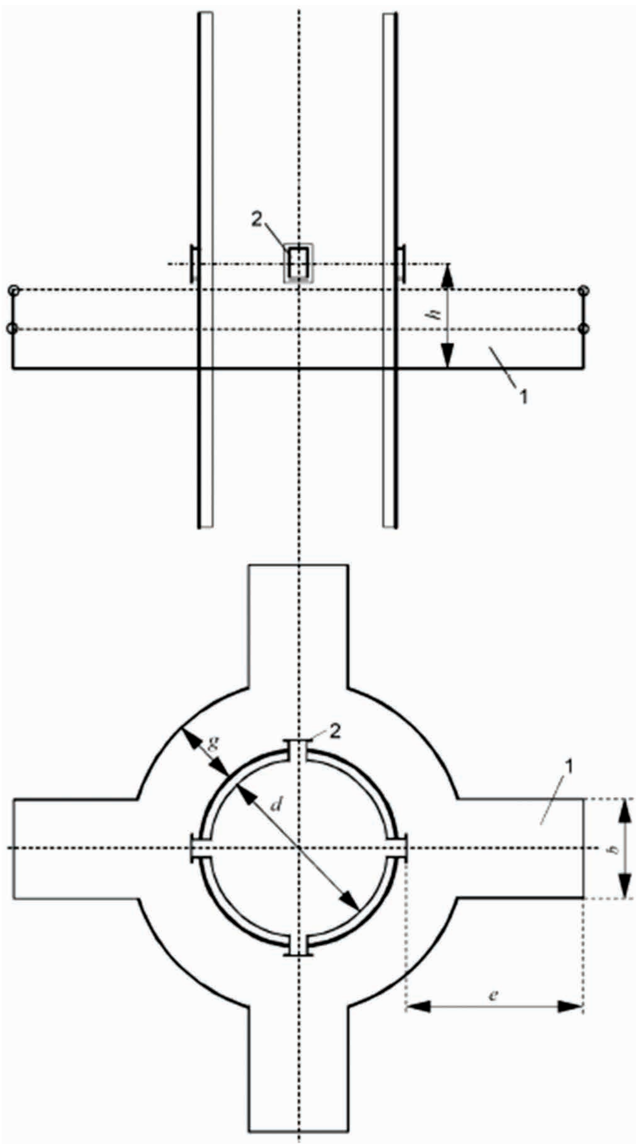

***Figure 3**: Location of the sampling ports*

***Figure 4**: Example of an unsuitable sampling location*

***Figure 5**: Example of a suitable sampling location*

It is important to note that if the emissions are typically below 30% of the ELV then EN13284-2 for low level particulate monitoring CEMs allows for the number of parallel measurements to be reduced from at least 15 measurements to three or five sets of parallel measurements. For the AST parallel measurements from at least five, to three to five repetitions. The total time of the measurement set should be at least 7.5 hours, however in certain circumstances such as batch process operations the times may be reduced in consultation with the operator and regulator justifying the request for reduced sampling.

Parallel measurements conducted for CEMs calibration purposes shall be performed with the CEMs and SRM in order to calibrate and validate the CEMs by use of an independent method e.g. BS EN13284-1. It is important to note that it is not sufficient to use reference materials alone to obtain the calibration function and this is therefore not permitted. Reference materials do not replicate sufficiently the matrix stack gas.

However, surrogate reference materials may be utilised to extend the valid calibration range of the CEMs which is typically 10% above the highest value measured with the SRM during the QAL 2 calibration procedure. It is also important to note that all test houses/labs conducting SRM tests must be accredited to EN14181 in addition to ISO 17025 accreditation for the applicable test methods.

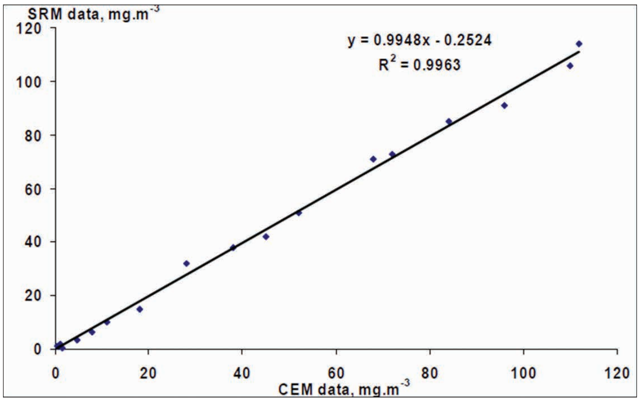

Figure 6: *A linear spread of data across a wide range*

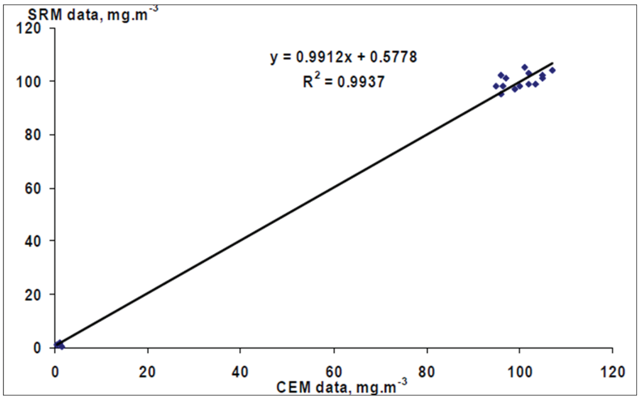

Figure 7: *A high level cluster*

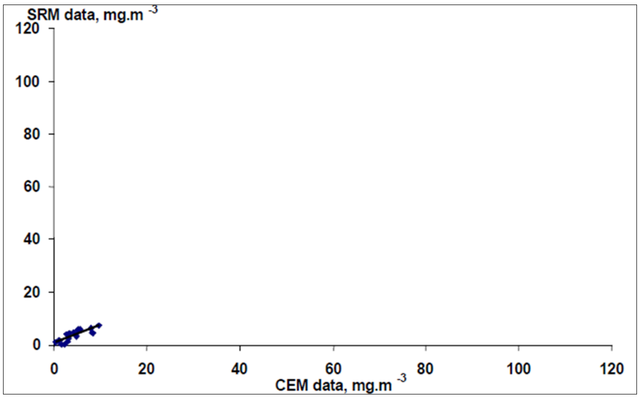

Figure 8: *A low level cluster*

Key points for parallel measurements include:

- Only test houses accredited to ISO17025 for the MCERTS performance standards for manual stack monitoring for the applicable SRM's may perform the reference monitoring tests in QAL 2 and AST
- The applicable SRM's are prescribed in TGN M2
- The SRM data should have a wide spread over the measurement range, a low scatter and show a linear response
- The calibration function within QAL 2 and the AST is based on the premise that the SRM is sufficiently accurate and precise, as well as producing an adequate spread of data over the applicable range.

The calibration function is given by the following equation below:

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

where

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

x_i is the AMS measured signal

Each measured signal X_i of the CEMs shall be converted to a calibration signal value Y_i by means of the above calibration function. Once the calibration function has been established then a test for variability needs to be conducted the following steps are required:

- Tabulate the CEM and SRM data;
- Express the raw SRM data in the same conditions as the CEM data(i.e. either dry or wet and standard temperature and pressure;
- Plot the CEM and SRM data together;
- Assess whether there are any outliers;
- Calculate the calibration function – a valid calibration function is a correlation coefficient of the linear regression line of R^2 =0.9 or more;
- Establish the calibration range (should cover the ELV).
- Convert the data to calibrated and standardised values;
- Carry out the variability test; and
- Apply the calibration function.

Figure 9 shows the linear regression and derived calibration function for the Table 2 data set. The data set returns a correlation coefficient >=0.90%. This particular data set also passed the test for variability and therefore the derived calibration function calculated from the linear regression can be applied to the applicable CEM.

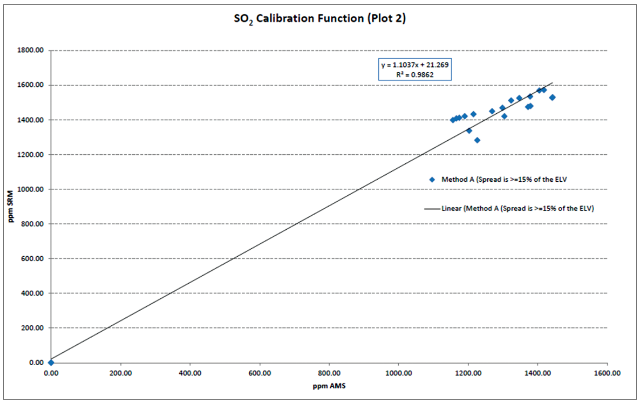

Figure 9: *Linear regression and derived calibration function for the table 2 data set*

Actual emissions data

Table 2 present a data set obtained from a CEMs calibration survey conducted at a typical coal fired power plant in South Africa according to EN14181.

***Table 2**: Data set obtained from a CEMs calibration survey conducted at a typical coal fired power plant in South Africa.*

Component SO_2

Table: Raw measurements for the QAL2 test

Date	Time	Sample Number i	AMS Signal x_i ppm	SRM Value y_i ppm	Difference $D_i = y_{i,s} - \hat{y}_{i,s}$	Difference $D_i - \bar{D}$	Squared Difference $(D_i - \bar{D})^2$
2014/10/02	19:00	1	1304.38	1420.05	115.67	-22.11	488.80
2014/10/02	20:00	2	1379.22	1478.81	99.59	-38.19	1458.50
2014/10/02	21:00	3	1441.97	1526.46	84.50	-53.29	2839.51
2014/10/02	22:00	4	1442.91	1529.62	86.71	-51.07	2608.59
2014/10/02	23:00	5	1372.25	1473.96	101.71	-36.07	1301.34
2014/10/03	02:00	6	1268.86	1448.79	179.93	42.15	1776.27
2014/10/03	03:00	7	1298.68	1468.96	170.28	32.50	1056.17
2014/10/03	04:00	8	1378.33	1533.92	155.58	17.80	316.74
2014/10/03	05:00	9	1417.93	1571.47	153.54	15.75	248.15
2014/10/03	06:00	10	1404.94	1568.21	163.27	25.49	649.51
2014/10/03	07:00	11	1347.18	1524.70	177.52	39.74	1579.06
2014/10/03	08:00	12	1323.65	1511.40	187.75	49.96	2496.27
2014/10/03	15:00	13	1155.96	1397.74	241.78	103.99	10814.63
2014/10/03	16:00	14	1166.14	1407.69	241.55	103.77	10767.76
2014/10/03	17:00	15	1174.55	1411.44	236.89	99.11	9822.08
2014/10/03	18:00	16	1190.08	1419.92	229.85	92.06	8475.64
2014/10/03	19:00	17	1215.37	1432.07	216.71	78.92	6228.94
2014/10/03	20:00	18	1202.93	1336.22	133.29	-4.49	20.16
2014/10/03	21:00	19	1226.35	1281.48	55.13	-82.66	6832.40
		20	0.00	0.00	0.00	-137.78	18984.36
		21	0.00	0.00	0.00	-137.78	18984.36
		22	0.00	0.00	0.00	-137.78	18984.36
		Sum			3031.24		126733.60
		Ave			137.78		
		SD					77.68

Conclusion

Considering the relative importance of obtaining reliable data to ensure legal compliance the correct implementation of EN14181 is critical.

Key points in addressing practical implementation of EN14181:

- It is recommended that South Africa develop or adopt its own technical guidance notes to address practical implementation of the standard applicable to the South African context.
- Test houses/laboratories in South Africa need to be accredited to ISO17025 to ensure data quality.
- Certification of personnel in South Africa equivalent to the UK Environment Agencies MCERTS scheme would be beneficial.
- Hierarchy of methods need to be established.
- Guidance from the regulator needs to be formalised to address the shortcomings in the legislation.
- Uncertainty and performance standards and requirements need to be established for ELV's and CEMs.

Establishing common reporting criteria with the help and guidance of the regulator with clear minimum requirements will help to standardise reporting allowing for proper permit compliance to be determined.

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