return to contents page

Centralised QA for CEM applications using AQM software

Andrew Newman BEng CEng MIEE

ABSTRACT:
This paper illustrates how software developed for ambient Air Quality Monitoring (AQM) applications has been used to provide a readily available and field tested solution for CEM reporting requirements.

Data processing to produce CEM compliance reports can be a significant task, requiring greater resource than the operation and maintenance of the CEM equipment itself. Where CEM equipment is specified by main contractors, who will not themselves be the plant operators there is often no provision made for compliance reporting software.

Many diverse reporting strategies are employed in the UK which lags behind other countries, such as the USA, where there is greater standardisation. Some plant operators manually compile compliance reports using spreadsheets, which is far from cost effective. Proprietary reporting packages from the CEM equipment manufacturers are also employed but are product specific. Incorporating the compliance report generation into the plant's Supervisory Control and Data Acquisition (SCADA) or Distributed Control (DCS) systems can be expensive and lacks the user configurable flexibility required to cope with legislative change. Both anecdotal evidence and formal studies indicate that poor or non-specialist management of bespoke software projects results in projects being delivered significantly over budget, late, or not at all.

A reporting package for CEM compliance reporting must be flexible enough to be user configurable to meet the diverse and evolving reporting requirements of the regulatory authorities. It must also be modular so that data from different manufacturer's CEM equipment can be saved in a common format. These requirements have been met for many years by software used in national or regional AQM networks. Using the experience from AQM network software for CEM applications offers a cost effective, ready to market solution, with many years of field experience behind it.

1. Introduction:

It is a peculiarity of the UK's 1990 Environmental Protection Act, that plant operators themselves carry out the majority of the continuous emissions monitoring, and then regularly present the results to the regulatory authority, who may be the Environment Agency or local authority depending upon the process.**[1]** In order to comply with this approach, plant operators must agree an appropriate technique for monitoring, following the BATNEEC principle (Best Available Technology not Entailing Excessive Cost). Confidence in this system can only be maintained if the quality of the data presented is high. The concepts of quality assurance and quality control are usefully defined by the British Standard BS EN 9000: "Quality assurance consists of all those planned and systematic actions necessary to provide adequate confidence that a product will satisfy given *requirements for quality*. Quality control is the operational techniques and activities that are used to fulfil requirements for quality.". (emphasis added).

Therefore, the appropriate QA/QC protocols for the emissions monitoring and the subsequent data handling cannot be defined without reference to an agreed "requirement for quality". By analogy with the BATNEEC principle, the duty of care is proportionate to the public policy objectives. Once the CEM requirements are agreed, the plant operators must provide the appropriate personnel and tools to implement it.

The Environment Agency also undertakes independent monitoring through the National Compliance Assessment Service. Although the independent contractors employed are much more experienced than typical site operators, the Agency has still found that "*inadequate prescription and poor formatting ..... has meant that consistent high quality reporting has often only been achieved after considerable debate and difficult contractual discussions with the contractors"*. **[2]**

Unfortunately, where CEM is to be undertaken by plant operators the practicalities of data handling and reporting are often not sufficiently anticipated. As CEM equipment manufacturers it is common to receive specifications for tenders where no allowance for this has been made, and sometimes no provision even for collecting data. Where plant is being purchased by main contractors who will not themselves be operating the plant, essential equipment maintenance is also sometimes omitted.

So plant operators starting to operate CEM equipment often find that they have no mechanism in place for controlling the data and summarising it to produce a report. CEM equipment requires operation by skilled technicians, but the data quality is also dependant upon having skilled staff who appreciate how to deal with measurement uncertainty and statistical analysis.

Software tools are invaluable is bringing this task within the resource capability of plant operators. The non-prescriptive approach of UK emissions regulations has meant that there is no common protocol for data management and no common format for reporting, this has restricted the market for software tools and impeded their development.

2 Data management

2.1 data integrity requires measurements to be high quality

Poor quality of measurement will invalidate any subsequent use of the data. A brief discussion of maintenance requirements is therefore included here, which also provides a comparison with the resources required for data processing and reporting.

The data must be representative. To a certain extent this is a question of selecting the correct type of equipment, an appropriate sampling point, and that the sample conditioning does not compromise the integrity of the measurement. However, it also entails appropriate day to day running of the CEM equipment, the requirements for which are typically not prescribed.

The following issues need to be considered in drawing up such a QA/QC program:

1. The performance of all sensitive scientific instrumentation will change subtlely as the equipment ages. A regime of regular calibrations is designed to compensate for this drift. However, the accuracy and precision of the instruments can also be compromised by component failure, operator error, or degradation of the operating conditions.

2. The data must be comparable and reproducible, therefore the integrity of the calibration standards must be checked. These calibration standards should be traceable through an unbroken chain back to international standards (the SI system).

It is important to ensure that the calibration system is satisfactory to the regulatory authorities.

3. Results must be consistent over time. Each time the analysers are calibrated, the responses to zero and span gases will be found to have drifted marginally since the last calibration. It is the site operator's responsibility to monitor that this drift does not exceed the specification of the instrument.

4. A high level of data capture is required during the year, for the calculation of the number of exceedences to be representative and meaningful. This is a question of system management, because although a regime of frequent maintenance and service intervention will improve reliability and accuracy, it will be at the expense of data capture. A compromise must therefore be reached. The inherent problem of CEM is that sensitive analytical instrumentation is operating in a harsh environment. "*Given the rather extreme nature of stack gases.... , ... it is not surprising that specialised instruments rarely operate for long periods without trouble*". "**[3]**

The resource implications of maintaining system availability is obviously of great concern. Between 1993 and 1998 National Power ran comparative trials of different techniques. It might be thought that stack mounted systems with simpler sample conditioning would entail significantly lower maintenance. however, Dr. Hans Jenson, reports: "*communication errors that occurred in the microprocessors of both the cross duct and IR folded beam systems show that typical instrument maintenance may not be as simple as "wiping a lens" or "realigning a transmitter". Instead the high level of microprocessor control and its potential failure means that National Power will only be able to maintain CEM systems with considerable support from the manufacturers*". **[4]**

Unfortunately Dr. Jenson could not draw conclusions about the maintenance requirements for extractive systems, as extraneous factors compromised the trial. However, Signal's experience as a manufacturer of these systems shows that even under aggressive operating conditions, a protocol of fully documented, weekly visual checks and monthly response checks, will pre-empt problems. These checks may only take a few minutes each week, and can be less frequent if operating conditions are benign.

Where a formalised QA/QC protocol institutes a regime of documented checks on the integrity of the equipment this leads into a virtuous cycle whereby the demands upon manpower are reduced, the measurements are of higher quality, and there is demonstrable "due diligence" from the point of view of the regulatory authorities.

2.2 Data processing requirements

The calculations required for reporting are not complex, and are defined by the relevant process guidance notes. The complexity is introduced by the volume of data, and the requirement to manage this data set to ensure that calculations are representative and defensible by maintaining back-tracability to the original measurements. The degree of rigour required will be proportionate to the pollution risk, and by the degree to which the data can be verified, for instance by comparison to fuel usage. In practice it will often be limited by the skill level of the operators.

Case studies are included here to illustrate the sort of data management issues that can cause real difficulty for plant operators.

2.2.1: Case study 1: anomalous oxygen correction in a gas fired power station

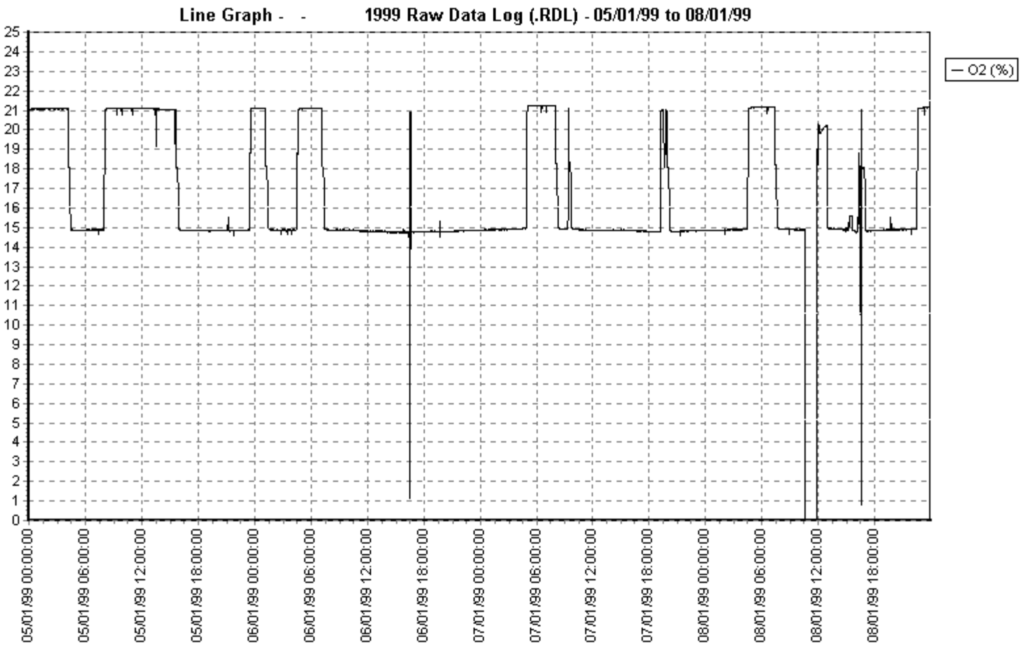
Consider the calculation for oxygen compensation using the formula:

$$O_2 \text{ Corrected Reading} = \frac{(\text{Atmospheric } O_2 \text{ Level} - \text{Ref}[O_2]) \times \text{Measured Reading}}{(\text{Atmospheric } O_2 \text{ Level} - O_2 \text{ Reading})}$$

Where Ref[O_2] is defined by the process authorisation, and Atmospheric O_2 Level is the constant 20.9.

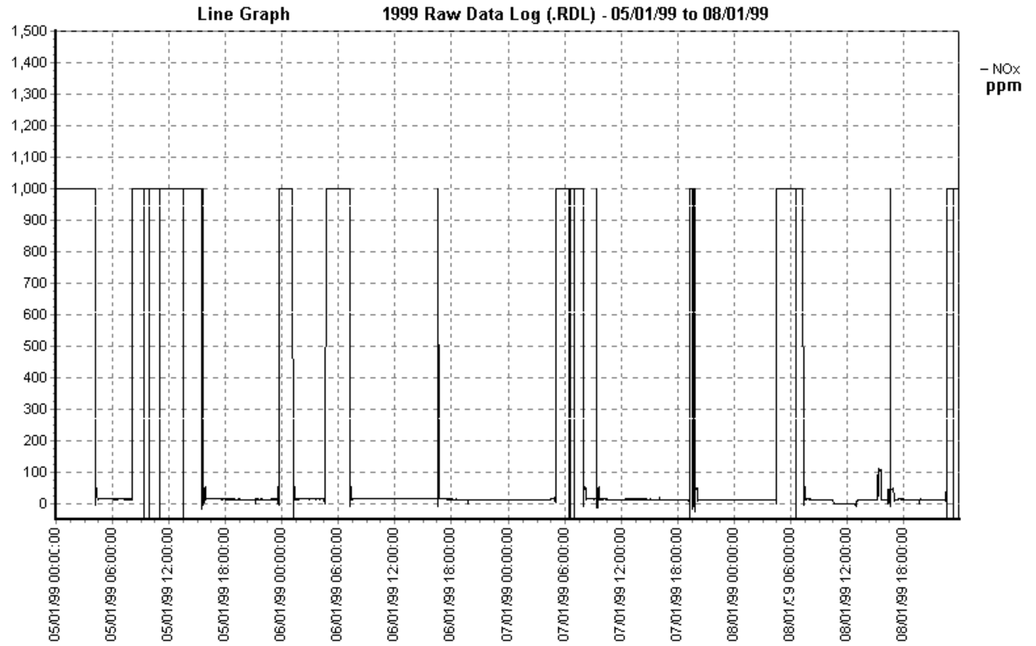
Problems would never arise if the plant were running continuously in steady state conditions. However, *figure one* shows the measured oxygen levels in a gas fired power station in the south of England for four days during January

Figure one:



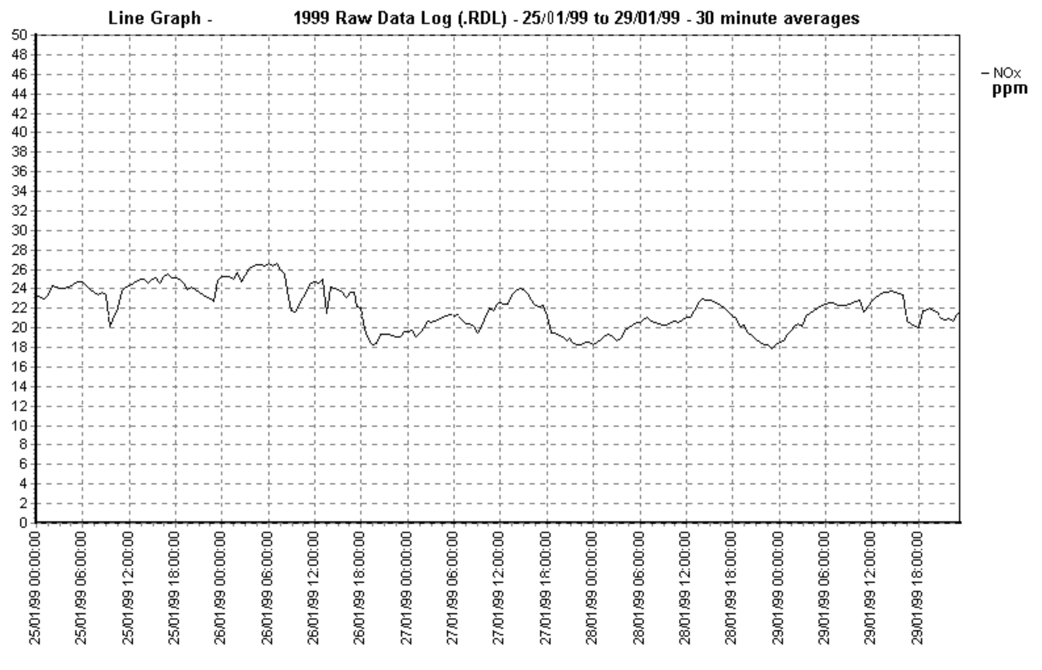
Observe that the gas turbine is brought in and out of service several times during this period. When not running the oxygen level swiftly rises to ambient. Observe also that there are a couple of low oxygen readings, which suggest that the plant was running in a fuel rich condition.

Figure 2:



When the plant is not running, the corrected NOx data is anomalous. In this application the oxygen correction is performed in the logger. *Figure two* shows the raw one minute averages direct from the logger, showing ludicrously high levels when combustion was not taking place.

Figure 3



Observe that in *figure three* by averaging the data into 30 minute averages, and excluding from the data set all those measurements made when the plant is not running, then a sensible set of data is obtained. The status of the plant is communicated to the logger by a volt free contact.

Now consider *figure four* which shows in more detail the period on the 8th January where the oxygen level became very low for a few minutes during fuel rich operation, and then returned to ambient. When the measured oxygen is less than the authorisation reference level, then the effect of correction is to *lower* the CO readings, even though during partial combustion high levels would be expected. (in this case, the reference level is 15%, so when the measured oxygen levels tend to zero, then the corrected CO is around 6/21 of the measured CO value) When the plant is not firing, and the oxygen levels return to ambient, the corrected carbon monoxide figures go through the roof. Following the same approach as with the NOx, this elevated CO data can be excluded, as shown in *figure five.* but note that whereas at 16:19 the anomalously high readings reached 450 ppm , at 16:35 the corrected level went off scale after fuel rich burning, suggesting that even before correction the CO readings were already genuinely high. By first under-representing and then over-representing the CO levels, the effect of oxygen correction has been to mask a possibly high CO release.

Figure four:

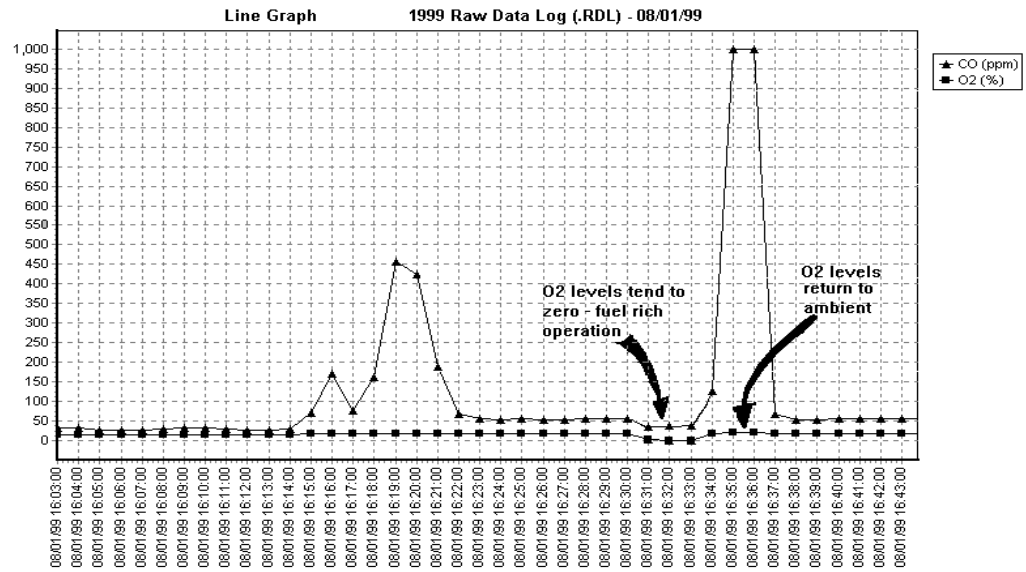
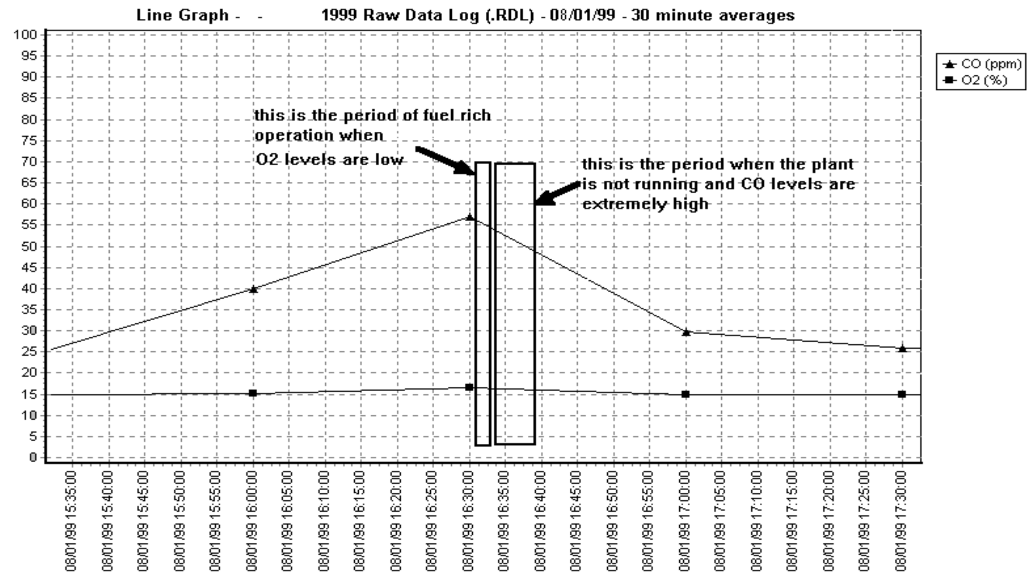


Figure five:



This a real case and the plant operator quite properly excluded the anomalously high CO readings from 8th January. However, it does illustrate that the excluded data is also of interest, and should a pattern of similar incidences emerge then CO measurements might be made for a trial period without oxygen correction .

2.2.2: Case study 2: anomalous oxygen correction in a CHP plant

This concerns a combined heat and power (CHP) boilerhouse at a large manufacturing plant in central England.

Each boiler has four burners, and a feedback mechanism modulates the firing pattern to maintain steam pressure, so each one of the burners can be brought into service independently. The efficiency of combustion of the overall boiler will depend on how many of its burners are active, but the authorisation level for oxygen compensation is constant, based upon assumed full load operation. Therefore application of oxygen correction by the datalogger yields artificially high corrected NOx levels when running under light loads.

2.3 Data management tools - some options

The data management must meet the requirements of its stakeholders, who are: i) the regulatory authority who typically require a summary report (with complete reports available for inspection); ii) the report's authors who require a data handling tool with which the provenance of the data can be established; and iii) the plant operators may also use emissions data as a real time diagnostic of plant performance, typically by interface with a SCADA system.

In the UK both the report format and the burden of proof behind it will be agreed on a site by site basis. This contrasts with the US EPA, which has adopted a much more prescriptive approach. As far back as 1975, the EPA developed a standard format of quarterly report which embodied the requirements of Federal Code Regulations: 40 CFR 60.7 **[5]**

The data handling requirement will therefore be defined by negotiation with the regulatory authority, however, it must at least perform the corrections and exceedence calculations defined by process guidance notes. The case studies presented above illustrate that the plant operator can rarely present data that has simply been corrected in the logger. Certainly data measured while the plant was not running must be excluded, but the case for excluding such measurements must be justifiable, which will require tools for parsing and graphically presenting the data set.

The CHP plant described above presents a more difficult task for the plant operator, who has to balance the conflicting demands of reporting to the precise terms of his authorisation, without misrepresenting the actual performance. This has been achieved by offering representative CEM data for periods when the boiler performance matched the authorisation model of full load operation. The rest of the CEM data is anomalous, and has had to be presented to the Environment Agency with a well argued case for how it should be interpreted. This has required filtering the data set based upon bands of oxygen level. The operators in this case manually process the data using a spreadsheet package, which entails several man-days effort per quarter. It also requires face to face meeting with the Agency inspector to present the results. Although the authorisation is based upon 30 minute averages, tracking the modulating burners requires one minute averages to be logged, which are based upon one second samples. The sheer size of the data set for a monthly period makes spreadsheets cumbersome.

Most CEM manufacturers will offer proprietary software packages for communicating with their own equipment and producing reports, however, these will be product specific, and may also not support the sophisticated data filtering and presentation required for dealing with "difficult" cases. Under UK legislation Part A processes are required to meet the demands of Integrated Pollution Control to monitor discharges into all media **[6]**, so using proprietary packages will always entail operators of such plant in using different reporting software for different types of emission.

Many operators log the CEM data into the SCADA system, and then use this to produce their reports. While SCADA systems have the capability of performing the corrections and exceedence calculations, and of generating reports, they will not support facilities for auditing the data. SCADA development environments such as Wonderware's In-touch™ are designed for plant control and are inappropriate for reporting packages. Changing regulations also require that CEM software has a degree of local configurability that is more easily achieved in a PC environment, particularly as this firewalls the plant control system from side effects generated by code changes in the reporting software.

Faced with this requirement for reporting tools operators may be tempted to commission bespoke software. Caution should prevail! The task of translating the application requirement as perceived by the domain expert into a conceptual model which can be developed into a usable program is far from trivial, even for software professionals. In this case the task is Herculean because the domain expert is also inexperienced! **[7]** Bespoke software in non-trivial applications also raises the questions of reliability and maintainability. All software has bugs, a formal study concluded that for every million lines of code there are 20000 bugs, (a bug every 50 lines) 1800 of which go undetected **[8]** In off the shelf software, bug detection and correction is spread over a wide user base, and there will be a structured protocol of updates and patches. With bespoke software all of the bugs must be detected by one user, and will often be discovered once the code is out of warranty. Indeed, it may not be maintainable, because software subcontractors find small bug fixes difficult to schedule. (Hence the practice of overcharging, or "stiffing" in the IT jargon)

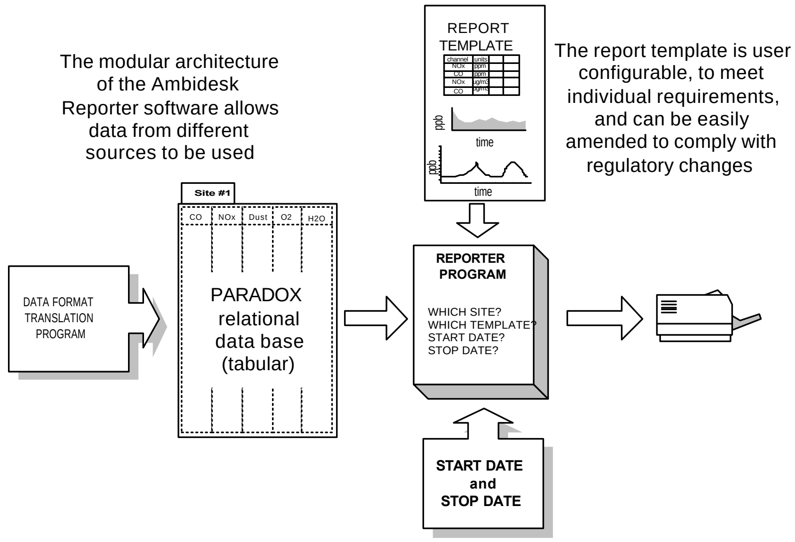
3 Software for ambient air quality monitoring (AQM)

In the history of science a theory is regarded as true if it is part of a "progressive problem shift", whereby it also provides the solution to a novel problem, which "*did not belong to the problem-situation which governed the construction of the hypothesis"* **[9]** In engineering terms this is observed as the "Teflon effect", where techniques developed in one application domain are transferable to another.

Although employing similar instrument technology to CEM, the domain of ambient AQM has developed two complementary differences of methodology. Firstly, although in the UK several bodies undertake AQM, the dominant role is taken by the Automatic Urban and Rural Network (AURN) run on behalf of the DETR. This employs centralised data collection, alongside centralised QA/QC and data ratification. Secondly, because data processing is centralised, the data manipulation and reporting software has been decoupled from the specific data formats of the diverse logging devices used.

Centralisation of the AURN has established *de facto* standardisation, and therefore a sufficiently large customer base to make the development of reporting software cost effective. The decoupling of data formats has been achieved by modularising the software architecture so that data from any new source must simply undergo a format translation prior to data manipulation (see *figure nine)*. Therefore, the core reporting and data management software need not be altered in order to support new data formats

Figure nine



The day to day operation of AURN sites, is by semi skilled Local Site Operators, and the integrity of the measurements are checked daily by the Central Management and Control Unit (CMCU).**[10]** Where PC based loggers are employed the CMCU can use a proprietary remote control package, such as Reachout ™ to fully control the remote system. This division of labour dramatically improves the leverage of the core of skilled network managers. Should the Environment Agency seek to increase their supervision, then the AURN would provide a paradigm that could *mutatis mutandis* be followed for CEM.

4 Conclusions:

Signal developed their Ambidesk software specifically for network management of AQM. However, they have found that it can be used without modification as a ready made solution for the data handling and reporting demands of CEM operators. The operator in case study one uses Ambidesk software, and monthly compliance reports can now be prepared in minutes, without losing any rigour in data management. A public domain data structure allows Ambidesk to be used as a general reporting package for data from different sources. The availability of data management and reporting software lessens the burden on CEM operators, and would facilitate the introduction of prescriptive report formats. Should CEM operators store their data in a common format then readily available remote control software would empower the Agency to undertake remote QA/QC audits.

ABOUT THE AUTHOR:

Andrew Newman is a chartered engineer and has a first class honours degree in Digital Systems Engineering from the University of the West of England. He is currently being sponsored by his employers, Signal Group Ltd, to study part time for an MSc in software engineering at Oxford University. Andrew designed and supervised the development of Signal's Ambidesk software which is used in both AQM and CEM applications in the UK and overseas. Ambidesk has recently been adopted to manage the new AQM network in Saudi Arabia by the King Abdulaziz City for Science and Technology. He has many years experience working as a development engineer for gas analyser manufacturers, firstly with Systech Instruments, and later for Rotork Analysis, who were acquired by the Signal group in 1997

REFERENCES

[1] Depending upon whether the plant is defined as a Part A or Part B process under the Environmental Protection (Prescribed Processes and Substances) Regulations 1991[3]

[2] *Standard Report Formats for Manual Stack Emissions Monitoring".* O. Joel, NCAS. Proceedings of the International Conference on Emissions Monitoring. London, 1998.

[3] HMIP Technical Guidance Note (Monitoring) M2", HMSO, 1993.

[4] "*Management of Emissions Monitoring of Power Stations - Course Notes for Industrial Air Pollution Monitoring*", Dr. Hans Jenson, Environmental Performance Officer for National Power. University of Leeds, 1998.

[5] "*Continuous air pollution Source Monitoring Systems - Technology Transfer Handbook"*, United States Environmental Protection Agency. 1979

[6] Environmental Protection (Prescribed Processes and Substances) Regulations 1991[3]

[7] "*A Model of the Problem or a Problem with the Model - Special Feature on Software Safety".* Peter Mellor, IEE Computing and Control Engineering Journal, Feb. 1998.

[8] *"Software reliability in the Systems Context",* Hecht H and Hecht M. IEEE Transactions in Software Engineering, SE-12(1)

[9] "*Why did Einstein's programme supersede Lorentz's?*". Zahar, E. British Journal of the Philosophy Science 1973, 24, 95-123. and "*Philosophical Papers - 2 Vols."* Lakatos, I. Cambridge 1978.

[10] See "*Automated Urban Monitoring - Site operator's Manual"* DoE, 1996, for a brief and useful overview. A full bibliography is to be found in "*Air pollution in the UK: 1995"* DoE, 1997.