MANAGING POWER STATION AMBIENT AIR QUALITY COMPLIANCE

Alan H Webb and Gill C Hunter
Environment Department, RWE Innogy plc, Swindon UK
alan.webb@rweinnogy.com & gill.hunter@rweinnogy.com

ABSTRACT
The potential for air quality impact management of industrial emissions using dispersion modelling and forecast meteorology has been trialled previously but was conclusively shown not to be an effective management methodology for UK power stations. The Air Quality Management Plan approach has been adopted by all major coal- and oil-fired power stations in England and Wales. These place the responsibility on operators to ensure compliance using a combination of modelling and measurement.

INTRODUCTION
In many countries, operation of industrial plant is subject to compliance with ambient air quality limits. In the UK, these limits are defined in the Air Quality Strategy (AQS) objectives[1] which include the hourly and daily SO_2, the hourly and annual NO_2 and the daily and annual PM_{10} limit values from the first EU Air Quality Framework Daughter Directive[2] and, also, the additional UK SO_2 objective of no more than thirty five 15-minute periods per calendar year greater than 266 $\mu g\ m^{-3}$ (100 ppb). The required compliance dates are 31st December 2004 for the EU-based SO_2 and PM_{10} limits, as required by the Directive, but 31st December 2005 for the NO_2 limits and the 15-minute mean SO_2 limit (Table 1). The objectives apply to the combined impacts of emissions from all sources and at all locations. The 15-minute mean SO_2 objective is the most demanding for many industrial combustion plant and substantially more demanding than the EU-based hourly and daily SO_2 limit values.

Most industrial plant emit the products of combustion as buoyant plumes from tall chimneys which ensures that the emissions are generally well dispersed in the atmosphere before the plume mixes to ground level. Thus, contributions to annual mean ground-level concentrations are small, typically no more than a few percent of ambient standards. However, under certain meteorological conditions, e.g. when it is windy or convective, the plume may be mixed to ground level at concentrations which may exceed the short-term air quality concentration thresholds defined in the AQS objectives. The challenge is, therefore, to devise a management structure capable of limiting the number of exceedances of the concentration thresholds to less than the number allowed in the AQS. This is particularly challenging for the 15-minute SO_2 objective where, in principle, the annual permitted number of exceedances could be exceeded in a single day.

The potential for air quality impact management using dispersion modelling and forecast meteorology has been trialled but was conclusively shown not to be an effective management methodology for UK power stations[3]. The errors in the forecast magnitude of the various dispersion-related meteorological parameters associated with significant ground-level impacts resulted in an unacceptably low frequency of coincident forecast and actual exceedances of the AQS threshold concentrations.

Pollutant	Objective		To be achieved by
	Concentration	**Measured as**	
Sulphur dioxide	266 µg m^{-3} (100 ppb) not to be exceeded more than 35 times a year	15 minute mean	31 Dec 2005
	350 µg m^{-3} (132 ppb) not to be exceeded more than 24 times a year	1 hour mean	31 Dec 2004
	125 µg m^{-3} (47 ppb) not to be exceeded more than 3 times a year	24 hour mean	31 Dec 2004
Nitrogen dioxide	200 µg m^{-3} (105 ppb) not to be exceeded more than 18 times a year	1 hour mean	31 Dec 2005
	40 µg m^{-3} (21 ppb)	Annual mean	31 Dec 2005
PM_{10}	50 µg m^{-3} not to be exceeded more than 35 times a year	24 hour mean	31 Dec 2004
	40 µg m^{-3}	Annual mean	31 Dec 2004

Table 1 Ambient air quality standards for SO_2, NO_2 and PM_{10} defined in the UK Air Quality Strategy

The Air Quality Management Plan approach has been agreed with the UK regulator, The Environment Agency, and adopted by all major coal- and oil-fired power stations in England and Wales. The Management Plans place the responsibility on plant operators to ensure compliance and represent a progression in environmental regulation from prescriptive control of emissions to a risk management approach under operator control.

OUTLINE OF AIR QUALITY MANAGEMENT PLAN

All major coal- and oil-fired power stations in England and Wales were issued with Authorisation Notices in January 2000 which required, *inter alia*, production of a Management Plan to ensure compliance with SO_2, NO_2 and PM_{10} AQS objectives and required the installation of "at least one monitoring station" to measure the station impacts. The Air Quality Management Plans (AQMPs) for all stations were produced, in discussion with The Environment Agency, and were issued in 2001. The Plans are supplemented by a number of methodologies which describe the procedures to be used in assessing whether stations are compliant with the Air Quality Strategy objectives.

The power station Management Plans comprise the following main elements:

- Demonstration that the anticipated generation scenario and anticipated fuel sulphur for future years are compliant with air quality objectives by dispersion modelling using 5 years of representative meteorology.
- A continuous comparison of the number of exceedances monitored at sites close to maximum impact locations with the number anticipated for the

planned compliant operational scenario and an assessment of the implications for year end compliance.

- The development of a number of tools and methodologies to judge compliance and to investigate the risks to potential exceedance associated with load and fuel-sulphur options. These have included a validation of the suitability of dispersion modelling for predicting high percentile ground-level ambient SO_2 concentrations resulting from power-station emissions.
- An annual review which includes: an appraisal of actual impacts during the preceding year; an update on anticipated impacts for the next year using the latest information on operating pattern and fuel burn; and proposed management actions which might be required to ensure compliance.

MODELLING FUTURE OPERATING SCENARIOS

The "new generation" atmospheric dispersion model ADMS3[4] has been developed over several years and tested against various available validation data[4], including from UK power station monitoring networks[5]. Annual ambient concentration statistics, corresponding to the AQS objectives, due to power station emissions have been modelled using ADMS3 and the anticipated generation load pattern and the highest fuel-sulphur content consistent with meeting the maximum allowed SO_2 emission from the station. Since most UK coal- and oil-fired power stations do not operate at base load, the generation pattern was varied at a resolution of, typically, 4-hour periods on a daily basis to reflect realistic behaviour. The fuel sulphur content was assumed to be constant during the year but the impacts of a range of sulphur contents were also considered, as was an alternative generation pattern. To investigate the range of impacts due to meteorological variability, five separate annual meteorology data sets were used in the modelling. Since the AQS objectives apply to the combined impacts from all sources, appropriate background concentrations were added to the modelled impacts. The modelling has been carried out in accordance with procedures agreed with The Environment Agency.

Thus, the range of likely impacts resulting from the anticipated generation pattern for different fuel-sulphur contents and representative meteorology was obtained and compared with the AQS objectives. The results from the modelling have provided an indication of the range of sulphur contents and generation patterns which can reasonably be expected to be compliant with the objectives. If necessary, the generation pattern or fuel purchasing intentions would be modified to achieve a compliant scenario.

The modelling has also shown the relative magnitude of impacts from station emissions for the different species compared to the AQS objectives. Scenarios which are just compliant with the 35 exceedances of the 15-minute mean SO_2 threshold of 266 $\mu g\ m^{-3}$ (100 ppb) are rarely associated with more than one or two exceedances of the hourly SO_2 threshold (350 $\mu g\ m^{-3}$, 132 ppb) or any exceedances of the daily SO_2 threshold (125 $\mu g\ m^{-3}$, 47 ppb). The maximum hourly concentration of total NO_x resulting from station emissions is always substantially less than the hourly NO_2 threshold (200 $\mu g\ m^{-3}$, 105 ppb) and contributions to annual mean total NO_x concentrations are typically of the order of 5% of the AQS objective for NO_2. Since there is generally insufficient ozone in the ambient air to oxidise all the NO in the plume to NO_2, only part of the total NO_x is in the NO_2 form in the areas of maximum power station impact[6] and the actual impacts for NO_2, the regulated species, are even smaller. Ambient PM_{10} concentrations resulting from nearby power-station emissions are negligible (of order 1%) compared to the AQS objectives.

MONITORING AMBIENT IMPACTS

Each coal- and oil-fired power station operating at a load factor above 10% has two continuous monitoring sites measuring ambient SO_2 concentrations; one of which is at a location as close as practicable to the anticipated point of maximum 99.9th percentile 15-minute mean concentration (i.e. the percentile equivalent to the 35th highest 15-minute period in the year). NO_x, NO, O_3, PM_{10}, $PM_{2.5}$ concentrations and wind speed and wind direction may be measured at some sites. The target area for the maximum impact site was identified by modelling a typical operational scenario with constant fuel sulphur over 5 years. The final proposed site locations have been agreed as appropriate with The Environment Agency.

Proprietary instrumentation are used for measurement of ambient gas concentrations and data logging. All instruments are from reputable manufacturers and operate using established techniques (e.g. UV-fluorescence for SO_2, chemiluminescence for NO_x and NO, and TEOM for PM_{10} and $PM_{2.5}$). The analyser readings are recorded every minute using a data logger and hourly mean values calculated from these 1-minute readings. The data logger also controls a daily gas analyser calibration for zero and span, using Purafil/charcoal filters and calibrated permeation tube source of SO_2 or NO_2 to provide zero and span gas, respectively, for the SO_2 and NO_x analysers. These daily calibration readings are used as a check of instrument operation, i.e. as an indicator of malfunction or calibration drift. The gas analysers are maintained and serviced to the manufacturer's schedule at six-monthly intervals.

Manual calibrations are carried out by the site operator every two weeks using cylinders of calibration gas traceable to National Physical Laboratory primary standards. These fortnightly readings are used to calibrate the logged analyser readings taking into account, if appropriate, any indication of drift or malfunction indicated by the daily checks. The analyser 5 µm inlet filters are changed fortnightly at the time of the manual calibration and the PTFE sample lines and zero filters changed every six months.

Data are transferred from the site loggers every working day and inspected for instrument malfunction. Period mean values are set to "missing" where data coverage was <75% or when the site operators were confident, using their professional judgement, that the recorded values were invalid as a result of analyser calibration check, servicing, malfunction or other error. These procedures ensure that the gas concentration measurements are made to standards equivalent to those of the UK Environment Ministry (Defra) automated network. The measurements are estimated to be accurate to ±3 ppb or 10% of reading, whichever error is the larger.

All exceedances of the AQS thresholds are recorded and notified to The Environment Agency within one working day of their occurrence and a running total of all measured exceedances at each monitoring site maintained for comparison with AQS objectives.

RISK MANAGEMENT FRAMEWORK

The Management Plan included the following general implied potential constraints on station operation:

1. Compliance with the authorised annual SO_2 mass emission cap and average SO_2 emission strength.
2. Compliance with the applicable SO_2 ambient concentration limit values (Table 1).

The first commitment is relatively easy to manage by adjusting the sulphur content of the fuel purchased and burnt according to annual generation expectations. However, the second commitment is more problematic as ground-level ambient concentrations are dependent not only on the emissions but also on the concurrent meteorology. Since the Air Quality Strategy objectives apply at every location, impacts must be managed so that no more than the highest twenty four one-hour periods and the highest thirty five 15-minute periods in the year at each location are greater than the appropriate AQS threshold. Although some of these high-concentration periods may occur consecutively, others may occur in isolation at almost any time of the year. Furthermore, the exact generation level, the exact fuel-sulphur content and the subtleties of the meteorology which determine the precise magnitude of the impacts in any 15-minute or hourly period are impossible to predict at the beginning of the year. Generation level and available fuels will vary with market conditions and may deviate substantially from those originally envisaged. It is necessary, therefore, to manage the risk of non-compliance continuously during the year.

To ensure compliance with the AQS objectives, the Joint Environmental Programme (JEP) of the major UK power generating companies have developed a Risk Management Framework[7] which amplifies the basic requirements of the Management Plans described in an earlier section of this paper. The key elements of the Risk Framework are:

1. Prior to the start of the year:
    - Assessment of the impact of the expected range of operations against the SO_2 objectives using dispersion modelling with five years of representative meteorology and consideration of the risks of non-compliance.
    - Establish an envelope of generation levels and fuel sulphur contents as a function of time of year which can be categorised as having a “Low”, “Medium” or “High” risk of exceedance of the AQS objectives by the end of the year.
    - If necessary, adjust the anticipated generation/fuel scenario to produce an acceptable level of risk.
2. During the year:
    - Comparison of the number of monitored exceedances with the number expected from the annual modelling for the anticipated scenario, supplemented, where compliance might be marginal, by periodic dispersion modelling of the actual generation pattern, emissions and meteorology. Use these data to reassess the risk category for compliance by the end of the year.

- Keeping a check on the likely implications of anticipated future station operations, including different fuels, especially where these deviate substantially from the original expectations. Reassess the risk category.
- Where the reassessed risk category is in the “Medium” or “High” band, consider the need for revised load and fuel management options to ensure year-end compliance. If necessary, implement appropriate revised option.

3. End of the year:
    - Assess actual impacts as part of the AQMP Annual Review and consider whether there are any implications for managing future compliance.

COMPLIANCE ASSESSMENT

At the end of the calendar year, retrospective compliance with AQS objectives is assessed by analysis of available ambient monitoring data and dispersion modelling of actual station emissions using hourly meteorology for the review year. Although the ambient monitoring sites have been located as near as practicable to where maximum impacts with respect to the AQS objectives are anticipated in a typical year, this may not be the case for the particular review year: the measurement site may not be close to the location of the modelled maximum. In cases where there is a conflict between compliance determined by monitoring and by dispersion modelling, a methodology for assessing compliance has been agreed with The Environment Agency.

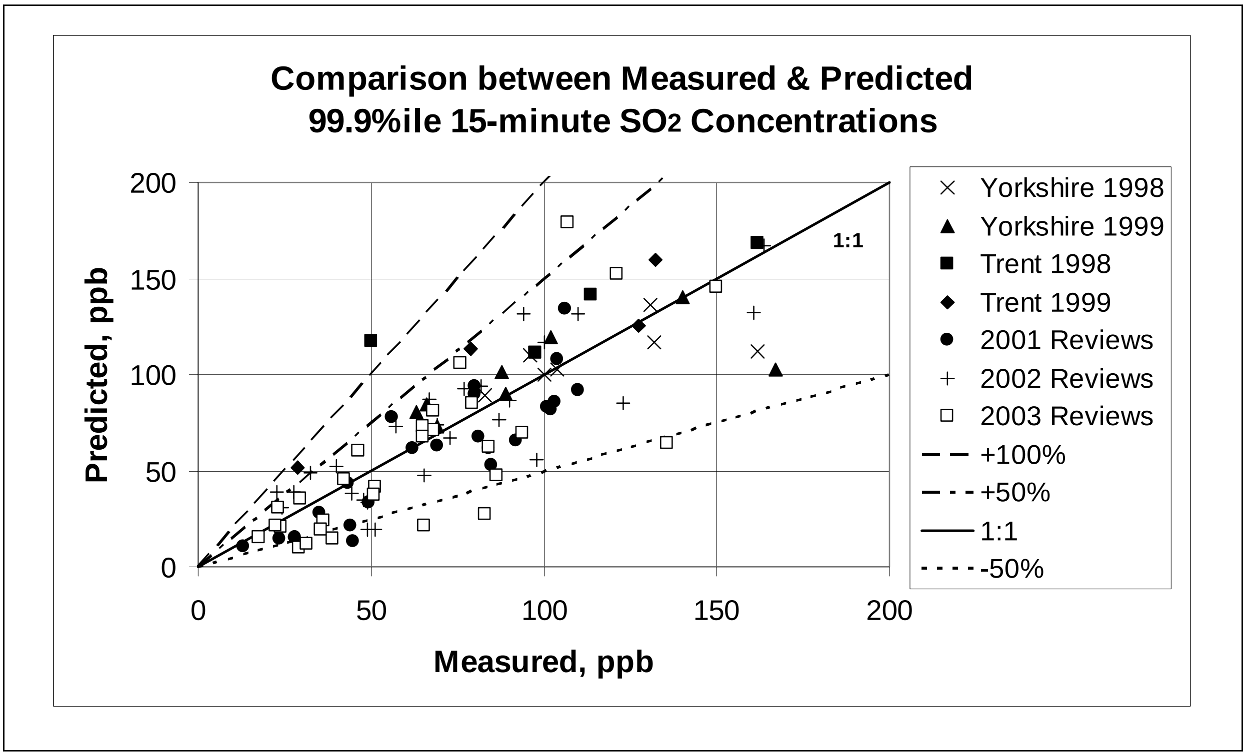

Figure 1 Measured and modelled 99.9%ile 15-minute mean SO_2 concentrations around UK power stations

The final draft EU guidance[8] on compliance with AQFD targets makes two important comments regarding the use of modelling results:

> "*Fixed measurements are regarded as more reliable than models by the public, policy makers and (implicitly) in the Framework Directive. Although this may not always be true, the Working Group proposes that in deciding legally whether an air quality threshold is exceeded, preference is always given to measured results in those cases where conflicts arise between measured and modelled data.*"
>
> and
>
> "*If a model is used to assess whether areas in exceedence exist within a zone, where no exceedence has been measured, the model result is only regarded as a legal exceedence if the Member State is able to show that the calculations are sufficiently reliable to warrant the important consequences of a limit value being exceeded.*"

The same principle as recommended for AQFD legal compliance has been adopted to judge AQMP compliance with AQS objectives. Thus, monitoring results are given precedence over modelled concentrations where these are judged appropriate for the purpose and modelling uncertainty is incorporated into the assessment where modelled concentrations are used.

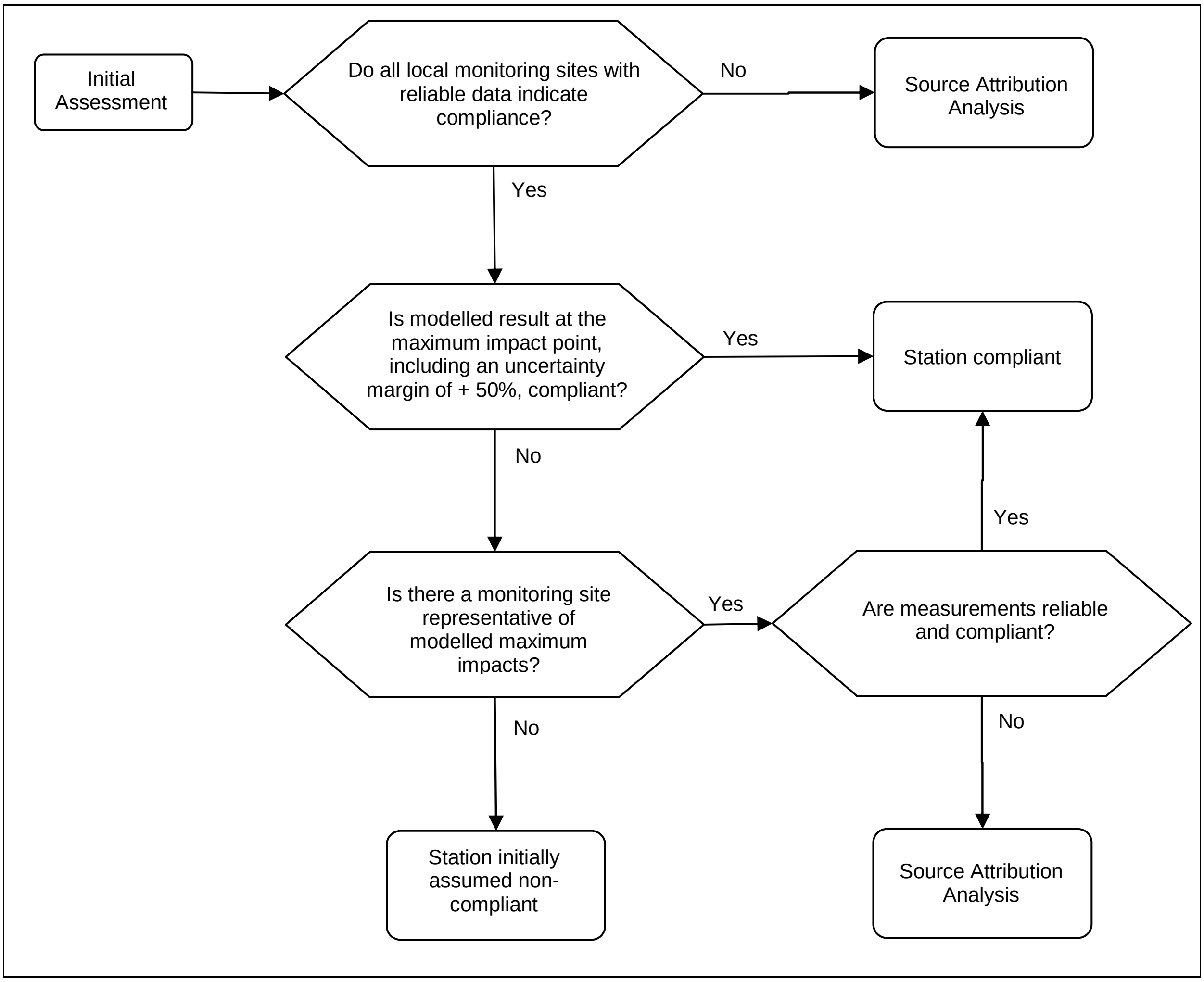

Figure 2 Simplified schematic of AQS compliance procedure for UK power stations

The criteria for judging compliance agreed with The Environment Agency include:

1. Data from a monitoring site is accepted as valid where the site is operated to standards equivalent to UK Defra sites and where data coverage is ≥90%. No uncertainty margin is included in the measurement data. These values are consistent with the requirements of the EU Air Quality Framework Directive.
2. The uncertainty in modelled concentrations has been set at 50%. This value is slightly less than the actual 95%ile uncertainty for ADMS derived from the JEP model validation studies for power station sources (Figure 1). The margin is added to the AQS threshold before judging compliance: e.g. the modelled 99.9%ile 15-minute mean SO_2 concentration must be >400 $\mu g\ m^{-3}$ (150 ppb) before it is classed as an exceedance.
3. Where the modelled concentration (including an appropriate background concentration) indicates non-compliance, measurement data from a "representative" site will take precedence over the modelled result. A "representative" site is defined as one which lies within a contiguous area around the modelled maximum 99.9%ile 15-minute SO_2 concentration and bounded by the modelled 99.9%ile of 15-minute mean SO_2 isopleth corresponding to 50% of the maximum. The 50% contour boundary is justified on the basis that the model uncertainties are such that any modelled concentration within the defined area can be considered not significantly different from any other concentration in the area.

A simplified version of the full procedure agreed with The Agency is shown schematically in Figure 2. Where measurement data indicate non-compliance with AQS objectives, source attribution analysis is applied to apportion responsibility between sources so that appropriate, fair and proportionate action can be taken to avoid future non-compliance. Where modelling indicates non-compliance and there are no representative monitoring sites with reliable data to confirm the magnitude of impacts, further investigation and data analysis may be carried out before non-compliance is confirmed.

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