Automatic Urban and Rural Network (AURN) LSO Manual - Essential Background Reading

Version 1.2 - November 2022

We are the Environment Agency. We protect and improve the environment.

We help people and wildlife adapt to climate change and reduce its impacts, including flooding, drought, sea level rise and coastal erosion.

We improve the quality of our water, land and air by tackling pollution. We work with businesses to help them comply with environmental regulations. A healthy and diverse environment enhances people's lives and contributes to economic growth.

We can’t do this alone. We work as part of the Defra group (Department for Environment, Food & Rural Affairs), with the rest of government, local councils, businesses, civil society groups and local communities to create a better place for people and wildlife.

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Table of Contents

Updating and Version Control

This manual is a working document, intended to be updated when equipment or procedures change. This manual is provided in electronic format, and the latest version is available on the Health and Safety Database. If you are a Local Site Operator, it is your responsibility to ensure that you download and use the most up to date version.

Changes are summarised in the table below.

Revision Date	Summary of Changes	Version Number
October 2021	Section 2.2: year-specific information on percentage of UK emissions from specific sources replaced with reference to the online National Statistics for pollutant emissions. Section 2.3: changes reflecting new contractors as of 1st October 2021, and clarifying the relationship of ALN sites as a subset of the AURN. Update of Figure 1.1. Sections 4,5,6: changes reflecting post-Brexit air quality legislation, including references. Section 7: changes reflecting the mix of particulate analysers used in the AURN. Throughout: changed 'CMCU/ Management Unit' to 'CMCU, as the management units for both the main AURN and ALN subset is are now referred to as 'Central Management and Control Units' in the contract specification.	1.1
October 2021	Addition of ALN reference in introduction. Section 4.1: Addition of ALN call out timescales (ESU & LSOs) Insertion of missing footnote for site classification report Section 7.1.2: Removal of gas cylinders from daily calibration of NOx analysers	
November 2022	No changes: version number changed for consistency with Parts A, B and C of this Manual.	1.2

1. Introduction

Within the AURN there is a subset of sites in and around London, called the Automatic London Network (ALN). In this document, 'AURN' means the whole network, including ALN sites, unless specifically stated otherwise.

This is the Local Site Operators' Manual Essential Background Reading document for the AURN Air Quality Networks covering Carbon Monoxide (CO), Sulphur Dioxide (SO_2), Oxides of Nitrogen (NO_2), Ozone (O_3) and Particulate Matter ($PM_{2.5}$ and PM_{10}) monitored across the UK. It has been prepared for the Local Site Operators responsible for day to day operation of the AURN air quality monitoring sites and is based on original documentation written by Ricardo Energy and Environment (a business name of Ricardo AEA). Its purpose is to provide the Local Site Operators (LSO's) with background information which is assist in understanding and operating the sites correctly.

The quality assurance and quality control (QA/QC) procedures for the AURN are fully documented elsewhere (AEA Technology plc, 2009): these can be found here . And for all Environment Agency and Defra networks (Defra, 2016), here: https://uk-air.defra.gov.uk/assets/documents/reports/cat09/1902040953_All_Networks_QAQC_Document_2012__Issue2.pdf.

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2. AURN Background Reading

The Defra UK-AIR website holds a wide range of information on the UK air quality networks including information on:

- the location of sites within the network including an interactive monitoring map,
- a brief history of how the network was established,
- a wide variety of other information which will help a new LSO familiarise themselves with this area of work such as the location of monitoring sites, a brief history of the AURN, and links to UK air quality information. For more information please go to https://uk-air.defra.gov.uk/networks/.

2.1. History

Measurement of air pollution in the UK dates back to the early years of the 20th century. However, until the early 1970s most of these measurements were made using non-automatic techniques. These usually involved sampling pollutants by drawing air through a filter, and/or through a bubbler, for subsequent analysis.

Research measurements of air pollution with automatic analysers began in the early 1970s in the UK. The UK's first automatic air pollution network, the Statutory Urban Network, was established in 1987 to monitor compliance with EC Directive limit values on air quality. This was expanded to form the Enhanced Urban Network (EUN) in 1992. This network was established as a result of the 1990 White Paper on the Environment 'This Common Inheritance' which committed the Government to a significant expansion in urban air quality monitoring in the UK. In particular, it also identified the need to improve public availability of air quality information. It comprised 12 urban background monitoring stations measuring five pollutants (CO, NOx, SO_2, O_3 and PM_{10}). The network was expanded in 1993 with the addition of a further 12 urban background sites.

In 1995 the Enhanced Urban Network and Statutory Urban Network were amalgamated to form the Automatic Urban Network (AUN) consisting of 30 sites in the UK's major urban areas. Throughout the next five years over 50 local authority sites were subsequently integrated into the network including 14 of the London Air Quality Monitoring Network sites. In 1998 the separate urban and rural networks were combined to form the joint Automatic Urban and Rural Network (AURN), then consisting of 103 sites.

Several phases of expansion have since taken place, as well as the addition of the $PM_{2.5}$ size fraction. At the time of writing this edition of the Manual, there are 172 monitoring stations within the AURN, including 16 Automatic London Network (ALN) sites.

2.2. AURN Pollutants Monitored

The AURN monitors five pollutants: oxides of nitrogen (NOx, which comprises nitric oxide (NO) and nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), ozone (O_3) and suspended particulate matter (PM). Particulate matter is subdivided into two size fractions, PM_{10} and $PM_{2.5}$. Information on the sources and effects of these pollutants is provided below.

Particulate Matter

Particulate matter (PM) is a complex mixture of organic and inorganic substances. Particles can be primary (emitted directly to the atmosphere) or secondary (formed by the chemical reaction of other pollutants in the air such as SO_2 or NO_2). Particles may arise from a wide variety of sources, man-made or natural. The main source of man-made particles is combustion, e.g. vehicles and power stations. Other man-made sources include quarrying and mining activities, industrial processes, dust from construction work and particles from tyre and brake wear. Natural sources include wind-blown dust, sea salt, pollens, fungal spores and soil particles.

Particles found in ambient air range in size from a few nanometres (nm, or 10^{-9} m) to several hundred micrometres (µm, or 10^{-6} m) in diameter. Particle size is usually expressed in terms of its aerodynamic diameter. Two size fractions of particulate matter are measured in the AURN: PM_{10} and $PM_{2.5}$. PM_{10} is the mass concentration (expressed in µg m^{-3}) of PM that has a mean aerodynamic diameter of 10 µm. These particles are small enough to penetrate deep into the airways, carrying surface-absorbed harmful compounds into the lungs and increasing the risk of health effects. $PM_{2.5}$ is of particular concern, as it can penetrate deeper into the lungs than PM_{10} and is harder for the body to remove.

The range of health effects associated with PM is broad, but is predominantly related to the respiratory and cardiovascular systems. Susceptibility to the effects of PM may vary with health or age. There is little evidence to suggest a threshold below which no adverse health effects would be anticipated.

Up to date information on UK emissions of PM, and the relative importance of various sources, can be found in Defra's National Statistics on Emissions of Air Pollutions, which is downloadable from the following web page, updated annually: https://www.gov.uk/government/statistics/emissions-of-air-pollutants

Oxides of Nitrogen

Nitrogen can form several oxides but only two are of interest in the context of air pollution. These are nitric oxide (NO) and nitrogen dioxide (NO_2), collectively referred to as NOx. (Nitrous oxide, N_2O, is implicated in climate change, but does not appear to have significant health impacts at ambient concentrations and is not measured by the AURN).

Combustion processes release a mixture of NO and NO_2, formed by oxidation of nitrogen in the air itself, as well as in the fuel. NO_2 is of concern because it is harmful to human health (it is a respiratory irritant). NO is not generally considered harmful to health at the concentrations found in ambient air: however, it is quickly oxidised to form more NO_2.

For the UK as a whole, approximately 30% of all NOx emissions originate from road vehicles, with most of the remainder arising from other forms of non-road transport, energy generation, industry, manufacturing and construction[1]. Since power station and industrial emissions are usually from high chimneys, away from city centres, motor vehicles represent by far the largest source of low-level NOx emission and therefore make the largest contribution to long term ground level concentrations in urban areas. For this reason, highest NOx levels in cities are usually found at roadside locations.

Up to date information on UK emissions of NOx, and the relative importance of various sources, can be found in Defra's National Statistics on Emissions of Air Pollutions, which is downloadable from the following web page, updated annually: https://www.gov.uk/government/statistics/emissions-of-air-pollutants

Sulphur Dioxide

Sulphur dioxide (SO_2) is an acidic gas, formed by the oxidation of sulphur impurities in fuels during combustion processes, particularly of coal, heavy fuel oil and petroleum coke (a solid fuel produced from oil), which account for over 90% of SO_2 emissions. The main source of SO_2 in recent years has been combustion in energy production and transformation, followed by domestic combustion and then combustion in manufacturing. SO_2 emissions and atmospheric concentrations levels have fallen by over 95% since 1990, largely due to the closure of coal fired power stations[2] which resulted in a decreased use of coal and increasing use of abatement equipment in the industrial and power generation sectors.

Up to date information on UK emissions of SO_2, and the relative importance of various sources, can be found in Defra's National Statistics on Emissions of Air Pollutions, which is downloadable from the following web page, updated annually: https://www.gov.uk/government/statistics/emissions-of-air-pollutants

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[1] https://www.gov.uk/government/publications/emissions-of-air-pollutants/annual-emissions-of-nitrogen-oxides-in-the-uk-1970-2018#:~:text=Major%20emission%20sources%20for%20nitrogen%20oxides%20in%20the%20UK&text=Road%20transport%20accounted%20for%2031,accounted%20for%2014%20per%20cent.

[2] https://www.gov.uk/government/publications/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-1970-to-2018-sulphur-dioxide-so2

SO_2 is a respiratory irritant and can cause constriction of the airways. It can also react with other pollutants in the atmosphere to produce secondary particulate matter (PM). Finally, at high concentrations it can damage plants, and through acid deposition (so-called “acid rain”) contributing to acidification of soils and waters.

Carbon Monoxide

Carbon monoxide (CO) is a colourless, odourless gas produced when fuels containing carbon are burned with insufficient oxygen to fully oxidise the carbon present. Petrol engines used to emit significant amounts of CO but concentrations are now very low due to the introduction of catalytic converters on car exhausts. However, ambient carbon monoxide in urban areas results almost entirely from vehicle emissions. In urban areas, concentrations are highest at the kerbside and decrease rapidly with increasing distance from the road.

Carbon monoxide affects health by preventing the blood carrying oxygen around the body. People are more likely to be exposed to dangerous concentrations of CO indoors – for example, from a faulty heating appliance. Cigarette smoke is also a major source of exposure.

Ozone

Ozone (O_3) is a form of oxygen containing three atoms per molecule rather than the usual two. In the stratosphere (part of the upper atmosphere) O_3 is formed by the action of ultraviolet light on oxygen molecules. This produces the “ozone layer”, and at this level the gas has a beneficial effect by absorbing harmful ultraviolet radiation from the sun.

In the lower atmosphere, however, O_3 is an air pollutant. It is produced by the photochemical effect of sunlight on oxides of nitrogen and volatile organic compounds produced by motor vehicles and industry. These reactions take place over periods of several hours or even days. Once formed, O_3 can travel long distances, accumulate and reach high concentrations often far away from the sources of the original pollutants. For this reason, levels of O_3 in the air are often higher in rural areas. For example, it is often the case that when O_3 levels are elevated in the South East of England, much of the O_3 has originated in continental Europe. O_3 concentrations are greatest in the summer (usually on hot, sunny, windless days) and lowest in the winter months.

Also, NO reacts with O_3 to form NO_2. This means NO emissions have a “scavenging” effect, reducing local concentrations of O_3. This often means that levels of ozone are low at roadside locations where levels of other pollutants are highest.

O_3 is an oxidising agent and acts as an irritant to the respiratory tract. It is also harmful to vegetation.

2.3. Overview of Operational Structure

The AURN is not operated by a single organisation but by a number of organisations working together, each under contract to the Environment Agency.

Figure 1 shows an organisational chart showing the links between the various participants. The main Network participants, their roles, and the current contractors, are also listed in Table 1.1.

The customer is the Environment Agency, they manage the contract on behalf of UK Government (Defra, and the Devolved Administrations of Wales, Scotland and Northern Ireland). At the time of writing, UK Government provides the data to the European Commission as required under EU law (European Commission, 2008).

Within the AURN there is a subset of sites in and around London, called the Automatic London Network (ALN). The contracts for management and QA/QC of the ALN are let separately, therefore may be different from those of the main AURN. In this document, 'AURN' means the whole network including ALN sites unless specifically stated otherwise.

At the time of this update, the main contractors are:

- the Central Management and Coordination Unit (CMCU). At the time of writing, there is one CMCU contractor, covering all sites in the main AURN, and the ALN subset.
- the Quality Assurance and Quality Control (QA/QC) Unit (which is independent of the CMCU). At the present time there are two QA/QC Unit contractors: one for the main AURN and one for the ALN subset.
- the Calibration Gas Supplier (responsible for providing the standard gas mixtures needed to calibrate the monitoring instrumentation.

Local Site Operators and the Equipment Support Unit are subcontractors to the CMCU.

Finally, the Data Dissemination Unit (DDU) is shown because although this is a separate contract and not part of the AURN, it has an important role in ensuring that the data from the AURN and other networks and conveyed quickly and accurately to the public.

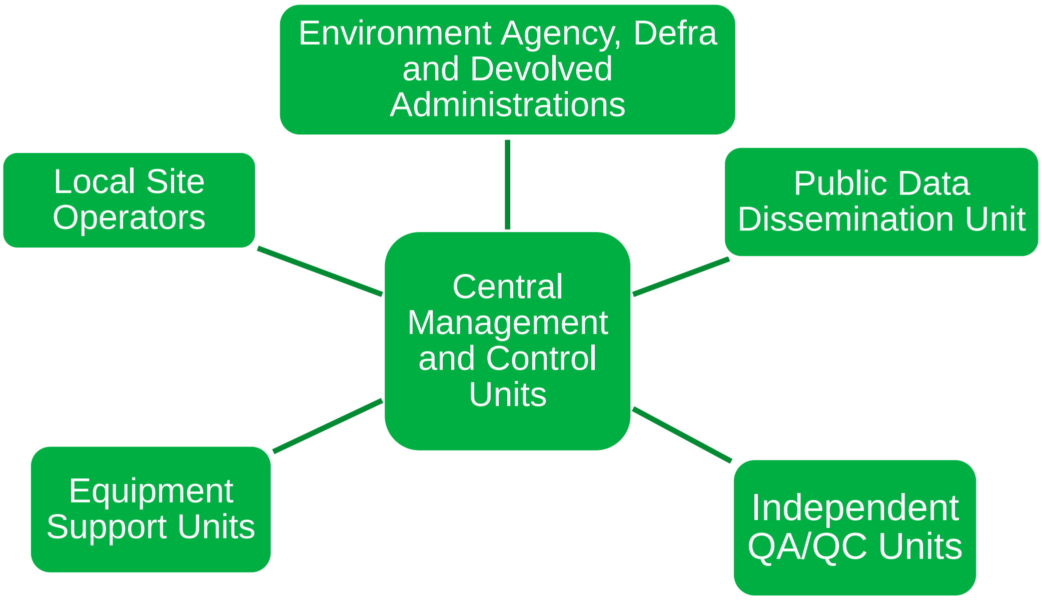

Figure 1 - Structure of the AURN: Main Network Participants

Table 1.1 Roles and Responsibilities of AURN Contractors

Role	Responsibilities	Current Contractor
Central Management and Co-ordination Unit (CMCU)	• Overall network management • Site selection and installation • Appointment and management of local site operators • Appointment and management of equipment support contractors • Data acquisition from sites • Front-end data validation • Provide provisional data to Communications Unit (DDU) and QA/QC Unit • Retain a copy of repair and service records for all sites	Bureau Veritas for all AURN sites (main AURN and ALN).
Quality Assurance and Quality Control (QA/QC) Unit	• Network intercalibrations • Local Site Operator training • Local Site Operator audits • Preparation and maintenance of operational manuals • Final data ratification • Investigation of poor data • Commissioning of new sites • Calibration of ESU photometers • Testing standard gases. • Supply the ratified datasets to the DDU.	Ricardo Energy & Environment for main AURN: NPL for ALN.
Equipment Support Units (ESUs)	• Equipment supply and maintenance • Emergency response to equipment breakdown • Six-monthly equipment servicing (inc. preventative maintenance) • Maintain spare equipment and parts inventory • Retain a copy of repair and service records for all sites	Various organisations
Local Site Operators (LSOs)	• Management of local site • Routine instrument calibrations	Various organisations

	- Emergency call-out visits	
Gas Standards Supplier	- Provision of gas calibration standards	BOC
Data Dissemination Unit (DDU) Note: this is actually a separate contract and not formally part of the AURN.	- Receive hourly data from network managers - Compile and disseminate air quality bulletins	Ricardo Energy & Environment

2.4. Direct-Funded and Affiliate Sites

In terms of how the site management is paid for, AURN sites can be grouped into two categories: “direct funded” sites and “affiliate” sites.

In the case of direct funded sites, the Environment Agency own the site and equipment, and pay for all the costs associated with operating the site.

“Affiliate” sites are usually pre-existing Local Authority-run sites, originally set up for Local Air Quality Management purposes, which the Environment Agency (EA) has incorporated (or “affiliated”) into the AURN. In this case, the EA pays for the data management, site audits and calibration gases. However, it does not pay the Local Site Operator organisation a fee to cover their time, or cover the cost of the Equipment Support Unit.

There are also some affiliate sites which contain Environment Agency-owned instrumentation, so the distinction between “direct funded” and “affiliate” sites is less clear-cut than it once was.

Both types of site are operated to the same standards of data quality, and data from both types of sites are treated identically.

2.5. Relationship with the London Air Quality Network

Some sites within the London Air Quality Network (LAQN) are also part of the AURN, managed under the Automatic London Network (ALN) contract and associated Management Unit and QA/QC Unit. LAQN sites are similar to affiliate sites in the way that they are operated and paid for.

The majority of AURN sites in London (although not all) are also part of the LAQN. However, a substantial proportion of the sites in the LAQN are not part of the AURN.

2.6. Relationship with the Data Dissemination Unit

The Data Dissemination Unit is the organisation contracted to disseminate the data from the AURN and the other networks, to the public and media.

The DDU ensures that provisional data from the AURN are uploaded every hour to the UK-AIR website, and a free telephone information service (0800 556677). In addition, they are distributed daily to the media via the air quality bulletin service. “Nowcasts” are also sent out three times per day via Twitter.

When the data have been further checked and ratified they are reissued to the UK-AIR website as ratified data. This happens on a quarterly basis.

The daily data summaries and the hourly data provided to the web and the Freephone service are primarily intended to inform the public of current air pollution conditions. Health advice is also provided so that sensitive individuals can take appropriate action, such as increased medication, staying indoors or reducing physical activity. This service also now fulfils the Air Quality (Standards) Regulations requirement for information to be provided to the public and for pollution alerts to be issued when specified alert thresholds are exceeded over a 3-hour period. During severe episodes, the Government may also issue advice to the public on how to reduce pollutant emissions by restricting car use or other polluting activities.

3. Quality Assurance/Quality Control Objectives

Good data quality and high data capture rates are essential if the AURN is to achieve its objectives. To ensure that data are sufficiently accurate, reliable and comparable, consistent data quality assurance/control (QA/QC) procedures are applied throughout the network.

Good QA/QC practice covers all aspects of network operation, including systems design and site selection, equipment evaluation, site operation, maintenance and calibration, data review and ratification. The successful implementation of each component of the QA/QC scheme is essential for the success of the programme.

The fundamental aims of a quality assurance/control programme are as follows:

1. The data obtained from measurement systems should be representative of ambient concentrations existing in each urban and rural area;
2. Measurements must be accurate, precise and traceable;
3. Data must be comparable and reproducible. Results from this geographically extended network must be internally consistent and comparable with international and other accepted standards;
4. Results must be consistent over time; and
5. In order for seasonally or annually averaged measurements to be meaningful, an appropriate level of data capture is required throughout the year.

The National Measurement System (NMS) exists to provide a formal infrastructure for all measurements in the United Kingdom. At its core are primary standards held by the National Physical Laboratory (NPL), together with appropriate absolute or traceable metrology standards maintained at other designated laboratories. Essential requirements for conformity with the NMS are as follows:

- Measurement methods used must be of known performance and defined scope of application;
- All calibrations must be traceable through an unbroken chain to international standards (the SI system);
- Measurements should be made within a documented quality system;
- Where possible, measurements should be harmonised with those made by organisations both within and outside UK.

The suite of AURN LSO manuals describes the documented procedures and record-keeping systems necessary to ensure that on-site network operations comply with the overall QA/QC programme objectives specified above, and are also compatible with the requirements of the UK National Measurement System.

However, documenting the procedures alone is not enough: they must also be followed properly by everyone involved. To help ensure that this happens, the QA/QC Unit provides full training to LSOs. This training is intended to ensure that the site operators understand the monitoring techniques involved, and the network procedures required, to maintain a high standard of performance.

Compliance with documented procedures is also closely monitored by the QA/QC Unit during intercalibrations, audits of site operators and on-going data assessments. It is a requirement that LSOs must make themselves available for an intercalibration visit if a member of the QA/QC unit requests that they do so.

4. Data Requirements

For many years, the primary data objective of the AURN has been to comply with the European Union’s Air Quality Directive (Directive 2008/50/EC) (European Commission, 2008).This Directive came into force while the UK was a Member State of the European Union (EU), and the UK was required to incorporate (or ‘transpose’) the its full into UK legislation. This was done by means of the Air Quality Standards Regulations, for England, Wales, Scotland and Northern Ireland (UK Government , 2010), (Welsh Government, 2010), (Scottish Government, 2010), (Department of Environment , 2010) plus subsequent amendments (UK Government , 2016), (Scottish Government, 2016), (DAERA, 2017).

The UK left the European Union in 2020. However, the European Union (Withdrawal) Act ensured that existing EU environmental law continues to have effect in UK law.

The Air Quality Standards Regulations, like the Directive on which they were based, set out data quality objectives regarding the maximum uncertainty of measurements and the minimum data capture. These are presented in Table 4.1.

Table 4.1 Measurement uncertainty objectives given in Air Quality Standards Regulations

Parameter	Uncertainty for Continuous Measurement[3]	Minimum Data Capture
NO_2, NOx	15%	90%
SO_2	15%	90%
Particulate Matter	25%	90%
CO	15%	90%
O_3	15%	90%

The methodology for calculating uncertainties is specified by the European Committee for Standardisation (CEN – Comité Européen de Normalisation). Details are given in the relevant CEN documents.

New types of analysers must be tested to ensure they meet CEN standards. In the UK, this is evaluated under MCERTS, the Environment Agency's Monitoring Certification Scheme reviews analyser test results to determine whether they meet the CEN standards. Only those analysers that meet the CEN standards are shown to be equivalent to the reference method. In compliance with the European Directive, all analysers used in the AURN had to be proven equivalent to the reference method as of June 2013. More information on the reference methods can be found in Section 6 of this document.

4.1. Data Capture

Data capture rates provide a good indicator of overall network performance and the temporal representativeness of the information gathered. They should not be assessed in isolation, however, as there is a trade-off in the operation of any network between data quality and capture. Overly stringent quality requirements will reduce data capture rates while, conversely, capture rates can always be maximised by relaxing or removing data quality/acceptance criteria.

To achieve an appropriate balance between these two factors, the data quality criteria should be set with regard to the overall aims and objectives of the network. The aim should then be to maximise data capture, within the constraints thus set. Only if acceptable data quality and high capture rates are achieved can the performance of a network be regarded as satisfactory. The data capture target for the AURN is 90%, as specified in the Air Quality Standards Regulations. There is a 5% allowance for planned maintenance, reducing the target to 85%.

Data loss in any network can result from a number of factors. The most important in practice are as follows:

- Analyser breakdown
- Site servicing

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[3] The percentages for uncertainty in Table $_{3.1}$ are given for individual measurements averaged over the period considered by the limit value (or target value in the case of ozone). For a 95% confidence interval. The uncertainty for the fixed measurements shall be interpreted as being applicable in the region of the appropriate limit value (or target value in the case of ozone).

- Site relocation/upgrading
- Failure or leak of gas sampling system
- Data acquisition system failure
- Power cut or other site disruption
- Communications Failure
- Operator error
- Vandalism
- Air conditioning faults
- Data rejection (after failing QA/QC criteria).

Automatic analysers carry out a daily automatic calibration. If properly designed and configured, these automatic calibrations should *not* result in loss of hourly average data. In well-run networks, the major failure mode will be analyser breakdown: these instruments are complex and 100% reliability cannot reasonably be expected. Data loss due to most other problems can be minimised by:

- Efficient data telemetry (enabling on-site problems to be identified rapidly)
- Backup data storage media on-site
- Rapid service, maintenance and repair
- Comprehensive and documented site operational protocols
- Regular application of these protocols
- Experienced site operators
- Proven site infrastructure and system backup, and
- The deployment of proven analyser types.

Detailed analysis of the reasons for loss of data is provided in the quarterly and annual data ratification reports produced by the QA/QC Unit(s). The quarterly operational reports are produced for the EA only: the annual technical reports are published and available on the reports database on UK-AIR and the AURN Hub.

In the AURN, one of the main reasons for data loss is analyser breakdown. For “direct funded” sites, owned by the EA, it is the CMCU’s responsibility to notify the ESUs of breakdowns. For affiliate sites, it is the LSO’s responsibility to notify the ESUs of any breakdowns. It is very important that the ESU responds to a “call out” as soon as possible to minimise analyser downtime. For EA-owned sites the ESUs are required to attend to the fault within 48 hours. For affiliated sites it is recommended that the site operators have a similar arrangement with their ESUs. For ALN specified sites, any ESU (or LSO) call out must be attended within 72 hours. An example specification for the servicing and maintenance of air quality monitoring equipment for the automatic urban and rural networks is provided in Appendix A to this manual, and on the AURN Hub.

5. Network Design and Site Selection

The main objective of the AURN has historically been to monitor the UK’s compliance with the European Union Air Quality Directive 2008/50/EC (the Air Quality Directive) (European Commission, 2008). Since the UK's departure from the EU, the main objective has been to monitor compliance with equivalent obligations in the Air Quality Standards Regulations. The network therefore has been designed to meet the criteria set by the Regulations. These relate to the number of sites, their distribution within the UK, and the characteristics of the monitoring site itself.

This chapter describes the design criteria used for the Automatic Urban and Rural Network as a whole, and the selection of the monitoring site locations.

5.1. Zones and Agglomerations

For compliance with the Air Quality Standards Regulations, the UK has been split into 43 reporting “zones” and “agglomerations” (continuous urban areas with a population of more than 250,000). These are shown in Figure 2. There are 28 agglomerations in the UK: the remainder of the country has been split into 15 zones. These zones coincide with Government statistical regions in England and areas defined by the respective Devolved Administrations (DA’s) in Wales, Scotland and Northern Ireland.

The Air Quality Standards Regulations, like Directive 2008/50/EC on which it was based (European Commission, 2008), specifies the minimum number of air quality monitoring stations required in each zone and agglomeration. The AURN was optimised during 2007/08 to ensure that these monitoring requirements were fulfilled (AEA Technology plc, 2010). Since then, it has been periodically re-assessed to ensure that it remains compliant, and new sites added as necessary.

For protection of human health, the required minimum number of sampling points per agglomeration/zone is based on two factors:

1. The population of the agglomeration or zone.
2. Whether maximum concentrations in the agglomeration/ zone exceed a threshold set by the Regulations (the “upper assessment threshold”, which is a certain percentage of the Limit Value).

This is not a factor when calculating the minimum number of sampling points for ozone.

For the protection of vegetation, in zones, the minimum number of sampling points required per unit area depends upon the maximum concentrations detected in the zone. (Limit Values for protection of vegetation are not usually applicable in agglomerations.)

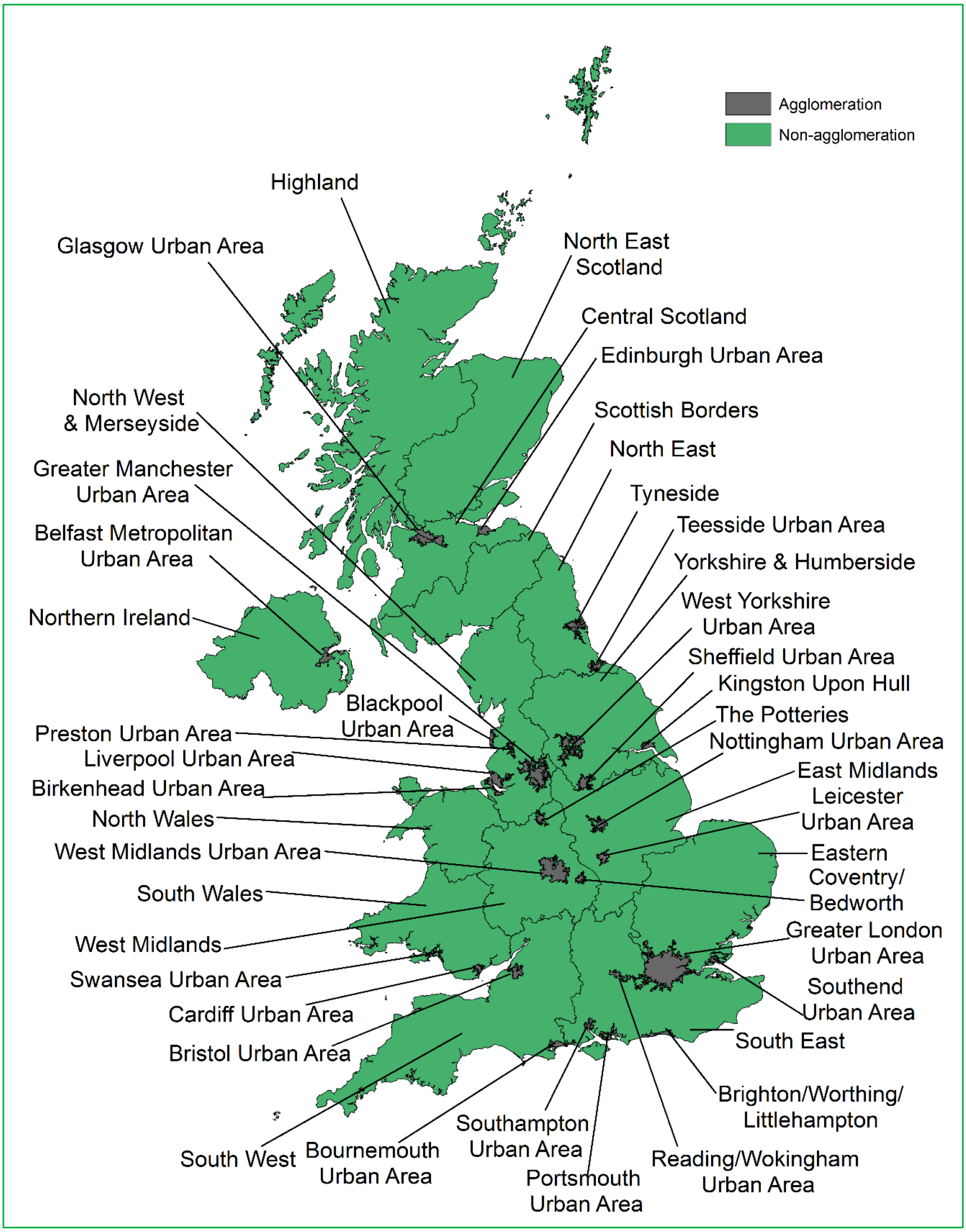

Figure 2 Zones and Agglomerations in the UK

5.2. Site Location Criteria

As well as the numbers of monitoring sites required, the Air Quality Standards Regulations refer to the Air Quality Directive's siting requirements. These are divided into two categories:

- “macro-scale” criteria, relating to the surroundings of the monitoring site, and the area of which it is representative, and

- “micro-scale” criteria, which relate to the positioning of the actual site and its inlet, taking into account factors such as distance from the kerb, and free flow of air to the inlet.

Sites within the AURN should meet these criteria. The Air Quality Standards Regulations do not reproduce these criteria but instead refer to Directive 2008/50/EC: therefore in this section we refer to the Directive rather than the Regulations.

In accordance with Directive 2008/50/EC from which they were derived, air quality need not be assessed at any locations situated within areas where members of the public do not have access and there is no fixed habitation. This includes factory premises and industrial installations where health and safety at work regulations (UK Government, 1999) apply. It also includes the carriageway and central reservations of roads except where there is normally pedestrian access to the central reservation.

5.2.1. Macro-Scale Siting Criteria

The text in the box below is taken directly from Annex III of the Air Quality Directive:

> 1. Protection of human health
>
> (a) Sampling points directed at the protection of human health shall be sited in such a way as to provide data on the following:
>
> — the areas within zones and agglomerations where the highest concentrations occur to which the population is likely to be directly or indirectly exposed for a period which is significant in relation to the averaging period of the limit value(s),
>
> — levels in other areas within the zones and agglomerations which are representative of the exposure of the general population,
>
> (b) Sampling points shall in general be sited in such a way as to avoid measuring very small micro-environments in their immediate vicinity, which means that a sampling point must be sited in such a way that the air sampled is representative of air quality for a street segment no less than 100 m length at traffic-orientated sites and at least 250 m × 250 m at industrial sites, where feasible;
>
> (c) Urban background locations shall be located so that their pollution level is influenced by the integrated contribution from all sources upwind of the station. The pollution level should not be dominated by a single source unless such a situation is typical for a larger urban area. Those sampling points shall, as a general rule, be representative for several square kilometres;
>
> (d) Where the objective is to assess rural background levels, the sampling point shall not be influenced by agglomerations or industrial sites in its vicinity, i.e. sites closer than five kilometres;
>
> (e) Where contributions from industrial sources are to be assessed, at least one sampling point shall be installed downwind of the source in the nearest residential area. Where the background concentration is not known, an additional sampling point shall be situated within the main wind direction;
>
> (f) Sampling points shall, where possible, also be representative of similar locations not in their immediate vicinity;
>
> (g) Account shall be taken of the need to locate sampling points on islands where that is necessary for the protection of human health.
>
> 2. Protection of vegetation and natural ecosystems

Sampling points targeted at the protection of vegetation and natural ecosystems shall be sited more than 20 km away from agglomerations or more than 5 km away from other built-up areas, industrial installations or motorways or major roads with traffic counts of more than 50,000 vehicles per day, which means that a sampling point must be sited in such a way that the air sampled is representative of air quality in a surrounding area of at least 1,000 km2. A Member State may provide for a sampling point to be sited at a lesser distance or to be representative of air quality in a less extended area, taking account of geographical conditions or of the opportunities to protect particularly vulnerable areas.

Account shall be taken of the need to assess air quality on islands.

The surrounding area, within say 100 m, should not be expected to undergo major redevelopment, so as to avoid disruption and to allow long-term trends to be followed. For industrial sites, where specific sources are being targeted, monitoring should be carried out at the point of maximum impact as determined by modelling.

5.2.2. Micro-Scale Siting Criteria

The text in the box below is taken directly from Annex III of the Air Quality Directive:

In so far as is practicable, the following shall apply:

- the flow around the inlet sampling probe shall be unrestricted (free in an arc of at least 270°) without any obstructions affecting the airflow in the vicinity of the sampler (normally some metres away from buildings, balconies, trees and other obstacles and at least 0.5 m from the nearest building in the case of sampling points representing air quality at the building line),
- in general, the inlet sampling point shall be between 1.5 m (the breathing zone) and 4 m above the ground. Higher positions (up to 8 m) may be necessary in some circumstances. Higher siting may also be appropriate if the station is representative of a large area,
- the inlet probe shall not be positioned in the immediate vicinity of sources in order to avoid the direct intake of emissions unmixed with ambient air,
- the sampler’s exhaust outlet shall be positioned so that recirculation of exhaust air to the sampler inlet is avoided,
- for all pollutants, traffic-orientated sampling probes shall be at least 25 m from the edge of major junctions and no more than 10 m from the kerbside.

The following factors may also be taken into account:

- interfering sources,
- security,
- access,
- availability of electrical power and telephone communications,
- visibility of the site in relation to its surroundings,
- safety of the public and operators,
- the desirability of co-locating sampling points for different pollutants,

- planning requirements.

Although not explicitly stated in the Directive, the site should be in as open a setting as possible in relation to surrounding buildings. In particular, immediately above should be open to the sky, with no overhanging trees or buildings. A site under a building canopy or bridge, or in a tunnel or alcove, is not suitable for the AURN. Other things to avoid include:

- Large or multi-storey car parks, within 50 m.
- Petrol stations, ventilation outlets from catering establishments within 20 m.
- Ventilation outlets from underground railway stations.
- Locations where vehicles stop with their engines idling within 5 m of the sample inlet.

5.2.3. Site Classifications[4]

The system of site classification used within the AURN is based upon that in the Air Quality Directive. Sites are classified according to two criteria:

- the nature of the surrounding area (which may be **urban, suburban** or **rural**) and
- the types of pollution sources involved (which may be **traffic, industrial** emissions, or **"background"** i.e. not located close to any specific emission source).

So, a site could be described as (for example) "urban traffic" – in an urban area, and close to a busy road where local concentrations of pollutants are dominated by vehicle emissions, "urban background" – in an urban area but well away from major roads and specific industrial emission sources, or "rural background" if it is in a rural area well away from emission sources. Any combination is possible, although some (such as "rural traffic" or "rural industrial", are likely to be rare).

Urban area (U)

Continuously built-up urban area meaning complete (or at least highly predominant) building-up of the street front side by buildings with at least two floors or large detached buildings with at least two floors. With the exception of city parks, the built-up area is not mixed with non-urbanised areas. For the measurement of ozone, the urban area is defined as locations such as residential and commercial areas of cities, parks (away from the trees), big streets or squares with very little or no traffic, open areas characteristic of educational, sports or recreation facilities. Urban sites should measure air quality which is representative of a few km^2.

Suburban area (S)

Largely built-up urban area. 'Largely built-up' means contiguous settlement of detached buildings of any size with a building density less than for 'continuously built-up' area. The built-up area is mixed with non-urbanised areas (e.g. agricultural, lakes, woods). 'Suburban' as defined here has a different meaning than in everyday English (where it

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[4] Full report on Site classification available here - https://uk-air.defra.gov.uk/assets/documents/reports/cat09/1312171445_UK_Air_Quality_Assessment_Regime_Review_for_AQD.pdf

usually means an outlying part of a larger city or town). Here, a suburban area can exist on its own without being part of a larger city. For the measurement of ozone, suburban areas include those where population, sensitive crops or natural ecosystems located in the outer fringe of an agglomeration are exposed to high ozone levels. Suburban sites should measure air quality which is representative of some tens of km^2.

Rural area (R)

Sampling points targeted at the protection of vegetation and natural ecosystems shall be sited more than 20 km away from agglomerations and more than 5 km away from other built-up areas, industrial installations or motorways or major roads, so that the air sampled is representative of air quality in a surrounding area of at least 1000 km^2. Stations can be located in small settlements and/or areas with natural ecosystems, forests or crops.

Traffic station (T)

Located such that its pollution level is determined predominantly by the emissions from nearby traffic (roads, motorways, highways). Air sampled at traffic sites must be representative of air quality for a street segment no less than 100m length. Sampling probes shall be at least 25m from the edge of major junctions and no more than 10m from the kerbside.

Industrial station (I)

Located such that its pollution level is influenced predominantly by emissions from nearby single industrial sources or industrial areas with many sources. Industry source is here taken in its wide meaning including sources like power generation, incinerators and waste treatment plants. Air sampled at industrial sites must be representative of air quality for an area of at least 250m × 250m. The sampling point shall be installed downwind of the source in the nearest residential area.

Background station (B)

Located such that its pollution level is not influenced significantly by any single source or street, but rather by the integrated contribution from all sources upwind of the station e.g. by all traffic, combustion sources etc. upwind of the station in a city, or by all upwind source areas (cities, industrial areas) in a rural area. These sampling points shall, as a general rule, be representative for several square kilometres. At rural background sites, the sampling point should not be influenced by agglomerations or industrial sites in its vicinity, i.e. sites closer than five kilometres.

5.2.4. Site Selection – Practical Considerations

In addition to the above, there are a number of practical considerations to be taken into account:

- It should be practical for power connections to be made at the site;
- The site should be accessible for a lorry to deliver the housing (if necessary)
- It should be reasonably easy for gas cylinders to be delivered close to the site and transferred to the housing (or the building in which the site is located).
- The LSO should be able to gain access to the site whenever necessary.

- The site should be in an area where the risks of vandalism are minimal.
- Account should be taken of visual impact of the housing.

All sites in the AURN were assessed in 2010 for compliance with the requirements of the EU Directive. The results of this assessment were published in a report[5] available via UK-AIR. Only eight sites were found not to be fully compliant, and these either underwent changes to make them fully compliant or were replaced. A full network re-assessment is planned within the next 12 months.

6. Selection of Monitoring Equipment

The selection of appropriate instruments is essential to the success of any monitoring network in achieving its stated objectives. The objectives of the Automatic Urban and Rural Network (AURN) require precise time-resolved measurements, necessitating the use of automatic analysers. The selection of instruments for the AURN was based on specific and proven analytical techniques for the pollutants measured.

Table 6.1 Operating Principles of Automatic Analysers used in the AURN

Pollutant Measured	Operating Principle
O_3	UV Absorption
NO/NO_2	Chemiluminescence
SO_2	UV Fluorescence
CO	IR Absorption
$PM_{10}/PM_{2.5}$	BAM (Beta Attenuation Monitor) Fidas 200 FDMS (Flow Dynamic Measurement System) Gravimetric Sampler

These techniques represent the current state-of-the-art for automated monitoring networks and, with the exception of the automatic $PM_{10}/PM_{2.5}$ analysers, are the Reference methods of measurement defined in the EU Directives. For the PM analysers, all have demonstrated equivalence under the MCERTS for UK Particulate Matter Certification annex, described fully here.

CEN

The EU requirements for achieving appropriate data quality are stated by the European Committee for Standardisation (CEN – Comité Européen de Normalisation). These standards give the detailed performance specifications for reference monitoring methods and include methodologies for sampling, calibration and on-going QA/QC as part of network operation. The instrument performance specifications are incorporated into the

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[5] **https://uk-air.defra.gov.uk/assets/documents/reports/cat13/1011121246_Site_Classifications_Report_v2.pdf**

Environment Agency's MCERTS (Monitoring Certification Scheme) and into other European product certification schemes, such as TÜV (Technischer Überwachungsverein – Technical Monitoring Association) in Germany. Typical performance specifications of analysers used in the AURN are given in Table 6.2 and have been taken from the following British Standards documents:

- Ambient air quality – Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence, BS EN 14211:2012; (BS EN, 2012)
- Ambient air quality – Standard method for the measurement of the concentration of sulphur dioxide by ultraviolet fluorescence, BS EN 14212:2012; (BS EN, 2012)
- Ambient air quality – Standard method for the measurement of the concentration of ozone by ultraviolet photometry, BS EN 14625:2012; (BS EN, 2012)
- Ambient air quality – Standard method for the measurement of the concentration of carbon monoxide by nondispersive infrared spectroscopy, BS EN 14626:2012; (BS EN, 2012)
- Ambient air — Standard gravimetric measurement method for the determination of the PM_{10} or $PM_{2.5}$ mass concentration of suspended particulate matter BS EN 12341:2014; (BS EN, 2014)2014[9]; and
- Ambient air — Automated measuring systems for the measurement of the concentration of particulate matter (PM_{10}; $PM_{2.5}$)) BS EN 16450:2016. (BS EN, 2016)

As already mentioned in previous sections, as of 11th June 2003, only analysers that are proven to be equivalent to the reference method are allowed in the AURN.

Table 6.2 Typical Specifications for AURN Standard Gaseous Pollutant Analysers

Pollutant Measured by Analyser	**NO_2**	**SO_2**	**O3**	**CO**
Repeatability: Zero At Limit Value	2 µg m^{-3} 6 µg m^{-3}	2.5 µg m^{-3} 8 µg m^{-3}	2 µg m^{-3} 6 µg m^{-3}	1.2 mg m^{-3} 3.5 mg m^{-3}
Linearity	4%	4%	4%	5%
Period of Unattended Operation	3 months	3 months	3 months	3 months
95% Response Time (max)	180 secs	180 secs	180 secs	180 secs

6.1.1. Accreditation

The QA/QC Unit(s) hold UKAS (United Kingdom Accreditation Service) accreditation to ISO 17025 for the on-site calibration of the gas analysers (NOx, CO, SO_2, O_3) used in the AURN, for flow rate checks on particulate analysers (PM_{10} and $PM_{2.5}$), and for the determination of the spring constant, k_0, for the FDMS analyser where applicable.

The accredited procedures for analyser calibration include the following analyser checks:

- Noise
- Linearity
- Response time
- Converter efficiency
- Uncertainty evaluation.

The QA/QC Unit(s) also hold UKAS accreditation for laboratory certification of NO, NO_2, CO and SO_2 gas cylinders, also for laboratory calibration of ozone photometers.

7. Principles of Operation - (How the AQ Monitors Work)

This section explains the principles of operation of the various types of automatic pollutant analyser used in the AURN. The on-site analysers are usually housed in temperature controlled rack units which also contain the data logger and auto-calibration system, where installed. If there is a Partisol or SEQ gravimetric PM monitor at the site, this may be in a separate cabinet. Block diagrams showing the main components of the analysers are included in this section. There may be slight operational differences between different analyser makes and models. However, the measurement methodology will be the same, and these are described below.

7.1.1. UV Absorption Ozone Analyser

Ambient air is drawn into the analyser by a pump, and passes through a reaction cell. Ultra-violet light of wavelength 254 nanometres (1 nm = 10^{-9} m) is passed through the sample. Ozone absorbs light of this wavelength, and this absorption is measured using a UV detector. An ozone-removing scrubber is used to provide a zero reference intensity. The analyser alternately measures the absorption I_0 of the air path with no ozone present and the absorption I_1 of the ambient sample. The concentration (c) is calculated using the Beer-Lambert equation:

$$I_1 = I_0 \, e^{-alc}$$

Where l = the length of the reaction cell, and a = the absorption coefficient at 254nm.

The UV absorption analysers used in the AURN have a single reaction cell, and pneumatic valving to switch between zero and ambient air paths (see Figure 3). Ambient air is sampled using a pump unit. The analysers continually display current O_3 concentrations, and depending on the make and model of analyser other parameters can be selected as necessary. An internal ozone generator and zero air scrubber are used to provide daily automatic check calibrations.

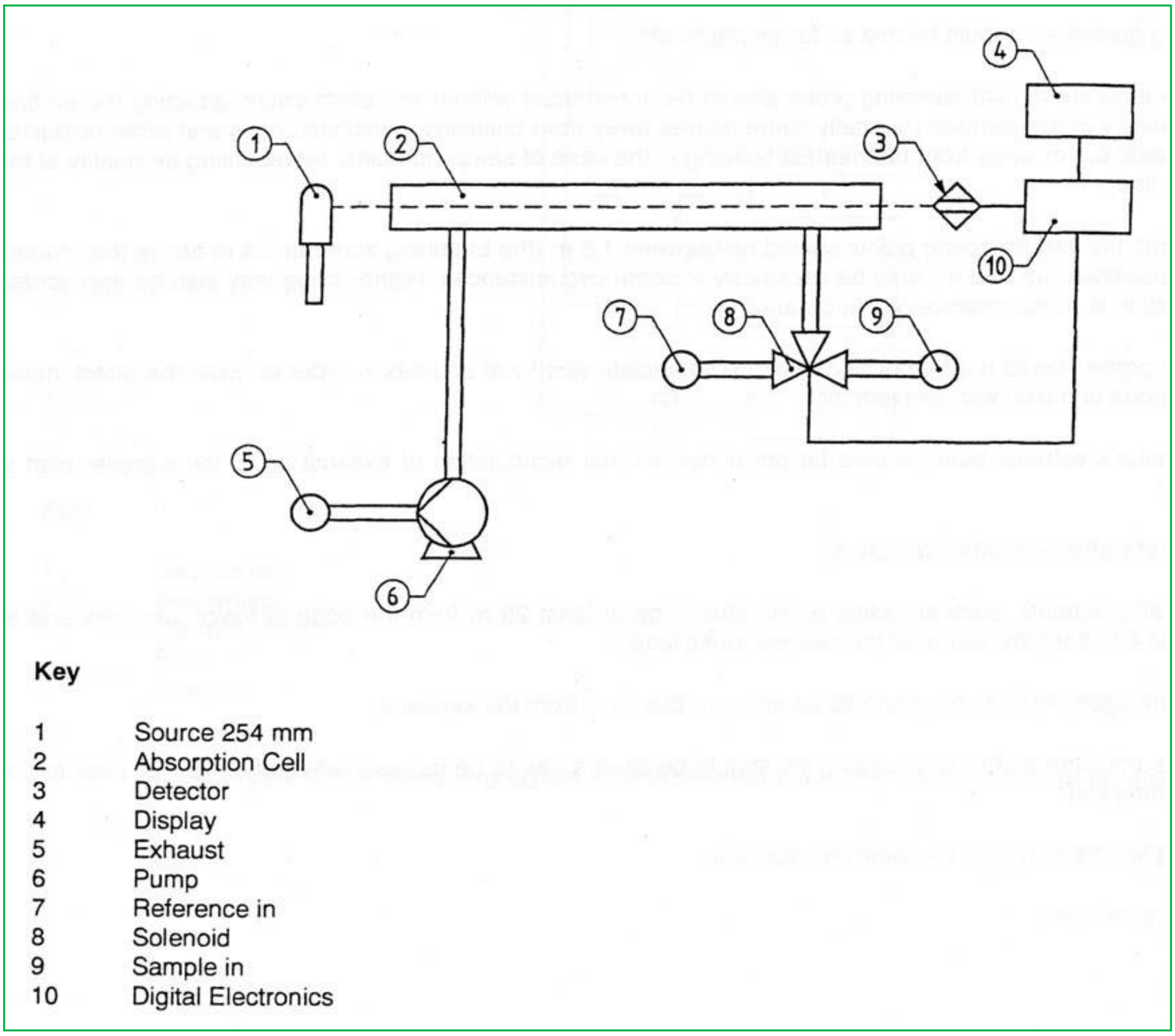


Figure 3 - Schematic Diagram of Ozone Analyser

7.1.2. Chemiluminescent Oxides of Nitrogen Analyser

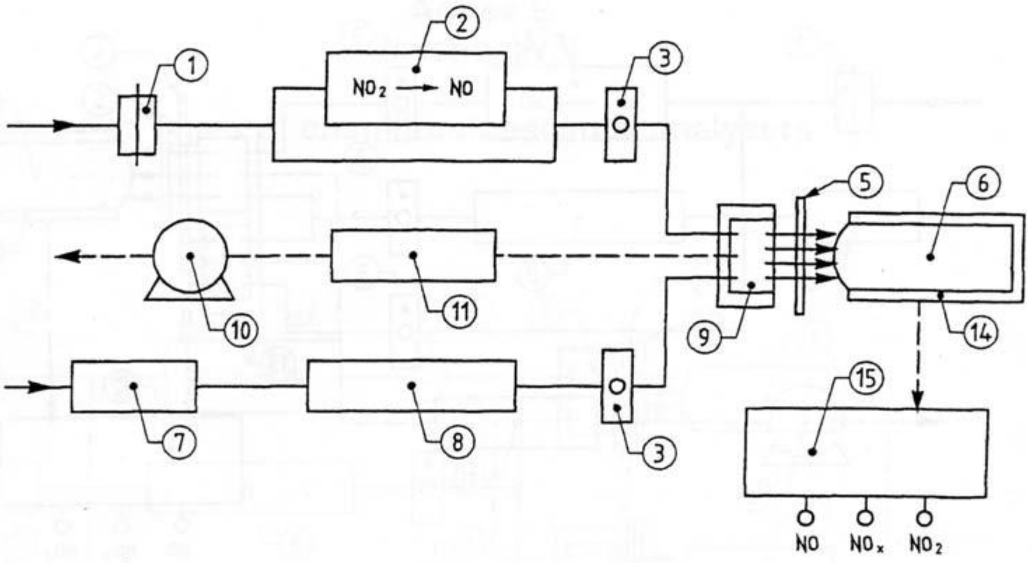
Nitric oxide (NO) in the sample air stream reacts with ozone (O_3) in an evacuated chamber to produce activated nitrogen dioxide (NO_2*). This then returns to its ground (un-activated) state, emitting a photon (chemiluminescence):

$$NO + O_3 \rightarrow NO_2^* + O_2 \rightarrow NO_2 + O_2 + h\upsilon$$

Where O_2 = oxygen and hυ = the energy of the photon of light emitted (h is Planck's constant and υ is its frequency).

The intensity of the chemiluminescent radiation produced depends upon the amount of NO in the sampled air. This is measured using a photomultiplier tube (PMT) or photodiode detector, so the detector output voltage is proportional to the NO concentration. The ambient air sample is divided into two streams; in one, ambient NO_2 is reduced to NO using a "molybdenum converter" (a molybdenum catalyst) before reaction. The molybdenum converter should be at least 95% efficient at converting NO_2 to NO. Separate measurements are made of total oxides of nitrogen NOx (= NO + NO_2) and NO. The ambient NO_2 concentration is calculated from the difference (NO_2 = NOx - NO).

The analysers are equipped with either a single or a double reaction chamber and PMT system. The main components of the analyser are shown in Figure 4. A solenoid valve is used to alternatively switch between NO and NOx (NO + NO_2) measurement typically at 15 second intervals. Ambient air is drawn through the system via a pump and drier unit. The analysers display current NO, NO_2 and NOx concentrations, and depending on the make and model of analyser other parameters can be selected as necessary. An internal permeation oven and zero air scrubber are used to provide daily automatic check calibrations.



Key

1 Particle filter
2 Converter
3 Flow rate controller
5 Optical filter
6 Photomultiplier tube
7 Drier
8 Ozone generator
9 Reaction chamber
10 Sampling pump
11 Ozone filter
14 Refrigerated housing
15 Controls NO-NOx cycling

Figure 4 - Schematic Diagram of Chemiluminescent NOx Analyser

7.1.3. UV Fluorescence Sulphur Dioxide Analyser

Ambient air is exposed to UV light, which excites SO_2 molecules in the sample to higher but unstable excited states. These excited states decay, giving rise to the emission of secondary fluorescent radiation. The fluorescent radiation is detected by a photomultiplier tube, causing an output voltage proportional to SO_2 concentration. A permeable membrane “kicker” is used to remove interfering hydrocarbons before reaction.

These ultra violet fluorescence (UVF) analysers use a filtered UV source and PMT detection system. The main components of the analyser are shown in Figure 5. A UV detector is used to monitor the source radiation and compensate for fluctuations in UV energy. Ambient air is drawn through the system via a pump unit. The analysers continually display current SO_2 concentrations, and depending on the make and model of analyser other parameters can be selected as necessary. Either external gas cylinders or an internal permeation oven and zero air scrubber are used to provide daily automatic check calibrations.

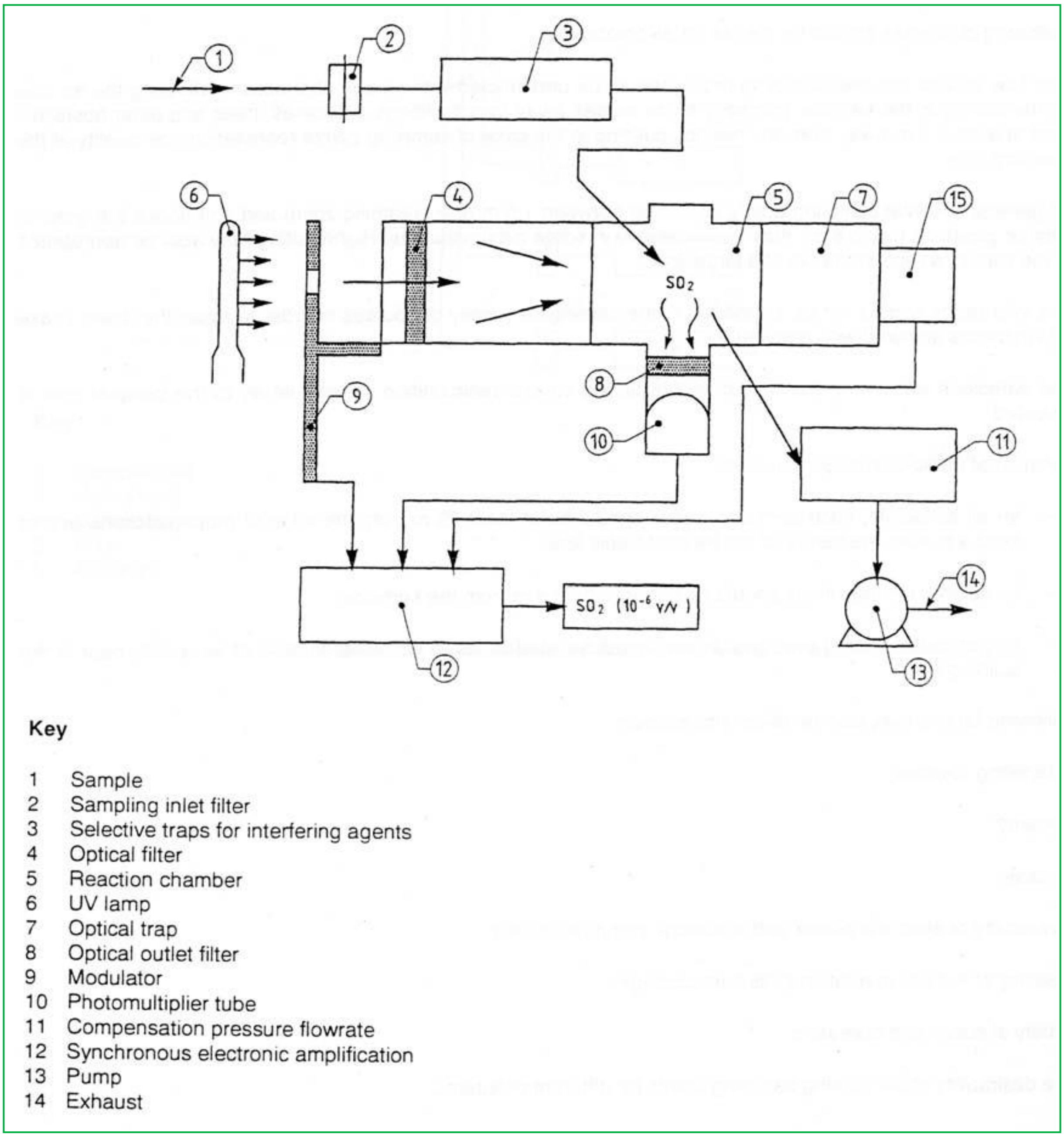


Figure 5 - Schematic Diagram of Sulphur Dioxide Analyser

7.1.4. IR Absorption Carbon Monoxide Analyser

Carbon monoxide (CO) absorbs infrared (IR) radiation in the 4.5 to 4.9 micrometres wavelength range (1 µm = 10^{-6} m). The concentration of CO in a sample of air is measured by absorption. A reference detection system is used to alternately measure absorption due to CO in the ambient air stream, and absorption by interfering species. An infrared detector and amplification system produce output voltages proportional to the CO concentration. The concentration is derived from the Beer-Lambert relation described in Section 7.1.1 above for ozone.

The analysers used in the AURN are usually gas filter correlation infrared absorption analysers. They use a filter wheel to allow alternate measurement of total IR absorption, and that due to interfering species in the absorption band selected (see Figure 6). Alternatively, some CO analysers use the similar Non-Dispersive Infra-Red (NDIR) system. Here, differences in IR absorption between ambient air and reference gas (air with all CO removed) cause a metallic membrane in the detector to move back and forth in accordance with the alternating gas flow and CO concentration.

Ambient air is sampled using a pump unit. The analysers continually display current CO concentrations, and depending on the make and model of analyser other parameters can be selected as necessary. An external carbon monoxide in air calibration cylinder and internal air scrubber or laser air cylinder are used to provide daily automatic check calibrations.

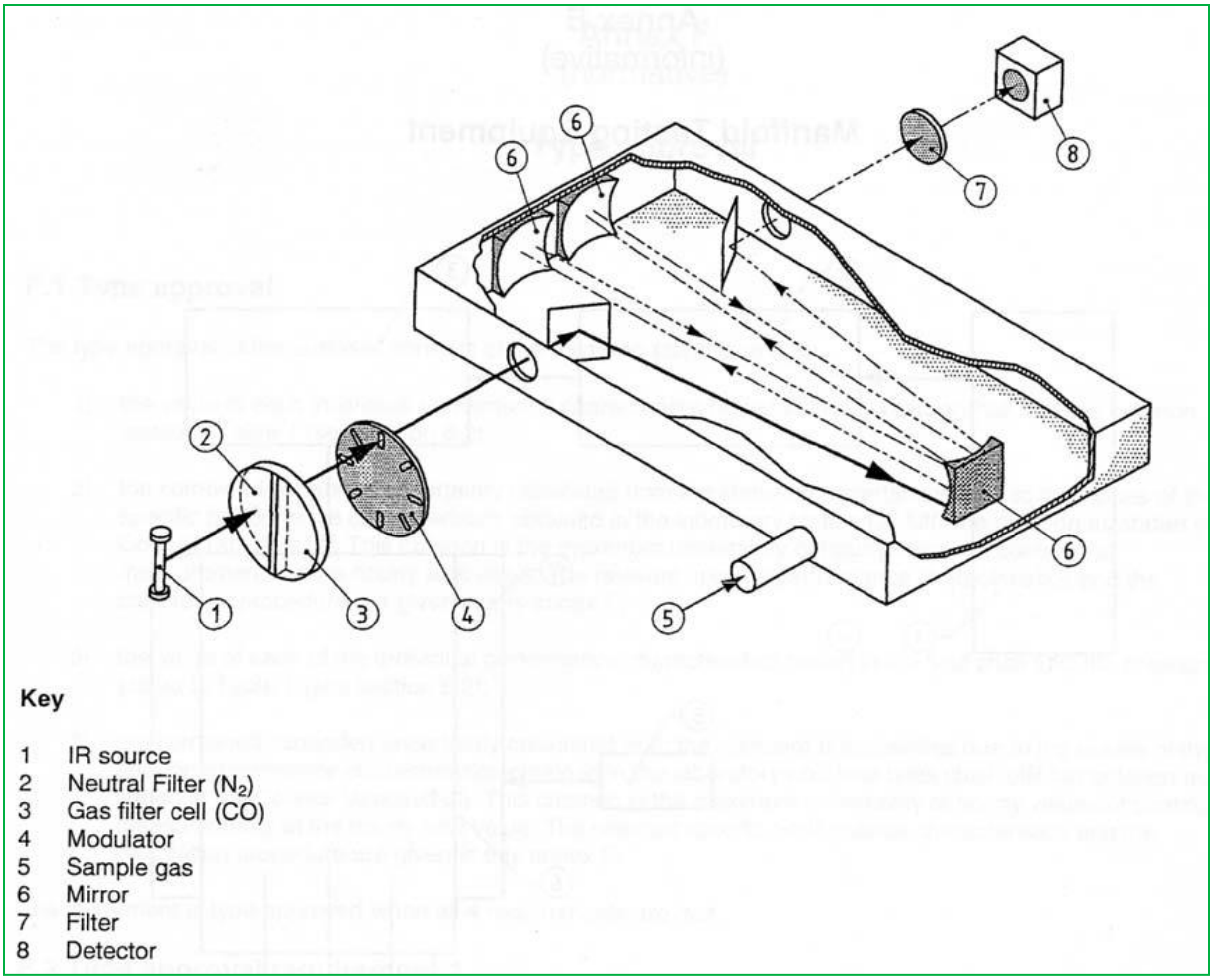


Figure 6 - Diagram of Carbon Monoxide Analyser

7.1.5. Particulate Matter

Within the AURN, two specific size fractions are monitored – PM_{10} (the thoracic fraction), and $PM_{2.5}$ (the high risk respirable size fraction). The same principles are used to monitor both: a size-selective inlet head or cyclone cut-off is used to ensure that only the required size fraction enters the particle analyser.

7.1.6. TEOM (Tapered Element Oscillating Microbalance)

There are no longer any TEOM particulate analysers in the AURN. All underwent modification by retrofitting with an FDMS unit in 2008-2009.

This section has been kept in the manual because it explains the operating principle of the TEOM, which is still applicable to the FDMS analyser.

The tapered element oscillating microbalance (TEOM) system determines particulate concentration by continuously weighing particles deposited on a filter. The filter is attached to a hollow tapered element, which vibrates at its natural frequency of oscillation.

As particles progressively collect on the filter the frequency (f) changes by an amount proportional to the mass deposited (m):

$$m = k_0/f^2$$

Where k_0 is a constant determined during calibration of the TEOM analyser.

The flow rate of air through the system is controlled using thermal mass flow controllers and automatically measured to determine mass concentration. The filter must be manually changed before the mass loading is at the maximum allowed by the system.

The TEOM analyser consists of a sample inlet head attached to the sensor unit, a control unit containing the mass flow controllers and system software and a carbon vane pump. The total flow of 16.67 litres per minute through the sampling head is divided using a flow splitter to give a main flow of 2 (or 3) litres per minute (l min^{-1}) through the filter cartridge and an auxiliary flow of 14.67 (or 13.67) l min^{-1}. The lower sample flow rate of 2 l min^{-1} is often selected to prolong filter lifetime, although the higher flow rate setting provides superior analyser response/noise characteristics, and is, therefore, to be recommended where possible.

The mass concentration, oscillation frequency, filter loading, flow rates, temperature and other diagnostic information can be displayed on the controller's LCD screen. In addition, mass concentration and filter loading are output to the data logger as analogue voltages or through the RS232 interface. The mass concentration is given at the reference conditions of 20°C (293 Kelvin) and 1 Atmosphere (101.3 KPa).

7.1.7. FDMS (Filter Dynamic Measurement System)

There are now very few FDMS remaining in the AURN. The majority have reached the end of their working lives the Environment Agency has undertaken a phased programme of replacement in which old FDMS instruments were replaced with either Fidas 200 or BAMs. This section is included for information about the technique.

The TEOM analyser has a relatively high operating temperature, which is necessary to prevent condensation forming inside the unit. However, this can result in the loss of volatile components of the particulate matter, resulting in under-estimation of the ambient concentration.

The filter dynamic measurement system (FDMS) is a retrofit that can be applied to existing TEOM analysers. When added to the TEOM, the FDMS unit allows measurement of both non-volatile and volatile components of particulate matter (PM) and closely correlates with the gravimetric PM mass concentration, as measured with a reference sampler. All TEOM analysers within the AURN were retrofitted with FDMS units between 2008 and 2009.

The FDMS analyser consists of a sample inlet head attached to the FDMS unit, which is connected to the sensor unit, a control unit containing the mass flow controllers and system software, and a carbon vane pump. As with the TEOM, the FDMS samples ambient air with a flow rate of 16.67 l min^{-1} through the sampling head. Again, this flow is divided using a flow splitter to give a main flow of 3 l min^{-1} through the FDMS and filter cartridge, and an auxiliary flow of 13.67 l min^{-1}.

In order to measure both volatile and non-volatile components of PM, the FDMS uses a switching valve to switch between a “base” measurement and “reference” measurement every six minutes. During the “base” measurement, the FDMS samples as a normal TEOM through the sensor unit filter and weighs the PM. During the “reference” measurement, the FDMS diverts the flow through a purge filter in order to remove all PM from the airstream and the filter is weighed again. The total PM measured during the 12-minute cycle is:

Mass Concentration = Base Concentration – Reference Concentration

During the “reference” measurement, any volatiles collected on the sensor unit filter may evaporate giving a negative mass concentration. This concentration is subtracted from the “base” measurement concentration to give the total PM present.

The mass concentration, base mass concentration, reference mass concentration, oscillation frequency, filter loading, flow rates, temperature and other diagnostic information can be displayed on the controller's LCD screen. In addition, mass concentrations, filter loading and other diagnostics are output to the data logger as analogue voltages or through the RS232 interface. The mass concentrations are given at ambient temperature and pressure.

The Local Site Operator is not required to calibrate the FDMS, but must change the tapered element filter and the purge filter as detailed the relevant site operations section. The auxiliary flow cartridge will be replaced once every six months as part of the service and maintenance procedure.

7.1.8. BAM (Beta Attenuation Monitor)

This instrument measures mass density using the technique of beta radiation attenuation. A small beta source is coupled to a sensitive detector, which counts the beta particles. As the mass of particles increases the beta count is reduced. The relationship between the decrease in count and the particulate mass is computed according to a known relationship – the Beer-Lambert equation (previously shown in Section 7.1.1, in relation to the ozone analyser).

The BAM monitor consists of a paper tape filter located between a source of beta radiation and a radiation detector. A pump draws ambient air through the filter and the reduction in intensity of beta radiation measured at the detector is proportional to the mass of particulate deposited on the filter.

The calibration of the BAM is performed by measuring the absorption of a blank filter tape and a calibration control membrane with known absorption coefficient.

The monitor can be set to operate for 1 to 24 hour cycles with intermediate averages if selected. The sampler will automatically take a measurement and feed the tape on if the filter loading reaches a pre-determined level.

When operated with a PM_{10} sampling head, the monitor is set to operate at a flow rate of 16.7 l min^{-1}.

7.1.9. Fidas 200

The Fidas 200 is an optical aerosol spectrometer. It determines particle size and particle number by analysis of scattered light. It then uses an algorithm developed by the manufacturer, to calculate the mass concentration (µg m^{-3}) of PM_{10} and $PM_{2.5}$.

Ambient air is drawn into the Fidas 200 through a Total Suspended Particulate (TSP) sampling head. The flow rate is 4.8 litres per minute. The sampled air passes through a moisture compensation module known as an Intelligent Aerosol Drying System (IADS); this avoids problems due to condensation inside the instrument. The IADS uses measurements of ambient temperature and relative humidity from outdoor sensors connected to the instrument.

Having passed through the IADS module, the sampled air travels to the aerosol sensor. Here, the particles pass through a measurement chamber illuminated with white light. Each particle causes light to be scattered; the scattered light is detected at an angle of 85º-90º. The Fidas 200 counts the number of scattered light impulses, and calculates the number of particles per unit volume. It also calculates the diameter of each particle from the intensity of the scattered light, and calculates the particle’s volume. It then applies the algorithm to calculate mass concentration. The algorithm which has demonstrated equivalence in the UK is known as ‘Method 11’.

The Fidas 200 provides measurement of TSP, PM_{10} and $PM_{2.5}$. However, like all optical methods its detection efficiency is lower for ultrafine particles: the Fidas 200 is unable to detect particles of size less than 200nm (although the algorithm does compensate for these).

7.1.10. Gravimetric Sampler

This type of sampler involves the collection of particulate matter onto a filter, which is conditioned and weighed before and after sampling, and the deposited mass of PM determined.

Unlike the above types of particulate monitor, the gravimetric sampler is not truly an automatic analyser, because the filters require weighing before and after exposure. This makes the gravimetric method more labour-intensive than the other methods, and also means that data cannot be disseminated in near real-time. Only a small number of gravimetric samplers are currently in use in the AURN.

The Partisol 2025 and SEQ47/50 currently used in the AURN has been designed to meet regulatory monitoring requirements for PM_{10}, $PM_{2.5}$ and other particulate fractions in the US, Europe and other countries. Filters are exposed for 24 hours (midnight GMT to midnight GMT) thus providing daily average concentration data. An active volumetric flow control system maintains a constant volume flow rate at a level specified by the user incorporating a mass flow controller and ambient temperature and pressure sensors. This flow rate provides the requisite $1m^3.hr^{-1}$ (Partisol) and $2.3m^3.hr^{-1}$ (SEQ) volumetric flow for the sample head to maintain its size fraction separation. The sampler uses standard 47mm filters. A filter storage and exchange system enables the instrument to collect daily samples for a period of up to 15 days before operator intervention is required. The temperature of the collection filter is maintained to within 5°C of the outdoor ambient temperature.

Filters are conditioned in a temperature and humidity controlled environment for 48 hours before being weighed both pre- and post- exposure.

At the time of writing (October 2021) only two AURN sites have gravimetric samplers: Port Talbot Margam and London Marylebone Road.

8. Equipment Support Unit Procedures

8.1. Introduction

This section is provided as background information. It provides additional details on the duties and responsibilities of the Equipment Support Unit (ESU).

Monitoring systems can only be relied on to operate satisfactorily and reliably for extended periods of time if they are properly supported and maintained. In the AURN, the maintenance and support of the analysers and associated site infrastructure is undertaken by a number of ESUs, which are usually equipment manufacturers, distributors or service agents.

ESUs are appointed and managed by the Central Management and Coordination Units for the EA and the DAs funded sites. In the case of affiliated sites however, the local authority itself may be directly responsible for arranging the service and maintenance contract. An example ESU contract specification is included in Appendix A for reference for affiliated site owners who appoint their own ESU.

Service and maintenance is of vital importance to the successful operation of the Network. As there are several different ESUs involved in the network, it is important to ensure that consistent operating procedures are followed, in order to achieve satisfactory data quality and capture rates throughout the network.

In order to ensure ESUs have sufficient resources (manpower and equipment) to carry out the work correctly, they may be subject to audit by the CMCU and/or the QA/QC Unit. The ESUs are expected to retain suitable and sufficient records of staff training, competence, equipment records (including proof of traceability) and service sheets for each contracted site visit.

A full technical description of the equipment service and maintenance procedures is not provided here, as these will differ from instrument to instrument and will be carried out following the manufacturer's recommendations. Instead, this section of the manual contains the basic operating guidelines for ESUs, describing the required service and maintenance support for the equipment used in the AURN.

The main tasks performed by ESUs are as follows:

- Routine equipment service (6-monthly)
- Non-routine maintenance and breakdown repairs (emergency call-out)

Each of these tasks is described in more detail in the following sections.

8.2. General Considerations for ESU Site Visits

The following considerations must be adhered to at all sites during both routine ESU service and emergency call-out visits:

3. On arrival at the site, check the pollutant levels on the analyser front panels to see if an episode is occurring (i.e. pollution levels are above or close to the trigger values set out in Section 9.5). In the event of a pollution episode taking place contact the CMCU before proceeding.
4. While analysers are being serviced or under test of any kind, activate the logger status switches (or "out-of-service" switches) to ensure that the analyser response outputs are not treated as ambient data. Reset the switches at the end of the visit. The CMCU should be contacted to inform them of the presence of the ESU on site and to stop dissemination of the data until such time as the tests/service are complete.

Before each six-month service exercise, the ESU should make arrangements with the QA/QC unit to have their photometer(s) calibrated against the network reference instrument. The QA/QC unit will contact all ESU's and request them to make photometers available for calibration one month prior to the start of the intercalibration exercise. ESUs are responsible for taking their photometers to the QA/QC Unit by arrangement for this work to be carried out.

8.3. Routine Equipment Service and Maintenance

Routine service and maintenance of the equipment at each site is carried out every six months, in conjunction with the QA/QC Unit intercalibration exercise. The servicing usually begins in January and July each year and is completed in accordance to a site visit schedule determined by the QA/QC and CMCU or Local Authority.

The ESUs must provide a timetable for the site service visits and this made available on the AURN Hub prior to each 6-monthly service exercise.

CMCU is responsible for ensuring that servicing is completed at each site and that any actions identified from the QA/QC audit are actioned and completed. The ESU must document work completed to the analysers in their service report. The service report is also used to record other tasks completed by the ESU which may include the exchange of fire extinguisher, PAT, ladder inspections and minor repairs to the housing.

The service is carried out in three stages:

- pre-service analyser tests and calibration,
- equipment servicing,
- post-service analyser calibration and tests

Details of these procedures are as follows:

8.4. Pre-Service Instrument Checks and Calibration

Immediately before the analysers are switched off-line for servicing, a full site calibration is undertaken together with basic analyser performance tests (See table below). The pre-service calibration is required to ensure that the analysers are functioning correctly prior to the service and that up-to-date calibration factors for the instruments are obtained for data scaling purposes.

8.5. Pre-Service Procedures

Procedure	Details
Pre-service analyser calibration	The analysers are calibrated in full accordance with the site operator's manual using the on-site gas calibration standards. The results are recorded on the routine calibration sheets and should be clearly marked as PRE-SERVICE results.
Ozone photometer calibration	The ozone analyser is calibrated against a reference photometer. A two-point calibration (at 0 and 200 ppb) is used to determine whether the agreement is to within ±5%. If the result is outside ±5%, then a full multi-point calibration (5 points and a zero) must be performed in order to provide a more accurate determination of the response deviation for data scaling purposes.
NOx converter efficiency	This test is undertaken to determine whether the converter needs replacing prior to service. Any reduction in converter efficiency will result in an under-estimation of measured NO_2 concentration. If the converter efficiency is found to be below 95% then the converter should be replaced. Converter efficiency is tested as follows: A high concentration of NO is diluted by zero air in a mixing vessel to a level near the upper range limit of the analyser. The response from the NO and NOx channels are recorded. The ozone generator is activated to oxidise a proportion of the NO present in the mixing vessel to NO_2. The converter efficiency is then determined from the relative change in NOx and NO outputs.

If the service is started within 14 days of the QA/QC intercalibration visit and the QA/QC unit did not identify any significant problems with the analysers (NOx converter efficiency was found to be >95%, ozone analyser found to be within ±5% of the reference photometer calibration), then these tests need not be repeated by the ESU.

8.6. Site Servicing

Routine service and maintenance of the instruments at each site is carried out according to the equipment manufacturer's recommendations. The visit also provides the opportunity to check, repair and/or replace many items of site infrastructure. Service details are given in the table below. Typical procedures carried out during routine service and maintenance include:

- replacement of all consumable components (e.g. filters, scrubber materials, O-rings)
- dismantling and cleaning of optical and other components
- checking the integrity of the sampling system and pneumatic systems
- lubrication of moving parts
- checking and replacing batteries

- Electrical safety checks on analysers and ancillary site equipment (i.e. PAT testing in accordance with ‘IEE Code of Practice for In-service Inspection and Testing of Electrical Equipment’) on an annual basis
- Replacement of fire extinguisher units, first aid kits
- Completion of the visual inspection of the ladders and installation of an updated ladder tag

8.7. General Servicing Procedures

Procedure	Details
Instrument servicing	The analysers are serviced according to the manufacturer’s recommended procedures. NOTE: The ozone analyser must be serviced first, in order to allow sufficient time for it to warm up and stabilise before recalibration.
Other equipment	Other associated equipment used on site is serviced according to manufacturer’s recommendations including, where applicable: Auto-calibration facilities loggers modems
Sample manifold	The sample manifold and manifold fan are completely dismantled and cleaned. All PTFE sample lines exposed to ambient air, and up to the first sample inlet filter, are cleaned or replaced. All other PTFE tubing is cleaned. If no manifold, sample line Teflon tubing is to be completely replaced.
Zero air cylinders/generators	For some sites the ESU will service and maintain the Zero Air Generator (ZAG) pumps. Zero cylinders will be supplied on the same basis as span cylinders. If requested by the CMCU the ESU will also change the PTFE lines between the ZAG and the instruments, and between the calibration gas cylinders and the instruments.
Air conditioning units	Service and maintenance of these units is carried out according to the manufacturer’s recommendations, either by the ESU or other contracted service engineer.

Ozone analysers must be set up with a slope of 1.00 and offset of 0 following calibration. Should this not result in accurate readings, this must be investigated before leaving site.

Procedure	Details
Leak tests	After service, the analyser's sampling and associated pneumatic systems are tested to ensure that no leaks are present.
Analyser reconfiguration	After a suitable stabilisation time (usually 24 hours) the NOx, SO_2 and CO analysers are reconfigured to show agreement with the gas calibration cylinders.
12-hour span drift test	The analysers are left overnight to sample span gas from the auto-calibration system in order to determine any response drift. . In the case of the CO analyser and analyser systems which use gas cylinders for the auto-calibration system, to conserve auto-calibration gas, the instrument can be left sampling periodically between auto-calibration, span and zero (e.g. once per hour).
Linearity test	A multi-point calibration of the analyser is carried out using five sample gas concentrations, evenly distributed across the analyser's normal running range, and a zero point. The span gas is generated using a high concentration gas species diluted with zero air. The analyser response is then plotted against the concentration of the span gas generated to give a measure of linearity.
NOx converter efficiency	This test only needs to be carried out if the converter has been replaced, adjusted or repaired during service.
Noise levels	The zero and span response noise are examined during tests or calibrations to ensure that they are within the manufacturer's specifications. The response noise can be easily quantified from the logger outputs.
Response time	The response time for the analyser to reach 90% of its final value is examined during calibration.
Kalman/Adaptive filtering	For Serinus 50 SO_2 analysers only, the Kalman filter should be enabled. For all other types of analyser, it is the preference of the QA/QC unit that this function is disabled for all analysers, and the corresponding time constant set to 30 seconds, which is a reasonable compromise between quick response and low noise. However, it is important that the adaptive filtering is set in accordance with the setting used in the type testing carried out on the instrument, and the corresponding time constant identical to that used in the type test.
Post-service analyser calibration	Before leaving the site, the NOx, SO_2 and CO analysers are calibrated in full accordance with the site operator's manual using the on-site gas calibration standards. A multi-point (five points and a zero in the

	range 0-250 ppb) calibration of the ozone analyser against the reference photometer is also performed. All calibration results are recorded on the routine calibration sheets and should be clearly marked as POST-SERVICE results.

8.8. Post-Service Calibration and Analyser Performance Tests

The process of servicing the instruments and associated equipment will usually change the response of the instrument from that obtained prior to service. For this reason, the instruments must be correctly configured and recalibrated before ambient sampling commences. After-service calibration and performance tests are therefore carried out to ensure that the equipment servicing has been successful and that the analysers are correctly set up for the next six months of operation. Post-service procedures are given in the table below.

8.9. Post-Service Procedures

8.10. Documentation of Service Visits

Routine service visits must be fully documented and describe in detail any adjustments modification or repairs undertaken. Results of the analyser tests performed during the service are recorded on the “Analyser Performance Test” form provided, or with any other electronic or paper system which has previously been agreed with the QA/QC andCMCU. The service records, together with the pre and post-service calibration sheets, are e-mailed to the CMCU and QA/QC Unit at the earliest opportunity and within 7 days at the latest.

Contact details are given in on the AURN Hub.

CMCU check through completed service sheets and store these electronically.

8.11. Emergency Call-Out Visits

In the event of equipment breakdown or site problem, the ESU is required to carry out an emergency repair (or call-out) visit.   Emergency call-outs are initiated by the CMCU or local authority responsible for the site. The ESU is normally only called out to a site following an initial investigation by the Local Site Operator. If the problem cannot be resolved by the site operator, then the ESU will be contacted.

In general, the ESU will be requested to attend the site in circumstances in which:

- Instrument malfunction affects data quality or loss of data;
- There is electronic or pneumatic instability of an instrument;
- Auto calibration checks are outside of acceptable tolerances as determined by the CMCU;
- Instruments are not operating within the manufacturer’s specifications;
- Manual calibration checks are outside acceptable tolerance limits, as determined by theCMCU;
- Malfunctions are occurring with the sample manifold, data logging/telemetry or gas calibration systems.

The ESU is usually required to attend an AURN site and effect repairs within 48 hours of being notified by telephone or, e-mail. At ALN sites, the call-out timescale must fall within 72 hours of notification. Call-out arrangements may, however, vary slightly depending on the agreement between the organisations involved. In many cases, the requirement for weekend cover by the ESU is not requested. It is important, however, that ESUs have adequate manpower and equipment spares provision to ensure that 90% data capture targets can be met.

The procedures undertaken during emergency call-outs are given in the table below.

8.12. Emergency Call-Out Procedures

Procedure	Details
“As-found” calibration	Immediately before repair, adjustment or replacement of the analyser, it is calibrated “as-found” using the on-site calibration gas. This calibration is very important as it may give an indication of the effect of the response fault on ambient measurements; it is usually during periods when the analyser performance is suspect or faulty that the quality of the data recorded is of most concern. Note: If a problem with the ozone analyser is suspected, then the ESU must take a reference photometer to the site and calibrate the analyser before and after repair.
Repair	The fault is rectified as appropriate.
Post-repair calibration	The analyser must be allowed sufficient time to warm up after repair, adjustment or replacement. It is then calibrated using the on-site gas calibration standards. The serial number of any analysers being removed or installed must be clearly noted on the calibration records.

8.13. Documentation of Emergency Call-Out Visits

All analyser checks and repairs carried out by the ESU must be carefully documented. For every emergency call-out visit, a “Service Engineer’s Emergency Call-out” form, or the form/spreadsheet agreed with the QA/QC and CMCU, is completed giving full details of the remedial action undertaken. Where appropriate, diagrams or flow-schematics illustrating faults or repairs (e.g. damage to glass sample manifolds or location of sample leak) should also be included as these are useful for data ratification purposes. The emergency call-out form, together with any before and after repair calibration records must be emailed to the CMCU and QA/QC Unit as soon as possible, and within 7 days at the latest.

8.14. Ad-Hoc ESU Visits

It may, from time-to-time, be necessary for the ESU to undertake site visits between servicing to perform analyser checks or carry out modifications. Instrument modifications or repairs which will affect the calibrations of the analysers must not be carried out during these visits without prior agreement of the CMCU. If adjustments or repairs are agreed, then the same calibration and reporting procedures, as carried out during an emergency call-out visit, should be followed.

8.15. Use of On-Site Calibration Gas Standards

The gas standards supplier is responsible for the supply and verification of the on-site gas calibration cylinders. These standards are an expensive resource and as such should not be used for any other purpose other than those stated below.

- “as-found” calibrations either before service or repair
- post-service or repair calibrations
- post-service reconfiguration of the analysers to agree with the standards

Site calibration cylinders should not be used for long-term response drift, linearity tests or as a general source of test gas during servicing or repair without prior agreement of the gas standards supplier.

8.16. Photometer Calibration

All photometers used within the AURN are required to be calibrated traceable to a Reference Photometer. All ESU’s must attend a calibration exercise arranged by QA/QC Unit twice a year for this purpose.

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