Technical Guidance Note M17 (Monitoring)

Monitoring Particulate Matter in Ambient Air around Waste Facilities

Foreword

This document is part of a suite of guidance notes issued by Natural Resources Wales. These notes are designed to help both holders and potential holders of permits understand how to apply for, vary and comply with their permits.

The top level in this suite is ***How to Comply with your Permit*** which covers a large proportion of what an operator needs to know. There are then notes that cover issues specific to particular business sectors, and the **H series** of "Horizontal" notes that go into more detail on particular topics such as risk assessment, noise or odour. The **M series** of guidance notes covers monitoring and M17 is one of these notes.

M17 describes our overall approach to monitoring particulate matter (dust) in ambient air around waste facilities and provides guidance on methods used for regulatory monitoring purposes. This version supersedes the previous M17 guidance.

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Contents

1 Introduction

1.1 Particulate Matter

Airborne particulate matter (PM) is all around us and has a wide variety of sources, both natural (e.g. sea spray, entrained dust, fires, Saharan dust) and from man‟s activities (e.g. road transport, combustion, industry, minerals extraction, construction)[1]. Particulate matter suspended in the air[1] is made up of a complex mixture of solid and liquid particles that come from local and regional sources and sources in other countries (transboundary sources). This mixture can include elemental and organic carbon (including complex organic chemicals), sulphate, nitrates, ammonium, sodium chloride, mineral dust, water and a series of metals. Some of these particles are ***primary particulates*** – emitted directly into the air from a source such as an engine or an industrial process. Others are ***secondary particulates*** – formed from reactions between other pollutants (e.g. NO_2, SO_2, NH_3) already in the air[2] and comprising mainly aerosols of ammonium sulphate and nitrate salts. Secondary PM makes a significant contribution to the overall atmospheric loading of particulates. Furthermore, much PM originates from outside the local area, with regional and transboundary pollution usually being the dominant source of background levels.

Waste management facilities[#] carry out many different types of operation. The principal types covered by this Technical Guidance Document are listed in Table 1.1.

Table 1.1 Principal types of waste management facility

Waste facility	Sub-divisions
Civic amenity sites	Or similar where householders deposit waste
Construction and demolition recycling sites	Building materials
Recycling facilities, including scrap yards	Materials recycling facilities (MRFs), Waste Electrical and Electronic Equipment (WEEE) recycling facilities, ferrous and nonferrous metals recycling facilities, mixed waste recycling facilities, paper/card sorting plants, scrap metal yards and other waste treatment facilities
Transfer stations (including those that also undertake some treatment activities)	For municipal solid waste (MSW), commercial and industrial (C&I) waste, clinical waste and inert waste
Anaerobic digestion (AD) facilities	Biogas from anaerobic digestion of biodegradable waste may be used to drive gas engines, stored for later use, or injected into gas networks. There is often associated shredding plant
Composting sites	In-vessel composting (IVC) and open windrow heaps, with different feedstocks (e.g. green waste, food waste, mixed waste)
Mechanical-Biological Treatment (MBT) facilities	Various configurations that usually include an element of mechanical separation, biological treatment (e.g. composting) and drying.
Thermal treatment facilities	Energy from Waste (EfW) plant of various types, incinerators, and associated infrastructure and plant, such as refuse-derived fuel (RDF) plant and incinerator bottom ash (IBA) processing plant.

[1] Suspended particulate matter comprises solid or liquid particles in a gas (air); the general term for this is an ***aerosol***. Phase-specific terms may also be used: a ***cloud*** or ***mist*** refers to liquid particles in a gas such as air; whilst solid particles in air is termed ***smoke*** or ***dust*****.**

[#] The term facility is used to include regulated sites, processes and installations.

	Advanced thermal treatment (ATT) plant using gasification or pyrolysis.
Landfills	Non-hazardous waste, inert waste and hazardous waste landfills

Some of these facilities generate very little airborne particulate matter, but others involve activities that are potentially dusty and may be a significant source of suspended particles unless good dust management controls are employed.

Measurement and monitoring of particulate levels around the site is an important tool in the wider dust management process; it complements other dust management tools (such as visual inspections and complaints monitoring) in providing feedback and evidence on (a) whether the dust control measures are operating effectively and (b) on the impacts of the process.

As well as the need to satisfy pollution control legislative and regulatory requirements (e.g. the Environmental Permitting Regulations 2010) there may be other drivers for dust and particulate monitoring. These include:

- monitoring (particularly of baseline levels) as part of an environmental assessment submitted in support of a planning application.
- monitoring imposed as a post-development planning condition to provide a continuing check on any environmental effects and the effectiveness of any mitigation measures proposed.
- other reasons for carrying out monitoring, such as: assessing the effectiveness of any abatement or control measures; to satisfy a requirement in an environmental management system; for research purposes; or in response to complaints, pressure groups or public opinion.

1.2 Scope and Layout of this Guidance

This guidance note starts by providing a brief overview of the relevant legislation, regulations and policy applying to England. The next section describes how particulate matter behaves in air around waste management facilities, highlighting the important distinction between the fraction of particulate matter that is falling out of the air at any point (dustfall), and the portion that remains airborne (suspended particulate matter (PM)). A section then follows on monitoring strategy, which outlines what monitoring approaches should be followed[1] to answer the very different questions that may need answering, for instance: What is the emission rate from the site? What is the nuisance impact at the nearest receptor? What is the likely health impact at the nearest receptor? What are the likely impacts on nearby ecologically-sensitive sites? These may require quite different monitoring approaches.

The remainder of the document describes the monitoring techniques and methods for quantifying the different types of particulates depositing from the air as dustfall, or remaining suspended in the air. As well as monitoring specific size ranges (e.g. PM_{10}), methods are described for monitoring particles of important shape (such as asbestos and mineral fibres), particles that are biologically-active (bioaerosols), and for determining the levels of specific chemical elements and compounds in particles and in the soils and vegetation that they deposit onto.

[1] We expect the guidance contained in this document to be followed in most cases; however, there may be exceptions where the particular circumstances make alternative monitoring suitable.

This guidance makes frequent reference to our Technical Guidance Note M8, *Monitoring Ambient Air*[3], which contains more details on monitoring strategy and individual monitoring methods. M8 is updated periodically to reflect changes in monitoring practice and you are strongly advised to refer to that document and use it as a companion to this guidance.

This guidance is restricted to monitoring of particulate matter in ambient air; it does not cover measurement of particulates from point source emissions such as chimney stacks, which is described in our Technical Guidance Note M2, *Monitoring of Stack Emissions to Air*[4].

2 Regulatory Framework

2.1 Waste Legislation and Policy Framework

The revised Waste Framework Directive 2008/98/EC (WFD) provides the EU overarching legislative framework for the collection, transport, recovery and disposal of waste and has been transposed into UK Law by means of The Waste (England and Wales) Regulations 2011. The WFD requires all Member States to take the necessary measures to ensure that waste is recovered or disposed of without harm to human health and the environment, and includes permitting, registration and inspection requirements. The Environmental Permitting Regulations 2010 implement the WFD in England and Wales, with us having the regulatory and enforcement responsibility for implementing the obligations set out in the WFD.

There are other Directives for specific waste streams that supplement the WFD, for example the Landfill Directive 1999/31/EC that was adopted by the European Union in 1999.

The requirements and objectives of the various EU Directives relating to the management of waste have been satisfied by the Government adopting the Waste Strategy for England 2007 (WS 2007) alongside the Waste Regulations and Landfill Regulations (now replaced by the Environmental Permitting Regulations 2010), and by updating (in March 2011) Planning Policy Statement 10: *Planning for Sustainable Waste Management* (PPS10) to reflect the changes in the waste hierarchy.

The Government has reviewed all aspects of waste policy and delivery in England (the „Waste Review") as part of its commitment towards a „zero waste" agenda. The findings of the Waste Review were published in June 2011, alongside a series of documents including an Action Plan for the future and an Anaerobic Digestion Strategy.

2.2 Air Quality Legislation and Policy Framework

2.2.1 Regulatory controls on emissions

There are three types of regulatory approach that are used together to control and improve air quality (including particulate pollution). Firstly, there are environmental protection regulatory mechanisms that seek to control what is being emitted in the first place. These include:

a) Regulations that limit pollutant releases from individual fixed-point sources, for example the Environmental Permitting Regulations 2010 (EPR) that implement in England and Wales the system of Integrated Pollution Prevention and Control (IPPC) under EU Directive 2008/1/EC with similar regulations in place in Scotland and Northern Ireland. These limit emissions from a wide range of industrial installations, including fuel production and power generation, metal production and processing, mineral industries, chemical industries, waste disposal and recycling, food and drink processing and intensive livestock.

b) Regulation of vehicle exhaust emissions via the "Euro Standards" series of engine type approvals; and

c) Legislation that limits pollutant releases collectively from countries – following the UNECE Gothenburg Protocol, the EU National Emissions Ceiling Directive (NECD) sets limits on the total quantities of certain pollutants (nitrogen oxides, sulphur dioxide, ammonia and non-methane volatile organic compounds (NMVOCs)) that a country as a whole can emit, to help to tackle low level ozone and acid and nitrogen deposition issues across Europe. This has been transposed into UK law as the National Emission Ceilings Regulations 2002. A revised version of the Gothenburg Protocol was agreed in May 2012. It contains revised, tighter targets to be achieved by 2020 and also now includes country targets for $PM_{2.5}$ releases.

2.2.2 Regulation of ambient air quality

Secondly, there are approaches that seek to manage and reduce harmful concentrations of pollutants in the ambient air around us once the pollutants from all sources (not just point sources but diffuse/mobile sources as well) have dispersed and diluted in the environment and mixed together. The 2008 Ambient Air Quality Directive (2008/50/EC) sets legally binding concentration-based limit values, as well as target values. There are also information and alert thresholds for reporting purposes. These are to be achieved for the main air pollutants: particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), lead (Pb) and benzene. This Directive replaced most of the previous EU air quality legislation and in England was transposed into domestic law by the Air Quality Standards Regulations 2010, which in addition incorporates the 4th Air Quality Daughter Directive (2004/107/EC) that sets targets for ambient air concentrations of certain toxic heavy metals (arsenic, cadmium and nickel) and polycyclic aromatic hydrocarbons (PAHs). Equivalent regulations exist in Scotland, Wales and Northern Ireland. The European Commission is required to review the Directive in 2013 and is expected to look at strengthening provisions for fine particulate matter ($PM_{2.5}$) and consolidate the 4th Air Quality Daughter Directive. Member states must comply with the limit values and the Government and devolved administrations operate various national ambient air quality monitoring networks to measure whether we comply and develop plans to meet them.

The Environment Act 1995 established the requirement for the Government and the devolved administrations to produce a National Air Quality Strategy, the first being published in 1997 and having been revised several times since, with the latest published in 2007. The Strategy sets UK air quality standards[1] and objectives[2] for the pollutants in the Air Quality Standards Regulations plus 1,3-butadiene and recognises that action at national, regional and local level may be needed, depending on the scale and nature of the air quality problem. The 1995 Environment Act also established the UK system of Local Air Quality Management (LAQM), that requires local authorities to go through a process of review and assessment of air quality in their areas, identifying places where objectives are not likely to be met, then declaring Air

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[1] Standards are concentrations of pollutants in the atmosphere which can broadly be taken to achieve a certain level of environmental quality. Standards, as the benchmarks for setting objectives, are set purely with regard to scientific evidence and medical evidence on the effects of the particular pollutant on health, or on the wider environment, as minimum or zero risk levels.

[2] Objectives are policy targets expressed as a concentration that should be achieved, all the time or for a percentage of time, by a certain date.

Quality Management Areas (AQMAs) and putting in place Air Quality Action Plans to improve air quality. These plans also contribute, at local level, to the achievement of EU limit values.

2.2.3 Planning and air quality

The third important tier is the land-use planning process, because it decides where, or indeed whether, potentially polluting new developments can be built. It also determines where, in relation to these and to existing areas with poor air quality, new developments such as housing can be built that would bring in new people who could potentially be exposed. As part of the Government‟s Localism agenda and to promote economic growth, radical changes have been made to the structure of the planning system in England and its supporting guidance: in March 2012 a concise, single high-level document, the National Planning Policy Framework (NPPF)[5], replaced the detailed guidance that had previously been given on specific issues by separate Planning Policy Statement documents, the exception was the planning policies for waste management set out in PPS10, *Planning for Sustainable Waste Management*, which will remain in place until the National Waste Management Plan is published. The NPPF contains a presumption that development will proceed if it is "sustainable".

2.3 Permitting and Enforcement

2.3.1 Environmental Permitting Regulations

Certain industrial installations and waste management facilities are regulated under the Environmental Permitting Regulations (EPR) 2013, which implement in England and Wales the **Industrial Emissions Directive** (IED). The IED recasts seven EU Directives including EU
Directive 2008/1/EC concerning IPPC, EU Directive 2000/76/EC on the incineration of waste (the "Waste Incineration Directive, WID") and two Directives concerning waste from the titanium dioxide industry (78/176/EEC and 92/112/EEC). As of the 7 January 2014 six of the seven EU Directives are repealed including the IPPC Directive, WID and the two titanium dioxide Directives. The EPR define activities that require the operator to obtain an Environmental Permit from us.

EPR is a regulatory system to control the environmental and health impacts across all environmental media (using an integrated approach) of certain listed industrial and waste activities, via a single permitting process. To gain a permit, Operators have to demonstrate in their applications, in a systematic way, that the techniques they are using or are proposing to use for their installation are the Best Available Techniques (BAT) to prevent or minimise the effects of the activity on air, land and water taking account of relevant local factors. We also regulate under EPR facilities where waste is handled, stored, treated or disposed of, such as landfills, waste transfer and treatment facilities. Some of these facilities are issued with a permit and some are exempt from the need for a permit but do have to be registered with us. Prior to EPR, these had been regulated under the Waste Management Licensing (WML) regime, with the Waste Management Licensing Regulations 1994 implementing the Waste Framework Directive (WFD) in the UK. These regulations covered activities where waste is recovered or disposed of and placed a duty on operators to apply best practice "to ensure that waste is managed properly, recovered or disposed of safely and *does not cause harm to human health or pollution of the environment*". This duty to apply appropriate measures has been transferred into EPR for waste operations and it is this aspect which is most relevant to air quality in general and the particulate matter and dust pollutants that form the focus of this guidance document.

We are committed to ensuring that any industrial installation or waste operation we regulate will not contribute significantly to breaches of an Air Quality Strategy (AQS) objective. It is a mandatory requirement of Environmental Permitting Regulations that we ensure that no single industrial installation or waste operation we regulate is the sole cause or significant contributor of a breach of these objectives.
To do this we will ensure that best available techniques (BAT) and other appropriate measures (in the case of waste management sites) are used to deliver the maximum improvements to air quality where UK air quality objectives are in danger of being breached*. We are committed to working in partnership with operators and local authorities to achieve the necessary improvements for the environment and local residents. We will ensure, as far as possible, that EPR permit conditions or action plans are in place that will enable improvements to be made to meet the relevant national AQS objective by the required date. Exempt waste operations will need to meet the relevant objectives laid down in the WFD, but do not as such, have conditions or action plans.

2.3.2 Nuisance provisions

Part III of the Environmental Protection Act 1990 defines a number of statutory nuisances and includes: *"any dust, steam, smell or other effluvia arising on industrial, trade or business premises and being prejudicial to health or a nuisance".* The Act places a duty on local authorities to investigate the likely occurrence of statutory nuisance and to take reasonable steps to investigate local complaints. Where a local authority is satisfied of the existence or recurrence of statutory nuisance it must generally serve an abatement notice requiring the execution of such works and other steps necessary to rectify the nuisance. If ignored, this can result in proceedings in the Magistrates Court and imposition of an order to prevent the nuisance and a fine. The Act provides a defence for the operator to demonstrate that the "Best Practicable Means" (BPM) have been used to control potential nuisance. For a nuisance action to succeed the offence also has to be a cause of material harm or to be persistent or likely to recur.

The above statutory nuisance controls will apply mainly to dust from premises not regulated under other specific environmental regulations: a local authority requires the consent of the Secretary of State to institute statutory nuisance proceedings arising from operation of a "regulated facility" (including a waste operation, a Part A(1), Part A(2) or Part B installation, mobile plant or mining operation); or an "exempt waste operation". This is designed to avoid the operators of such regulated facilities or exempt waste operations being exposed to action by both Natural Resources Wales and the local authority for the same incident (i.e. to avoid "double jeopardy")[6].

Statutory nuisance may well also be an "ordinary" nuisance at common law. It may still be possible for tort proceedings to be brought by persons aggrieved by the common law nuisance by applying directly to the Magistrates Court, if for any reason the local authority is unwilling to act on their behalf.

3 Particulate Matter around Waste Management Facilities

3.1 Dust and its Journey from Source to Receptor

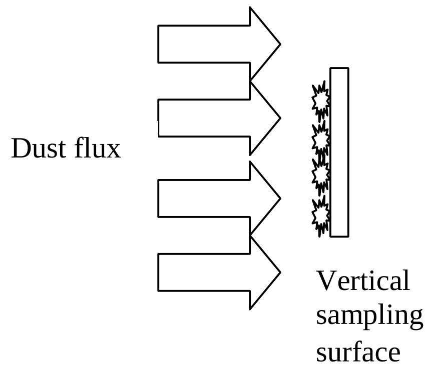
To understand the monitoring of dust and particulate matter (PM) around waste facilities, it is necessary to understand how it behaves in the air. The terms dust and PM are used fairly interchangeably, although in some contexts one term tends to be used in preference to the other, as summarised below.

The dust will be generated by an emission source on the site and released to the air, for example by the tipping of waste from a lorry onto a stockpile. Once the dust is in the air it is

* Natural Resources Wales is legally obliged to go beyond BAT requirements where EU Air Quality Limit Values may be exceeded by an existing operator.

termed ***suspended PM*** and will spread out from the source and be carried on the wind away from the site. The impacts of dust released from a non-elevated source (i.e. close to the ground) will decrease with distance[1], due to dispersion and dilution.

The quantity of particles travelling past a particular location in a given time is termed the ***dust flux*** and this can be measured by placing a sampling device (a dust flux gauge) in the vertical plane to capture the dust as it passes by in a direction nominally parallel to the ground. The dust flux is often expressed in units of mass per unit area in the vertical plane per unit time, e.g. milligrammes per square metre per day (mg m^{-2} day^{-1}), although metrics other than mass (e.g. staining effect) can also be measured.



If the flux gauge is located on the site perimeter, then the flux that is measured is the fugitive dust release rate across the site boundary.

As the "parcel" of particles in air is carried by the wind away from the source, some of the particles settle out of the air – this is called, naturally enough, ***dustfall***. The larger dust particles deposit almost immediately and fairly close to the source (and quite possibly within the site boundary), whereas finer particles fall out of the air only after some considerable time and distance. We can measure the dustfall rate at a particular point by placing a dust gauge in the horizontal plane to collect the particles as they are deposited out of the air and onto the surface[1#]. Dustfall rate (also known as the dust ***deposition rate***) is often expressed in units of mass per unit area in the horizontal plane per unit time (e.g. mg m^{-2} day^{-1}), although as with dust flux it is also possible to use parameters other than mass (e.g. dust coverage, staining effect, loss in surface reflectance) as an indication of the quantity of dust.

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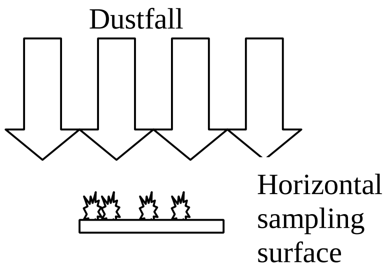
[1] However, for elevated sources such as stacks, the maximum ground level concentration will be some distance from the source, at the point where the plume intersects the ground.

In reality, only the very largest and densest particles fall at an angle approaching the vertical with most particles being deposited at a very shallow angle to the horizontal[1]. Nonetheless, gauges having upward-facing collecting surfaces will collect a different fraction of particulate matter from those with vertical collection surfaces such as the directional flux gauge.



It will be clear that there must be an inverse relationship between dust flux and dust deposition: as dust falls out of the air during its journey, the mass of dust remaining airborne and continuing to travel away from the source must reduce by the same amount. This latter fraction of dust that is still (for the time being) suspended in the air, becomes dispersed by the wind and diluted in an ever greater volume of air; in other words, the concentration of the suspended PM falls as the dust cloud moves downwind. We can measure what this concentration is at any particular location by drawing in a known volume of air into a sampler and estimating the mass of the particles it contained. The concentration of suspended PM is therefore normally[□] given in units of mass per unit volume, e.g. microgrammes per cubic metre ($\mu g\ m^{-3}$).

For the particles to have an impact, they must reach a ***receptor***. Receptors include people and their properties (users of the adjacent land), materials, flora and fauna, soils and water bodies. Different receptors vary in their sensitivity to dust and a number of classifications of sensitivity to dust are given in other guidance[7,8]. The impact at any particular receptor will depend on how much dust there is (the dust exposure[#]) and the sensitivity of that receptor to dust. The particle size has a very great effect on the physical behaviour of the dust and its impacts and we therefore look at this aspect next.

3.2 The Importance of Particle Size

Despite the standard definition[9] of "dust" being particulate matter in the size range 1-75 µm in diameter (particles greater than 75 µm being termed grit), particles suspended in air can vary from the extremely small (in the nanometre size range) up to the rather sizeable (around 1 mm). As noted earlier, the terms dust and PM are used fairly interchangeably.

The normal fate of suspended (i.e. airborne) particles is, eventually, deposition; but the rate of deposition depends largely on the size of the particle and its density. The size of a particle and its density influence the aerodynamic and gravitational effects that determine the distance it travels and how long it stays suspended in the air before it settles out onto a surface. (In reality it is not quite as simple as that, because some particles may agglomerate to become fewer, larger particles, whilst others may react chemically.)

As noted earlier, the larger particles deposit out of the air within a short time and distance, whilst finer particles remain suspended in the air for considerably longer. For example, particles with diameters >50 µm tend to be deposited quickly, whereas particles of diameter <10 µm have an extremely small deposition rate in comparison[10]. Particles that are suspended and are up to 10 µm aerodynamic diameter[*] are known as *PM_{10}* and these can be breathed in by people. The convenient simplification is usually made that the dust fraction comprising particles larger than 10 µm diameter deposits out from the air within a few hundred metres to a kilometre or so of the source[11]; and that those particles suspended in the atmosphere for any significant length of time (and therefore distance) comprise the PM_{10} fraction.

The distinction between suspended particulate matter and deposited dust is of crucial importance, as it determines the potential adverse effects that can occur:

 PM concentration can also be measured as the number (rather than mass) of particles per unit volume of air; however, this is not commonplace and should be considered currently to be a research topic as there are no standards or adopted criteria against which to judge significance.

For dust, the most common types of exposure that are considered are from inhalation of particles, potentially leading to health effects; and exposure to annoyance or nuisance. However, it should be noted that people can also be exposed to dust via the oral route (ingestion – directly, or indirectly from food grown or reared nearby) and the dermal (skin contact) route.

* The Air Quality Expert Group‟s 2005 report *Particulate Matter in the United Kingdom* defines PM_{10} as airborne particulate matter passing a sampling inlet with a 50% efficiency cut-off at 10 µm aerodynamic diameter and which transmits particles of below this size.

I. **Dustfall** - the effects of deposited dust can be divided into:

a) The effects of the bulk property of the dust, irrespective of its composition, to cause nuisance[1] by its sheer prevalence or its capacity to soil surfaces (e.g. a car, window sill, laundry, buildings, etc). The bulk smothering effect of dust can also, potentially, have impacts on vegetation and invertebrates[12].

b) The effects of the deposited dust resulting from the toxic or corrosive nature of the elements (e.g. metals) and compounds from which it is composed. This may lead to impacts on soils and vegetation and also (though ingestion of these) add to people‟s (and animals‟) total exposure to the substances on top of what they receive from inhalation of the PM_{10} fraction.

II. **Suspended particulates** - the PM_{10} particles are small enough to be breathed in[#] and so can potentially impact on people‟s health – see Box 3.1. So when we monitor suspended dust, we are normally interested in measuring the PM_{10} fraction rather than ***total particulate matter*** (TPM) that contains the larger suspended dust particles as well. Measurements of PM_{10} concentrations in the air will include the $PM_{2.5}$ sub-set (the ***fine fraction*** of particulates that is <2.5 µm aerodynamic diameter); however, $PM_{2.5}$ concentrations may also be reported separately and this metric has taken on an increased importance as it is thought that the combustionderived particles in this size range have the greatest adverse impact on human health[3]. It is not commonplace to measure ultrafine particles (<0.1 µm diameter) or nanoparticles and the current official advice of Public Health England[13] is that the health effects of these are adequately covered by the Air Quality Standards set for PM_{10} and $PM_{2.5}$. Similarly, it is not commonplace to routinely monitor particle number concentration (particles per unit volume of air): the advice[13] notes that we do not know how to interpret measurement of number concentrations of particles in health terms, no generally accepted coefficients that allow the use of number concentrations in impact calculations have yet been defined, and no Air Quality Standards are defined in number concentration terms. Work in this area is developing.

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[1] Deposited dust is also sometimes called amenity dust or nuisance dust, with the term nuisance applied in the general sense rather than the specific legal definition. Deposited dust as sampled by the Frisbee gauge (or any other horizontally orientated deposition gauge), is for simplicity often considered to be the larger fraction (>PM_{10}) because only large particles are usually visible to the naked eye. However, smaller particles (i.e. PM_{10}) will also be present in the deposited dust, even though these are unlikely to cause nuisance effects. # All PM_{10} can be breathed in, but not all travels as far down as the lungs. Part of it does though, the most significant sub-fraction of PM_{10} from this perspective being the $PM_{2.5}$ range (particles with a diameter smaller than

[2] .5 µm), which can travel deep into the lungs.

[3] The emerging scientific evidence is that the most biologically active (and potentially damaging) component of most particulates we are exposed to is the soot (elemental, or black, carbon) from road traffic, particularly diesel engines, which can make up a considerable proportion of the PM_{10}, and especially the $PM_{2.5,}$ in many urban areas.

Box 3.1. Classification of Suspended PM Size Ranges from a Health Perspective

The human breathing system has evolved to filter out large particles at an early stage, and the proportion of particles reaching the lungs depends strongly on the particle size. The American Conference of Government Industrial Hygienists (ACGIH), the International Standards Organisation (ISO), and the COMEAP/HPA Handbook on Air Pollution and Health[14] have defined particle fractions on this basis:

- Inhalable fraction - the mass fraction of total suspended particles that is inhaled through the nose and/or mouth; there is no sharp cut-off point in terms of particle size for particles that can be inhaled, but particles greater than 15 µm are trapped in the nose and go no further. However, the proportion of dust that can penetrate further depends on the particle sizes.
- Thoracic fraction - this is the mass fraction of inhaled particles that penetrates the respiratory system beyond the larynx. It has a median diameter of 10 µm, broadly corresponding to what we call the PM_{10} fraction.
- Respirable - the mass fraction of total suspended particles that penetrates to the unciliated regions of the lung (cilia sweep mucus and dirt out of the lungs and are found in the "conducting zone" that routes the air, comprising the trachea, the bronchi, the bronchioles and the terminal bronchioles). This fraction has a median diameter of 4 µm.
- "High-risk" respirable - the mass fraction of total suspended particles that penetrates to the ciliated regions of the lung (this is the respiratory zone, comprising the respiratory bronchioles, the alveolar ducts and the alveoli). This fraction has a median diameter of 2.5 µm, broadly corresponding to the $PM_{2.5}$ fraction.
- Those "ultrafine" particles that are <20 nm (<0.02 µm) can reach the alveoli. As a size range, ultrafine particles ($PM_{0.1}$) are defined by AQEG[1] as <100 nm and nanoparticles as <50 nm).

In view of the different effects of deposited dust compared to suspended PM, it is unsurprising that their monitoring techniques and the compliance limits differ markedly.

3.3 Sources and Types of Particulate Matter around Waste Management Facilities

3.3.1 Contributions to the total

Not all the airborne or deposited particulate matter around the waste management site will be due to the facility itself; a proportion probably will be, but this ***process contribution*** (PC) will be superimposed on top of the underlying, ambient ***background contribution*** (BC). The ***total environmental level*** (the sum of PC + BC) is what is important from an exposure point of view, although in terms of environmental regulation there will tend to be a strong focus on the PC from the waste management facility. A basic understanding of the make-up of the underlying ambient background is necessary, as well as a knowledge of the likely types of particulates added on top of this by different waste operations, if a successful monitoring scheme is to be designed that will enable useful conclusions to be drawn on the impact of the site.

High background levels may leave limited headroom for additional emissions from future developments in the area. This has implications for the setting of appropriate action levels for compliance monitoring purposes. Background levels are also important in considering enforcement action: though there may be no argument about the adverse environmental or health impacts of elevated levels of particulate around a waste facility, if it is largely due to background levels then an operator may be limited in his ability to influence this and care will need to be taken in these circumstances to ensure a proportionate approach is followed.

3.3.2 Particulate matter from the ambient background

Large particles (suspended PM greater than 10 µm) generally do not travel far, so it is mainly local sources of these that usually contribute to the ambient background concentrations in the air and to dustfall levels. The chemical and physical composition of the larger particles tends, therefore, to show a strong dependence on the characteristics of the local sources.

The picture is different for PM_{10} and the fine subset of this, $PM_{2.5}$: for these, the underlying ambient background concentrations in a given area depend not only on local emission sources, but also on regional pollution and pollution from more remote sources brought in on the incoming air mass[1]. These can have quite different chemical compositions: in urban areas the predominant "primary" local source (i.e. emitting directly into the air) is road traffic, including re-suspended dust from the road surfaces, particles from brake and tyre wear, and diesel engine exhausts. The latter contain the highly biologically reactive sooty particles known as ***black carbon*** that are thought to be responsible for much of the observed adverse health effects of these particle size ranges. In rural areas on the other hand, the background PM concentrations from local sources may be due to, for example, agriculture, quarrying or mining. These primary local particles are added to an underlying regional level of PM, a substantial proportion of which is transboundary (mainly from continental Europe); this may have been generated from direct emissions from traffic, industry and agriculture, but much of this long-range pollution is "secondary" PM, which is formed from gases such as sulphur dioxide and ammonia during their long journey on winds from their points of origin. Longrange particulate pollution tends to have a large proportion of $PM_{2.5}$ and is usually high in volatile PM, sulphate and nitrate. Further information on ambient background PM can be found in the AQEG report, *Particulate Matter in the United Kingdom* (2005)[1] and the SNIFFER report, *$PM_{2.5}$ in the UK* (2010)[15].

3.3.3 Releases of particulate matter from waste management activities

We can see from the preceding section that there is a wide variety of sources and particle compositions that can potentially contribute to the background PM in ambient air around a given waste site. Added on top of this background contribution is the process contribution of the waste management facility itself. There are many potential sources and release mechanisms for PM at waste management facilities.

For a waste material to generate airborne particulate matter, there must be a release mechanism. Some of the activities that generate particulate matter and disperse it in air include (in no particular order of importance): movement of waste to and from the facilitiy;

- storage of waste (under certain conditions) on site;
- the handling and processing of the waste materials, e.g. shredding of green waste; turning of windrows; daily cover; and
- wind scouring of waste surfaces.

Vehicles driven on and off site can also have a significant impact by:

- re-suspension of deposited particulates on roadways and hard standing;

[1] High PM_{10} and $PM_{2.5}$ levels across southern England often results from low-altitude easterly air flows bringing pollution in from mainland Europe to combine with local emissions.

- the transport of particles on vehicle bodies, which are subsequently released; and
- emission of particulates in vehicle exhaust fumes.

The relative importance of individual release mechanisms will differ between waste management facilities, being dependent on the type, scale and duration of operations, and the nature of the waste. Furthermore, external factors influence the degree to which the release and dispersion take place. Meteorological conditions are important, especially the amount of rain and strength of wind. Topography can be significant, with sheltered areas sometimes having reduced potential for dust releases; similarly, facilities that process wastes inside buildings are typically (subject to building design) affected less by meteorological conditions than wastes processed in the open air.

Earlier, Table 1.1 showed the types of waste found at the different types of waste facilities; Table 3.1 shows some of the types of waste that may act as sources of different types of airborne and deposited PM under certain conditions. As well as “general particulate matter” (the term applied collectively to dust that is not of concern specifically because of its chemical composition or shape), a range of more specific types of particulate releases are encountered including specific inorganic elements and compounds, complex organic species, biologically-active particles and particles with special shapes (e.g. fibres). Although air quality criteria for PM_{10} and $PM_{2.5}$ are designed to provide protection from health effects of general particulate matter, and numerical guidelines exist to protect against nuisance effects of deposited dust, there are occasions where it is appropriate to further speciate the particles and compare them with more specific air quality criteria[1]. The approaches for monitoring these types of particles, and their benchmark criteria, are described in Sections 5 to 7 of this guidance.

Table 3.1 Potential particulate-phase contaminants at waste facilities

Type of particulate	Examples of particulate contaminants	Examples of waste types that may act as sources
General particulate matter	Deposited dust, suspended particulates, e.g. PM_{10}, $PM_{2.5}$	Many waste materials including household, commercial and construction/ demolition waste
Organic species	Cellulose-based particulates	Green waste, paper and packaging waste
	Dioxins and furans	Combustion of chlorinated plastics, flaring of landfill gas
	Polychlorinated biphenyls (PCBs)	Contaminated oils and transformers
	Polycyclic aromatic hydrocarbons (PAHs)	Diesel exhausts, combustion
Inorganic species	Metals (e.g. lead, cadmium, mercury, copper, aluminium, vanadium, zinc)	Electronic and electrical waste components, ferrous and non-ferrous metal waste, Incinerator ash, batteries, glassware, leather, plastics, paint chips
Fibres	Asbestos, man-made mineral fibres (MMMFs)	Insulation materials, some building materials
Biologically active particles (microorganisms and bioaerosols)	Viable or total pathogens, bacterial toxins, bacterial endotoxins, cellwall components, β-glucans, fungal spores, viruses.	Municipal waste, composts, green waste, biosolids, industrial sludges from food processing and papermaking, faeces of domestic animals, clinical waste, sanitary waste, putrefying foods and packaging materials

[1] Speciation and further analysis of the particles may also be carried out to better understand the sources of the dust at the receptor, e.g. to distinguish between the process contribution and the background contribution.

It should be emphasised that these are simply examples; other sources could well lead to the same airborne particulate contaminants. Also, the table does not signify that these particulate contaminants are present in the greatest quantities: some are present at only trace levels but nevertheless may be important because of their significant exposure impacts.

4 Deciding on your Monitoring Strategy

4.1 Basic Aims of the Particulate Monitoring Strategy

Monitoring is an environmental assessment tool, rather than an end in itself. The data from a monitoring survey or programme are normally used together with other investigative tools (e.g. modelling, observations, complaints, compliance audits) to answer a particular question that has been posed. Being clear on the question you want to answer is the key to designing a successful monitoring programme or framing permit conditions properly; for example, the question may be:

- is the waste management activity giving rise to nuisance impacts from dust at local residential dwellings?
- is the waste management activity giving rise to ambient particulate levels in surrounding areas where people are exposed that exceed air quality standards (e.g. for PM_{10}) designed to protect against adverse health effects?
- what is the flux (movement) of particulate matter across the site perimeter?

These questions require quite different monitoring approaches; because more than one question may be relevant to the site in question, a number of monitoring approaches may be needed. This monitoring guidance describes how a monitoring strategy can be drawn up that properly aligns the monitoring survey with the aims and objectives of the study.

It is essential that, from the outset, you are clear on whether you want to measure the impact at receptors, or the emission rate from the site, because fundamentally different monitoring approaches apply:

- *Quantifying the impact* – monitoring will ideally be carried out at receptors. If the question is one of human health impacts, then measurement of the concentrations of suspended PM (and possibly specific constituents, such as metals) will be relevant. If the issue is one of nuisance impacts, then measurement of deposition rates using a horizontally-orientated collection gauge will be relevant (e.g. total mass dust deposition rate by Frisbee gauge and/or soiling rate). If the concern is ecological impacts, then it may be appropriate to carry out soil and vegetation sampling and analysis. Most monitoring at receptors is omni-directional; however, if there are other significant local sources as well as the waste site then it may be necessary to also carry out directional monitoring.
- *Quantifying the emissions rate from the site boundary* – monitoring will ideally be carried out at the site perimeter, to measure the rate at which PM is crossing the site boundary. The monitoring may be simple subjective observations of visual dust emissions, or fully-quantitative monitoring of dust flux using vertically-orientated collection gauges.

Once you have decided on the basic aims of the survey, you need to decide exactly what, where, when and how to monitor. These fundamentals of monitoring strategy are described in more detail in Technical Guidance Note M8, *Monitoring Ambient Air*[3]; you are strongly advised to refer to that document and follow those basic principles of good practice. Some additional guidance is provided below on specific points relevant to monitoring around waste facilities.

Monitoring must be subject to proper quality assurance (QA) and quality control (QC) safeguards if it is to have any value at all. This is covered in some detail in M8, *Monitoring Ambient Air*. In addition, Section 8 of this guidance describes the minimum requirements for reporting dust and particulate monitoring surveys, including the QA/QC safeguards that should be employed. All persons carrying out ambient air quality monitoring and assessment should hold the relevant qualifications and have the necessary practical experience that demonstrates their competence, with membership of a relevant professional body providing additional reassurance.

4.2 Where to Sample

4.2.1 General principles

The decision on where to sample is inextricably linked to the objectives of the monitoring survey: as stated above, if you are interested in quantifying the impact, then monitoring will ideally be carried out at receptors; if you are interested in quantifying the emission rate across the site boundary (flux) or checking the effectiveness of pollution control measures, then monitoring will ideally be carried out on the site perimeter. If background levels are to be estimated, then monitoring will be carried out some considerable distance from the source or at least upwind of it.

There are two separate issues to consider:

i. firstly, there are the individual sampling site criteria (the microenvironment) that should be met for any location to be suitable, e.g. position relative to local emission sources and any interfering effects.
ii. secondly, there is the need to select suitably representative locations for these sampling sites relative to the study area or the emission source.

These issues are covered in the following two subsections.

4.2.2 What makes a suitable monitoring position

Individual monitoring positions must meet certain requirements to be suitable for measuring airborne particulates or deposited dust around a waste management facility. Most measurements should be made in an open setting with the sampler located well away from large structures such as buildings to avoid the aerodynamic effects they impose. This distance should be equivalent to at least five building heights, subject to an absolute minimum distance from any building of three metres (but preferably at least five to ten metres), unless the objective of the study is to assess the impact at a particular sensitive receptor within this distance. Local topography and building effects are covered in more detail in Technical Guidance Note M8.

The detailed recommendations in Box 4.1 are drawn from a number of sources and are designed to apply to active[1] suspended particulate monitoring (e.g. PM_{10}, $PM_{2.5}$, or

[1] Active sampling involves collecting the dust from the air sample using a pump.

concentrations of specific compounds or elements), although many of the criteria are also relevant to passive[1] dust deposition monitoring.

Box 4.1 Suitable monitoring positions for active PM sampling methods[16,17,18]

- **Sampling Height**. The sample air inlet should generally be 1.5-2 m above ground level to reflect the human breathing zone. This is sometimes not practicable, but the height of the sample intake should be no higher than 10 m above ground level, ideally less than 5 m.
- **Obstructions**. The sampling position should not be located in the lee of major obstructions such as tall buildings or walls. In such circumstances, wake effects can sometimes cause recirculating air flows and the build up of air pollutants. In other instances, such obstructions can shield the sampling site from the pollution source. As a general rule, the top of obstructions should subtend less than a 30 degree angle with the horizontal of the sampling point.
- **Overhang**. The sampling position should be open to the sky, with no overhanging trees or structures as these can act as very efficient pollutant sinks. A US guideline sets 20 m as the minimum distance from the dripline of trees.
- **Interfering Sources**. The sampling position should not be subject to the interfering influences of sources not encompassed by the survey objective, e.g. nearby rooftop vents, chimney stacks, multi-storey car parks. There should be no major sources of pollution within 50 m, and no intermediate sources within 20 m. The surrounding area (within 100 m) should not be undergoing major redevelopment. Vehicles should not be left running within 5 m of the sample inlet.
- Unless monitoring of dust along roadways to the waste facility is an objective, samples should not taken be within 30 m of a very busy road (>30,000 vehicles per day); 20 m of a busy road (10,000-30,000 vehicles per day); or 10 m of any other road (<10,000 vehicles per day).

Monitoring within rural areas should preferably be at greater distances.

- Where these criteria cannot be met, it may be necessary to use directional sampling apparatus to enable the emissions from the waste facility to be clearly distinguished.
- **Access & Security**. Sampling sites must be accessible for servicing, calibration or data collection, but should be secure and in a location where the risks of vandalism or accidental damage (e.g. by wildlife) are minimised.
- **Services.** Where required, adequate services should be available to the monitoring site. Requirements vary according to the equipment, but could include electrical supplies for sampling equipment, telephone line for data retrieval and air conditioning.

4.2.3 General guidelines for locating monitoring sites around waste facilities

Monitoring equipment must be located in suitably representative positions relative to the study area or emission source. There is no universal set of rules for locating monitoring equipment because monitoring studies will have different objectives, but some of the main issues to take into account are described in Technical Guidance Note M8; you are strongly advised to refer to that document and follow those basic principles of good practice. Some additional guidance is provided below on specific points relevant to locating monitoring equipment around waste facilities.

Number of sampling locations

Sampling, as an approach, involves obtaining data from a limited number of points in space and time; the rationale being that it is not practicable to obtain data, continuously, from all possible locations that could be affected. It is therefore necessary to choose a limited number of sampling locations that are broadly representative of the general characteristics of the wider area.

[1] Passive dust sampling involves collecting the dust that has naturally settled out of the air or impinged on the collection surface.

As a general principle the sampling positions are located to enable the maximum amount of relevant information to be obtained from the minimum number of sites. The whole philosophy of fixed-point monitoring is based on the principle of representative sampling. It is assumed that the particulate concentration measured by the monitoring equipment represents not only the concentration at the precise location of the sampler, but also that it is a good estimate of the typical concentration in the immediately surrounding area. The size of that surrounding area, and hence the number of monitoring stations required to adequately characterise the wider survey area, is dependent on the spatial variability of the pollutant in the area. This may be assessed by computer dispersion modelling or by a pilot survey, but very often it is simply based on expert judgement or rules of thumb.

The monitoring technique that is to be used will also influence the number of monitoring sites that can be practically established: for example, sampling of dustfall using sticky pads or slides is simple and cheap; this means they can potentially be deployed in greater numbers than more costly and complex monitoring such as that for suspended particulate concentrations (PM_{10} and $PM_{2.5}$).

Other than these considerations, there are no hard-and-fast rules on the number of sampling stations as this will depend very much on the objectives of the study and some further guidance is provided below.

Locations for monitoring exposure impacts or annoyance at sensitive human receptors

For monitoring the dust annoyance or particulate exposure impacts of the waste management facility, the sampling stations should be located at or very close to[1] places where people spend reasonably lengthy and continuous periods of time, e.g. residential dwellings, and any places where the occupants may be especially sensitive to poor air quality such as schools or hospitals.

Where there are many types of the same receptor nearby, for example a residential housing development or a town, then monitoring is usually carried out at the nearest[#] receptor of that type to the waste facility.

Where there is only a single, isolated sensitive receptor local to the waste facility, dust measurements at a single sampling location may be acceptable. However, it is usually appropriate to have at least one further sampling location to establish background levels in the area and/or sufficient sampling locations to allow upwind-downwind comparisons to be made.

The Institute of Air Quality Management (IAQM) recommends the following in its guidance on monitoring dust from construction and demolition sites[19].

[1] It is sometimes not practicable (for reasons of security, power, etc.) to monitor directly at or adjacent to the sensitive receptors and it is necessary to monitor at “proxy receptors” – other locations that can nevertheless be considered reasonably representative of the actual sensitive receptors. *In extremis*, the monitors may have to be positioned just inside the fenceline of land under the control of the operator; because this is usually much closer to the source than the receptor, it can be considered as a worst-case proxy receptor. If the relevant receptorbased benchmark limits are complied with at that location, then it can usually be assumed that they would be complied with at the (more distant) receptor itself.

[#] The exception is when monitoring is being carried out to quantify the exposure impacts of particulates from elevated point sources (e.g. stacks); the point of maximum impact will be some distance downwind, where the plume first intersects the ground. In such cases, atmospheric dispersion modelling may have been carried out as part of the Environmental Statement, planning application, or Permit application and the results can be used as the basis for locating sampling stations where peak pollutant levels are expected.

a) For monitoring PM concentrations:
   i. a minimum of two sampling sites, one upwind and one downwind of the site (in relation to the prevailing wind) should be established; this allows analyses of source contributions to be carried out if necessary, particularly if wind speed and direction data are available[1], and also allows for coverage during variable weather conditions (although additional sites may be required to ensure there is adequate coverage over all wind directions, subject to the proximity of the closest sensitive receptors to the site boundary);
   ii. in some circumstances it can also be useful to establish additional sites in the downwind direction from the site, along a transect; data from these additional sites are useful in assigning source contributions (as the contribution of site dust emissions will fall off with increasing distance from the site boundary);

b) For monitoring dust deposition or dust soiling rates:
   i. a minimum of two sites (upwind and downwind of the site, in relation to the prevailing wind) should be established;
   ii. it is useful (where applicable) to co-locate dust deposition gauges with PM analysers;
   iii. it is useful to establish additional sites around the site to cover other wind directions and along a downwind transect.

As always, the costs and practicability need to be taken into account: large numbers of monitoring sites may be economic and practical for passive sampling of deposited dust, but may not be so for more complex monitoring of suspended particulate matter (especially where further analysis is required, e.g. for heavy metals).

Locations for monitoring dust flux (particulate emissions) from a waste site boundary

Monitoring of dust flux will ideally be carried out at the site perimeter, to measure the rate at which PM is crossing the site boundary.

For monitoring using simple subjective observations of visual dust emissions, the visual assessment may be made at specific locations (which may be stipulated in the permit), or as part of a more general perimeter walkover.

For fully-quantitative monitoring of dust flux, vertically-orientated collection gauges are used; these devices are directional, i.e. they can resolve the rates of dust travelling towards the gauge from different directions[2], which makes them very useful for distinguishing the dust contribution of the site from dust coming from other sources (such as roads, construction or agriculture). This means site operators often choose to augment dustfall monitoring at receptors (which is not directional) with dust flux monitoring at the perimeter, even if the latter is not required by the permit conditions, to be able to understand their own relative contribution to the total environmental level of particulates.

There is no simple formula to determine how many dust flux monitoring positions should be established around the site boundary. The flux across the waste site boundary will be different in different directions, depending on their orientation to the prevailing wind direction; it is therefore usual to have at least two flux gauges, one on the "downwind" boundary and one on the "upwind" boundary. The IAQM recommends in its guidance on monitoring dust from

[1] Where local meteorological data are not readily available, consideration should be given to installing appropriate wind speed and direction sensors at the site.

[2] Dust flux gauges can be orientated in two ways: either with the datum point on the sampling surface being towards the source to be assessed, or with the datum pointing to north. See Section 6.1.1 for more details.

construction and demolition sites that three dust samplers may be required in order to enclose the site boundary, but (depending on the location of the closest sensitive receptors) additional monitoring sites may need to be included to ensure there is adequate coverage. For minerals workings it has been suggested[10] that four to eight sampling positions are suitable for large sites covering many hectares (with more needed for sites that are complex or situated close to built-up areas); this would be equivalent to two sampling stations along each boundary for a quadrilateral-type site.

Locations for monitoring sites to measure dust against site-specific action levels and compliance limits

As part of the ongoing regulation of a waste management site, we may set site-specific Action Levels and Compliance Limits for particulates; monitoring results exceeding such values would require further actions to be taken to manage dust releases. Such Action Levels and Compliance Limits may be applied to impacts at receptors (e.g. dustfall monitoring) or to the rates of dust release across the site boundary (dust flux monitoring) and the previously described principles for locating such samplers should be followed.

Locations for monitoring sites to check that agreed mitigation measures are being effectively applied

Such monitoring may incorporate flux monitoring at the perimeter (to show an agreed reduction in emissions released across the boundary) and/or monitoring exposure (to nuisance dustfall or PM_{10}) at sensitive receptors. The previously described principles for each of these should be followed.

Though dust gauges can provide useful quantitative evidence on the effectiveness of controls, the results typically are not known for about six weeks from the gauges being setup and the results are of little benefit for providing <u>immediate</u> feedback on the effectiveness of improvements to dust controls; visual inspections (see Section 6.2) are a better monitoring tool for providing immediate feedback, combined (where necessary) with real-time PM_{10} monitoring against short-term Action levels (see Section 7.1.2).

Locations for monitoring exposure impacts at sensitive ecological receptors

The monitoring locations will depend on where the sensitive ecological sites are in relation to the waste management facility and the likely zone of influence of the waste site. For waste sites where residual pollutants are released from elevated point sources (e.g. stacks), atmospheric dispersion modelling studies will often be available that identify the main areas of impact.

4.2.4 The value of baseline monitoring and background monitoring locations

If you are monitoring to quantify the impacts of the waste management facility on receptors, you will usually need to understand how much of the dust is due to the waste management facility (the process contribution, PC), and how much was due to the general background and other sources in the area (the background contribution, BC). There are a number of ways of tackling this.

i. For proposed developments not yet in operation, it is possible to carry out a period of ***baseline monitoring*** on the development site, or close to it, in an area representative of where people[1] are to be located. The duration of such monitoring surveys should ideally be a full year, although six-months of data spanning both the winter and summer months may be adequate; surveys of less than three months duration are unlikely to provide sufficiently representative data. ii. For sites already in operation, baseline monitoring is clearly not possible. Instead, a ***background monitoring*** location can be used to provide control samples that show the underlying background pollution levels. Ideally, this will be at a location that is (predominantly) upwind of the waste site and far enough away so that the sampler is not significantly influenced by dust from the site in question, and where the normal day-to-day background influences for the area can be expected. The

zone of influence will vary from one waste facility to another and will depend upon factors such as the source emission strength, prevailing wind direction and terrain: former planning guidance for surface minerals sites[11] stated "*residents can potentially be affected by dust up to 1 km from the source, although concerns about dust are most likely to be experienced near to dust sources, generally within 100 m, depending on site characteristics and in the absence of appropriate mitigation"*; and for construction and demolition sites the IAQM guidance[19] has set a default[2] cut-off distance for dust effects of 350 m. It should be emphasised that the aim is *not* to select a background location that is divorced from all possible and potential sources of dust that people may be exposed to as part of their normal day-to-day life. Almost any possible sampling location is likely to have some advantages and disadvantages and may not be ideal in every single respect; this is simply a reflection of the fact that the normal background for the area does itself vary from place to place, and from time to time. For example, some receptors may experience higher background dust from roads, whilst others may experience higher background dust from agricultural activities. For this reason, any review of the suitability of a potential background location needs to take a pragmatic view on whether there are <u>major</u> factors that make it unsuitable for characterising the background of the wider area, whilst noting that there will inevitably be detailed differences between the chosen location and any individual receptor.

iii. Sometimes it is not practicable to install monitoring equipment at an off-site location (due to vandalism and the need for security, noise, power connection and access) and in these instances the sampling locations may need to be placed on land within the site operator‟s control, e.g. just inside the site boundary. In such cases, at least one of the samplers should be located in the predominantly upwind direction of the site activities, to enable upwind-downwind comparisons of results to be made. It needs to be recognised that "upwind" locations close to the site will not give true background results: they may be predominantly upwind, but will still receive winds from the on-site sources for some of the time.

5 Monitoring Dust Deposited from the Air (Dustfall)

5.1 Mass Deposition Rate and Soiling Rate – Complementary Measures

People experience nuisance from dustfall in several different ways, sometimes in combination. For example, someone may be annoyed about the sheer prevalence of the dust, or they may

[1] Assuming monitoring is to quantify nuisance or human health impacts, rather than dust flux or ecological impacts.

[2] Subject to revision as more data and evidence on dust effects with distance become available.

be annoyed by the soiling that it causes to their property and belongings such as car paintwork, window sills or laundry.

One way to gauge the size of this nuisance is to measure the community response directly by, for example, monitoring levels of complaints or asking people with surveys and questionnaires. The other way is to try and measure quantitatively some physical feature of the dustfall that is correlated with the nuisance effect; the following measures are in use:

Table 5.1 Summary of dustfall monitoring techniques

The nuisance effect	Monitoring technique
Nuisance from the sheer prevalence of the dust	Measurement of the mass deposition rate to a horizontal sampling surface as a surrogate for nuisance[1]. The units are mass per area per unit time (conventionally mg m^{-2} day^{-1}). The mass deposition rate is usually sampled using a deposit gauge (e.g. Frisbee gauge) followed by gravimetric analysis (weighing the sample).
	The proportion of the horizontal (sticky pad) sampling surface that been dusted, irrespective of dust colour and reflective properties, is termed Absolute Area Coverage (AAC). The exposed sticky pad is optically scanned and image processed and expressed as % Actual Area Coverage (AAC) per day.
Nuisance from the soiling caused to property and belongings	Soiling can be measured as staining, the discoloration of a surface due to deposited dust. Sampling is by a sticky pad, laid out horizontally to collect the dustfall. The degree of staining (which depends in part on the blackness of the dust) is measured using a reflectometer (or optically scanned followed by computerised image processing) and expressed as the % Effective Area Coverage (EAC) per day.
	Alternatively, soiling can be measured as the loss of surface reflectance of a glossy surface. Glass slides, exposed horizontally, are used as the sampling medium. The loss of surface reflectance is measured using a reflectometer and expressed as soiling units (SU) per week.

It will be clear that because of the nuisance effect that the monitoring is attempting to track, nuisance dustfall should (wherever practicable) be monitored <u>at receptors</u>[2] to gauge the nuisance dust impact at those locations.

The two main dustfall monitoring approaches of mass deposition rate and soiling rate are complementary: sometimes one will be more appropriate to a particular site, process emission

[1] People are not annoyed by the mass of dust *per se*; but the mass is related to the prevalence of the dust and is easily and reproducibly measured.

[2] However, sometimes this will not be practicable and it will be necessary to locate the dustfall samplers on land under the control of the site operator, e.g. just inside the site perimeter. In such cases, the assumption is usually made that the results can represent a worst-case estimate of the impact at receptors, since dustfall generally decreases with distance. No symbol on the footnote – not sure where it applies to or what"s gone wrong

or receptor than the other, but monitoring both may sometimes provide a more complete measure of the nuisance impact.

- For example, monitoring Effective Area Coverage (%EAC) is best suited for monitoring of dark coloured dusts. Results can be compared with a widely-used custom and practice nuisance limit.
- Another example is low density material, such as woodchip: the normal custom and practice mass deposition rate guideline (see Section 5.2.2) does not properly reflect the nuisance effects from these materials. To use mass deposition rate as a measure of nuisance from such low-density materials, a bespoke benchmark limit should be derived by correlating observed dustfall rates with complaints data or community responses. Such a study may be able to use monitoring and complaints data that the site has already collected. The alternative approach would be to use a metric of nuisance that is based on the prevalence of the dust rather than its mass, such as measuring Actual Area Coverage (%AAC day^{-1}). Unfortunately no universally accepted nuisance benchmark limit yet exists for dustfall as %AAC day^{-1} and further research and study is needed to establish one by correlating observed measurements with complaints data (complaints to all bodies, not just to the operator) or community responses.

All of the nuisance dustfall monitoring methods are manual techniques (no automatic methods being available). A brief description of each approach is provided below.

All the above dustfall monitoring techniques use horizontal samplers that are omnidirectional and give no information on the direction the dust has been sampled from. If it is required to distinguish dust from different directions, then the dustfall samplers may (noting that this will increase the cost) be complemented with vertical dust flux gauges, which are "directional", i.e. they allow the amounts of dust coming from different quadrants to be distinguished (see Section 6.1.1 for further details). It should be noted that such vertical dust gauges do not, however, provide measures of dustfall in the conventional sense, although they can provide an estimate of the dust deposition that may be experienced by a vertical surface (such as a building façade or laundry) and this may be the issue of concern on occasions.

5.2 Mass Deposition Rate (Frisbee Technique)

5.2.1 Summary of measurement technique

The preferred technique for measurement of dustfall by gravimetric means uses the Frisbee deposition gauge, which provides a great improvement in performance over the older-style BS gauge[20] and ISO gauge[21] (see Technical Guidance Note M8, *Monitoring Ambient Air* for further details). Although there is currently no CEN, ISO or BS standard method covering the Frisbee technique, a custom and practice method exists - the Stockholm Environment Institute at York (SEI-Y) method[22]. As noted earlier, Frisbee gauges are omni-directional, i.e. they do not differentiate between dusts coming from different directions.

The plastic (or preferably aluminium) inverted Frisbee (diameter 235 mm) device is mounted horizontally on a pole 1.75 m above the ground, with a drain hole in the centre leading to a rainwater collection bottle. A polyester foam dust trap can be used to reduce contamination from falling leaves, etc. Deposited matter on the collection surface, and the insoluble matter in the rainwater collection bottle are quantitatively removed and separated by gentle vacuum filtration. Insoluble matter is dried and determined gravimetrically and the deposition rate is expressed as mg m^{-2} day^{-1}. Note that the SEI-Y method determines insoluble matter only and if, as is often the case, dissolved solids are also determined then that portion of the deposition rate should be clearly identified in the reported result.

The shape of the Frisbee has superior collecting efficiency and aerodynamic characteristics that make it suitable for short-term sampling periods of about a week[23], but the gauges are usually exposed for longer as the custom and practice default nuisance limits are based on monthly exposures.

Regarding method performance, for gravimetric determination on a 0.1 mg resolution balance and with a one-month sampling period, a theoretical lower detection limit of 0.07 mg m^{-2} day^{-1} is obtained. No details on uncertainty are available, but an improvement in performance over BS and ISO gauges can be expected.

5.2.2 Guideline limits for mass deposition rates of dustfall

Guideline limits to prevent dust nuisance

Currently no UK statutory standards or limits exist for the assessment of deposited dust and its tendency for causing nuisance. Similarly, no official air quality criterion has been set at a European or World Health Organisation (WHO) level, although a range of national yardstick criteria from other countries is found in the literature.

Gravimetric dustfall monitoring results generated by mass deposition gauges (normally Frisbee gauges) at sensitive receptors are usually compared with a “complaints likely” dust guideline of 200 mg m^{-2} day^{-1}, the limit being applied to the individual monthly-average samples and not (for instance) the annual-average value. This value, which has been adopted generally in this country as a custom and practice guideline, was derived by Vallack & Shillito[24] by multiplying a historical, typical UK median background by 3.5 (which was the ratio of the 95^{th} percentile to the median). It should be noted that because background dust levels can vary significantly from place to place and with season, the authors were clear that the preferred approach is to calculate a bespoke site-specific “complaints likely” dust guideline, where sufficient local baseline monitoring data are available (at least 12-months worth) based on 3.5 times the median background level. However, such bespoke local baseline data are often not available and in such cases the authors recommended using as a fall-back the 95^{th} percentile of typical UK background data, which gives a default “complaints likely” guideline of 200 mg m^{-2} day^{-1} for receptors located in residential areas and outskirts of towns.

In the absence of any other criteria, this custom and practice guideline of 200 mg m^{-2} day^{-1} is widely used for general (i.e. non-toxic and non-corrosive) dust deposition measured by Frisbee gauges.

It is important that the limitations of the 200 mg m^{-2} day^{-1} benchmark are appreciated: firstly, although the value has been adopted widely, it is simply a custom and practice yardstick and it was never based on actual dose-response data; secondly, in deriving this default “complaints likely” guideline, Vallack & Shillito used a dataset that was quite old and not necessarily indicative of today‟s background; additionally, it was necessary to use a substantial correction factor to convert those historical results (obtained using older-style BS Deposition gauges) to equivalent Frisbee gauge results.

As noted earlier, this custom and practice guideline of 200 mg m^{-2} day^{-1} does not properly reflect the nuisance effects from low density material, such as woodchip. This cannot be wholly resolved by simply adjusting the mass by a correction factor based on the density to enable a comparison with the mass-based 200 mg m^{-2} day^{-1} nuisance benchmark, as the latter is still subject to the limitations that that are described above. A better approach is to use a bespoke benchmark limit derived by correlating observed dustfall rates with complaints data or community responses.

Guideline limits for non-toxic dust effects on ecological receptors

The effects of general, non-toxic particulate matter on ecological receptors have not been subject to extensive research and therefore little published guidance is available. A summary of a review of available research on behalf of the DETR[25] concluded that: "*The issue of dust on ecological receptors is largely confined to the associated chemical effect of dust, and particularly the effect of acidic or alkaline dust influencing vegetation through soils."* Monitoring of the chemical species in dusts, and the guideline limits that apply, are covered later in Section 5.5.1; the summary below concerns guideline limits for general, non-toxic particulate matter on ecological receptors.

Our interim guidance[26] concluded that most[1] relatively insensitive vegetation species will not be significantly affected by smothering at dust deposition levels below about 200 mg m^{-2} day $^{-1}$, i.e. the human nuisance custom and practice guideline. The report concluded there were insufficient data to derive thresholds for impacts of dust on invertebrates. The Highways Agency in its Design Manual for Roads and Bridges[27] suggests that only dust deposition levels above 1000 mg m^{-2} day^{-1} are likely to affect sensitive ecological receptors and states that most species appear to be unaffected until dust deposition rates are at levels considerably higher than this.

5.3 Soiling Rate (Sticky Pad Technique)

5.3.1 Summary of the measurement technique

Measurement of soiling rate can be carried out by passive sampling of dust onto a horizontally positioned, white, sticky Fablon pad; the soiling of the exposed sticky pad is measured using a reflectance meter and expressed as the percentage ***Effective Area Coverage*** (%EAC) per day, which can be related to likely complaint levels. The technique was developed for assessing the annoyance caused by the soiling of surfaces, e.g. window sills or car paintwork. Because the loss of reflectance depends in part on the „blackness" of the captured dust, the technique is best suited to tracking the nuisance effects of darkcoloured dusts. Although there is currently no CEN, ISO or BS standard method covering this technique, a custom and practice method exists[28]. Inexpensive Fablon samplers allow large or detailed surveys to be carried out at modest cost. The standard sampling exposure period is seven days.

One equipment manufacturer has developed the approach further: a transparent rather than white horizontal sticky pad is optically scanned followed by image processing using a specially developed computer program to give a %EAC value that is traceable back to the custom and practice reflectance meter calibration curve. Being a horizontal dustfall gauge, the sticky pad is of course omnidirectonal and not to be confused with the directional flux gauges offered by the same manufacturer that are also analysed optically.

The same company has used this technology to determine another measure of nuisance dusts, which they term ***Absolute Area Coverage*** (AAC%) - a measure of the proportion of the sampling surface that has been dusted, irrespective of dust colour and reflective properties[29]. This allows the sticky pad sampling technique potentially to be used for any dusts, not just dark dusts (e.g. some light-coloured metal dusts).

[1] However, in habitats in which Sphagnum and possibly other mosses are important species within the protected site, effects may be observed at levels above about 70 mg m^{-2} day $^{-1}$. The report did, however, note that the uncertainties were considerable and exceedence of these values should not be assumed to demonstrate harm.

5.3.2 Guideline limits for soiling rates of dustfall sampled by sticky pads

Suggested[28] complaint thresholds for staining are:

0.2%EAC per day: noticeable

0.5%EAC per day: possible complaints

0.7%EAC per day: objectionable

2.0%EAC per day: probable complaints

5.0%EAC per day: serious complaints

It is common for monitoring programmes to use the 2.0% EAC per day "probable complaints" threshold as a guideline limit.

For dustfall measured as Absolute Area Coverage (%AAC), no similar official or custom and practice guidelines have yet been published that are based on any nuisance dose-response study. Further research and study is needed to correlate observed measurements with complaints data or community responses before a universal guideline limit can be recommended. However, waste facilities should be collecting complaints data as a matter of routine, which can provide operators with a body of data to make a site-specific correlation with %AAC so as to establish a no-compliant threshold.

5.4 Soiling Rate (Dust Slide Technique)

5.4.1 Summary of the measurement technique

Measurement of soiling rate can also be carried out by passive collection of dust onto a horizontally positioned microscope slide. The technique was developed for assessing the annoyance caused by the soiling effect of deposited dust on glossy surfaces, e.g. window sills or motor vehicles. A clean microscope slide is exposed for, typically, one week. The slide is positioned horizontally on a surface between one metre and two metres above the ground. The dustiness of the exposed slide is quantified by measuring the reduction in specular reflectance relative to a clean unexposed slide, using a reflectometer instrument. A measurement in Soiling Units (SU) is obtained by subtracting the reflectance value from 100. The soiling level can be related to perceived annoyance. Although there is currently no CEN, ISO or BS standard method covering this technique, a custom and practice method exists[30]. Inexpensive microscope slide samplers allow large or detailed surveys to be carried out at modest cost. The measurement uncertainty is reported to be better than 2 SU, or 2%.

5.4.2 Guideline limits for soiling rates of dustfall sampled by glass slides

Acceptance criteria in terms of SU have been established following social surveys. A soiling rate of greater than about 25 SU per week is considered likely to cause complaints[30].

5.5 Further Analysis of Deposited Dust

5.5.1 Loss on ignition (LoI)

By determining the loss in mass of the dried dust sample after ignition in a crucible at high temperature, an estimate of the organic content of the bulk sample of dust can be obtained. The fraction that remains is assumed to be non-organic in nature (although losses can also occur from carbonates and hydrates).

5.5.2 Chemical analysis

The bulk sample collected by, for example, Frisbee gauges can be analysed to give a comprehensive compositional breakdown of the deposited dust. This may be of some limited use in characterising the sources of the dust; however, examination of individual particles under the microscope (see Section 5.5.3) is likely to be more effective, as is the use of directional sampling (or upwind-downwind comparisons).

Chemical analysis is valuable, however, in quantifying the levels of specific contaminants in the deposited dust. The most likely requirement to chemically analyse the collected samples of deposited dust in the vicinity of waste facilities is to determine the levels of ***heavy metals and metalloids***, often those with emissions limits controlled under the Waste Incineration Directive, ("WID"): cadmium (Cd), thallium (Tl), mercury (Hg), antimony (Sb), arsenic (As), lead (Pb), chromium (Cr), cobalt (Co), copper (Cu), manganese (Mn), nickel (Ni), and vanadium (V).

Sample preparation involves acidifying the filtered solid deposited matter from the Frisbee gauge and its collection bottle, and the filtrate. The digested metals content of the combined solution will then be analysed by, typically, Inductively Coupled Plasma - Atomic Emission Spectrometry (ICP-AES), Inductively Coupled Plasma - Optical Emission Spectrometry (ICPOES), Inductively Coupled Plasma - Mass Spectrometry (ICP-MS) or Cold Vapour - Atomic Fluorescence Spectrometry (CV-AFS).

The deposition rate for each metal will be calculated in units of $mg.m^{-2}.day^{-1}$ from the amount of metal collected, the sampling area of the Frisbee gauge and the number of days the gauge was exposed.

Numerical guideline criteria for deposition of metals

The document H1 - *Environmental Risk Assessment for Permits*[31] provides guidance on the method to be used for those operators needing to assess the impact of their emissions deposited onto surrounding land. H1 notes that there are no statutory Environmental Quality Standards in the UK for deposition onto land and few other suitable standards, but lists those benchmarks that are available and provides guidance on assessing the ecological impacts of releases to land. Deposition rates from the process can be compared with ***Maximum Deposition Rates*** (units of $mg\ m^{-2}\ day^{-1}$) for the protection of soils. The MDR is the quantity of pollutant that can be added to the soil daily over 50 years before the corresponding Soil Quality Criterion (units of $mg\ kg^{-1}$) is exceeded. H1 advises that if the Process Contribution (PC) of a substance is ≤1% of the MDR then it can be screened out as insignificant; if it exceeds 1% then a detailed assessment is required. It should be noted that reliable MDRs are available for only a limited number of substances.

As noted above, MDRs are designed to protect soil quality - refer to Section 5.6 for more information on this – rather than human health directly. Notwithstanding this, because the Soil Quality Criteria currently listed in H1 are derived from standards set for the use of sewage sludge in agriculture[32,33], they can in practice be reasonably expected to also be protective of human health, at least via ingestion of foods. For complete assessment of the impacts of human exposure to deposited substances, a Human Health Risk Assessment (HHRA) would be required, with comparisons made with the reference doses (e.g. for dioxins and furans, the ratio of exposure to the Committee for Toxicity Tolerable Daily Intake, TDI).

5.5.3 Particle identification

The optical and morphological properties of individual particles can be examined by light microscopy (conventional reflected light microscopy, polarised light microscopy, or dispersion staining), electron microscopy (transmission electron microscopy, TEM, and scanning electron microscopy, SEM); and the chemical composition of the individual particles can be determined by advanced analytical techniques such as electron diffraction, x-ray fluorescence (XRF) spectroscopy, energy dispersive analysis by x-ray (EDAX) and electron or ion probe microanalysis.

Particles can be identified by comparison with reference materials, or by comparison with a particle atlas - a database of identifying information and photomicrographs of thousands of microscopic particles. Approximate estimates can sometimes be made of the proportions of different types of particles in the sample.

5.6 Soil and Vegetation Monitoring

5.6.1 General considerations

The presence and fluctuation of metals and other contaminants in soil may lead to deleterious effects on plants and animals, particularly for soil microbial communities. Metals and ***toxic organic micropollutants*** (TOMPs) may enter the soil through natural processes, such as weathering of parent materials for metals and burning of vegetation for PAHs; and through human activities such as atmospheric deposition from industrial and vehicle emissions or direct application of waste (slurry, sludge and landfill), pesticide and fertiliser. Levels of metals and organic contaminants must therefore be viewed in relation to soil types, land uses and other external influences[34].

Box 5.1 Heavy metals and metalloids[35, 34]

Heavy metals belong to the group of elements described geochemically as “trace elements” because they collectively comprise <1% of the rocks in the earth‟s crust. All trace elements are toxic to living organisms at excessive concentrations; however, some are essential at low but critical concentrations for the normal healthy growth and reproduction of plants and animals - these are referred to as “essential trace elements” or “micronutrients” and deficiencies can lead to reduction in crop yield for agricultural systems or deleterious effects on development and reproduction in animals, in extreme cases leading to disease and even death of the plant or animal. These include the heavy metals Co, Cr, Cu, Mn, Mo, Ni, Se and Zn. Other essential elements that do not fit the criteria of heavy metals are B, Cl, Fe, I and Si. High concentrations of essential elements are harmful, e.g. excessive levels of copper and zinc can damage soil fertility.

Other elements, including Ag, As, Ba, Cd, Hg, Tl, Pb and Sb, have no known essential biological function and, like the essential trace elements cause toxicity above a certain tolerance level, e.g. accumulation of cadmium and lead can affect human and animal health. The most important heavy metals with regard to potential hazards and occurrence in contaminated soils are: As, Cd, Cu, Cr, Hg, Pb and Zn.

Particles may have an effect through their deposition directly onto vegetation; particles may also exert an effect if they change the soil chemistry. Many metals are toxic to plants at elevated concentrations; however, uptake of metals is largely via the roots of plants with only minor amounts being taken up from deposition onto plant surfaces, and heavy metals may accumulate in soils over time. It has also been suggested that heavy metals can affect microbial activity in the soil, although metal bioavailability may be more important than metal concentration[36].

The natural range of many metals in soils is very wide. Additionally, our research[34] notes that soil properties are notoriously spatially variable: 50% is not unusual as the standard errors of the mean of many typical soil parameters. Against this, many soil parameters change only slowly with time, so it can be a challenge for long term monitoring surveys to discriminate long term trends from this “noisy” background. In choosing a suitable period for sampling intervals, it is important to understand the likelihood of detecting significant changes: for example, if the soil contaminant concentration is likely to change by 5% between samplings, and the 95% confidence limits of the measured mean are equivalent to 50% of the mean, it will be many years before a significant change is detected.

5.6.2 Summary of the measurement technique

For the sampling of soil and vegetation around waste facilities, the main procedural requirements of ISO 10381-2:2002 Soil Quality Sampling[37] and Natural Resources Wales guidance[38] are of general relevance. The as-received soil samples will then undergo suitable preparation (e.g. drying at 105°C) and a representative sub-sample obtained from the larger bulk sample.

The chemical analysis technique used on the sample will depend on the determinands of interest: for heavy metals, the sample will be digested (for example in Aqua Regia) followed by analysis by Inductively Coupled Plasma - Optical Emission Spectrometry (ICP-OES), Inductively Coupled Plasma – Mass Spectrometry (ICP-MS) or Atomic Absorption Spectrometry (AAS). For TOMPs such as dioxins and furans, the sample will be extracted with solvent which is then analysed by Gas Chromatography – Mass Spectrometry (GC-MS).

These analyses can be very technically challenging because of the difficult sample matrices and the often low levels of pollutant that are present. It is therefore crucial that this is carried out by a laboratory experienced in this type of analysis and having robust quality assurance and quality control procedures. United Kingdom Accreditation Service (UKAS) accreditation under ISO 17025 for the analyses in question provides good evidence of this. Additionally, our Monitoring Certification Scheme (MCERTS) covers chemical analysis of soils (albeit for contaminated land applications, where we only accept analytical data from laboratories who are accredited under the MCERTS scheme for the Chemical Testing of Soil); our website **www.mcerts.net** provides further details.

5.6.3 Guideline limits for particulate deposition levels in soils

Soil Quality Criteria (in units of $mg.kg^{-1}$) for different substances are listed in horizontal guidance note H1. The document notes that for inorganic compounds, the Soil Quality Criteria listed have been corrected for the median ambient soil concentration and no allowance has been made for degradation or other removal processes. Further information of the use and interpretation of Soil Quality Criteria are provided in our Science Report SC030265[34].

6 Monitoring the Rate of Dust Travelling through the Air

6.1 Monitoring Dust Flux

6.1.1 Summary of the measurement technique

Dust flux monitoring is best suited for assessing dust releases across the site boundary, i.e. what is entering and leaving the site. Dust flux is always sampled with a collection device positioned in the vertical plane to intercept dust as it travels nominally parallel to the ground, but the detail of the collection device and the analysis stage can differ:

i. BS 1747 directional gauges intercept the dust in vertical tubes with a slot aperture. The dust collects in a sampling pot at the bottom and is then determined (usually) by weighing. Sampling periods of about 10 days to one month are usual. Although the results are expressed in units of mg m^{-2} day^{-1}, this is the mass flux, *not* the mass deposition rate (unless the vertical gauge is being used to assess dust deposition on a vertical surface, such as a building facade), and so the results are not comparable with those of a Frisbee gauge. There are known limitations on the capture efficiency of these gauges.

ii. Sticky pad samplers can be used to sample dust flux, the sticky collection paper being wrapped around a vertical cylinder, which has improved efficiency over the BS 1747 directional gauges when used for one to two week exposure durations[39]. The results are expressed in units of %EAC day^{-1} but it should be noted that this is the soiling flux, not the dustfall soiling rate (again, unless the vertical gauge is being used to assess dust deposition on a vertical surface, such as a building facade). One equipment manufacturer has used optical scanning and image processing technology to determine another measure of nuisance dusts, which they term Absolute Area Coverage (AAC%) - a measure of the proportion of the sampling surface that been dusted, irrespective of dust colour and reflective properties.

A more detailed description of both methods is provided in Technical Guidance Note M8, *Monitoring Ambient Air*.

The above dust flux samplers are directional, due to the design of the sampling equipment, allowing the dust from different quadrants (or for the sticky pad samplers, 5° or 15° arcs around the monitor) to be resolved, therefore potentially allowing discrimination between sources (even without the availability of meteorological data). Dust flux gauges can be orientated in two ways: for older BS1747 gauges that have four sampling tubes, each with a slotted aperture, facing in four directions 90°° apart, it is usual to face one of the slots towards the source to be assessed; for sticky-pad flux gauges there is a continuous sampling surface through 360° and the sampler body is fitted with an indicator that is usually aligned with north.

6.1.2 Guideline limits for dust flux

There are difficulties in setting a universal limit value for the rate of nuisance dust travelling past a location (dust flux) for the following reasons:

- What would be an acceptable flux past a particular location will depend upon what the subsequent impact will be when the dust eventually settles out of the air as dustfall, at some point downwind, at a sensitive receptor.
- Flux gauges should be located at some point between the source and the receptor, preferably at the site boundary. When a flux gauge is located on the site perimeter, it gives a measure of the site‟s fugitive dust emission rate across its boundary.
- The dust flux from one site may have an entirely different significance to the dust flux at another site, dependent on the pathways (e.g. distance and direction) to the nearest receptors and the sensitivities of those receptors.

Consequently, there are no universally-agreed numerical standards for dust flux from waste facilities, whether measured by a vertically-orientated gravimetric-type deposition gauge (e.g. BS1747 gauges) or using vertically-orientated sticky pad soiling gauges[1].

Dust flux across the site boundary is, essentially, the emission rate. The setting of an appropriate numerical compliance limit for dust emission rates across a particular waste site boundary would be a matter for the environmental regulator, taking into account the level of emission that would be likely to cause an adverse impact at receptors in that particular case. To set a proper risk-based limit, the regulator would need to correlate the levels of dust emissions across the site boundary (the dust flux) with the level of impact at the nearest sensitive receptors: for existing sites this can be done either qualitatively (e.g. by correlating measured dust flux with community responses such as complaints frequency or the results of dust diaries) or quantitatively (e.g. by correlating measured dust flux with dust deposition rates monitored at receptors). Operators of waste facilities should be collecting complaints data as a matter of routine, which can provide operators with a body of data to make a sitespecific correlation with dust flux, so as to establish a basic no-compliant threshold.

In the absence of a site-specific dust emission rate limit, a useful gauge of the significance of the emission rate across the boundary can be made by comparing this to the background dust flux. A comparison can be made between the measured dust flux from the quadrant facing the site (i.e. the dust emission from the site boundary) with the dust fluxes from other directions. This will give an estimate of the magnitude of the cross-boundary emissions as a multiple of the normal background dust flux.

There is a separate very useful diagnostic application of vertically-orientated flux gauges that takes advantage of their ability to resolve the relative intensities of dust flux from different directions. This allows the process operator to have an understanding of the relative importance of dust sources from different directions. This can add value to any measurements of dustfall measured at receptors using horizontal, omni-directional gauges; which of course cannot distinguish from where the dust is likely to have emanated. Many process operators use vertically-orientated flux gauges in this way as a management tool to monitor the effectiveness of their dust controls, the advantage being that the relative contribution of their own site can be disaggregated from the interference of sources from other directions; in such cases the lack of a numerical limit value is no impediment, as the approach depends on simply looking for changes that depart significantly from the norm.

6.2 Visual Assessment of Dust Emissions

Operators may be required to make regular (e.g. daily) visual assessments of dust emissions across the site boundary as part of their routine walkover inspections. Visual observations of dust emissions are affected by the subjective opinion of the observer, his visual acuity and powers of observation, and the environmental conditions at the time (e.g. light and wind conditions). The assessment criteria may be similarly subjective: for instance a permit may state that "*there shall be no visible dust emissions*".

Despite its subjective nature, this simple, cheap and easy to implement assessment approach has the significant advantage of providing instantaneous information on problems (e.g. it may be possible to directly observe the source of the dust emission, such as a particular stockpile) allowing rapid actions to be taken to deal with the problem. Visual assessments therefore

[1] Default flux limits for coal extraction are given in Welsh Minerals Planning Technical Advice Note 2 (MTAN2), paragraph 155; however, it is not clear that these are based on observed correlation with annoyance effects.

complement well other, more-quantitative dust monitoring that may take several weeks to produce results.

7 Monitoring of Concentrations of Particulate Matter Suspended in the Air

7.1 Monitoring of Particulate Matter by Size Fraction (PM_{10}, $PM_{2.5}$)

7.1.1 Summary of the measurement technique

It was explained in Section 3.2 that when we monitor particulate matter suspended in air, we are normally interested in the PM_{10} fraction - particles with a mean aerodynamic diameter less than 10 microns – that can be breathed in. There are other particle size categories that are sub-sets of the PM_{10} fraction:

- fine particles or $PM_{2.5}$ - particles smaller than 2.5 μm in aerodynamic diameter; coarse particles: the fraction of PM_{10} particles larger than $PM_{2.5}$; and
- ultrafine particles or $PM_{0.1}$ - particles smaller than 100 nm.

The current official advice of Public Health England[13] is that the health effects of particulates are covered by the Air Quality Standards set for PM_{10} and $PM_{2.5}$. This includes the effects from that subset of PM_{10} and $PM_{2.5}$ that we term ultrafine particles and nanoparticles. Monitoring of suspended PM therefore focuses on PM_{10} and $PM_{2.5}$.

The decision on whether to monitor one of these fractions, or both, around a waste facility should be considered early in developing the monitoring strategy. Generally speaking, PM_{10} emissions from industrial combustion processes and road transport are considered to contain more fine material (i.e. $PM_{2.5}$) than, for example, mechanically-generated particulates from quarries and construction sites[1]. Waste management operations that involve mechanical generation of PM rather than combustion, are also likely to release predominantly coarse particles. In its guidance for monitoring PM around construction and demolition sites[19], the IAQM recommends that priority should be given to monitoring PM_{10} (unless it is necessary to demonstrate compliance with the $PM_{2.5}$ limit value) and that $PM_{2.5}$ should not be the primary metric, although if instruments are used that measure both then they should be reported.

There are numerous techniques and published standard methods for monitoring suspended PM; these can be grouped broadly into real-time monitoring using automatic instruments that give a near-instantaneous read-out of airborne particle concentrations, and manual or semiautomated samplers that collect PM over a defined duration to give a period-averaged concentration. A European reference monitoring method exists for governments of member states to demonstrate compliance with the EU Directive limit values and targets, but member states are not obliged to employ this across all their networks and can use other methods shown to be “equivalent”. Defra provides on its website a list of equivalent instruments and, in addition, we have recently worked with Defra to extend our MCERTS scheme for PM instruments to cover Defra`s equivalence testing requirements.

Of course, not all particulate monitoring is carried out by the Government and Devolved Administrations to demonstrate compliance with Directive levels; there are other instruments and techniques that do not meet the full specifications for equivalence and have a wider uncertainty, but which may be perfectly adequate for many other applications. For example, we have broadened MCERTS to include a category for “indicative PM instruments”. Some of these are of modest cost, small weight and size and have small power requirements. The performance of the instruments provide the response time, accuracy and precision that is needed for the aims of an indicative monitoring programme.

The techniques, standard methods and instruments, together with their performance characteristics, are described in more detail in our Technical Guidance Note M8 *Monitoring Ambient Air*, which the reader is strongly advised to consult. Further very useful information on the advantages and limitations of the main PM monitoring techniques is given in the IAQM monitoring guidance[19].

7.1.2 Limits, objectives and guidelines for suspended PM

Horizontal Guidance Note H1, *Environmental Risk Assessment for Permits*, available from our website provides the statutory air quality limit values, target values and objectives that relate to PM_{10} and $PM_{2.5}$, .

The statutory limits for suspended particulates are concentrations averaged either over a year or a 24-hour period. We may set, on a site-specific basis, much shorter-term Action Levels and Compliance Limits to provide a quick indication of when there is a need for the waste management facility to take further actions to manage dust releases. For monitoring PM around construction and demolition sites, the IAQM recommends[19] a site Action Level of250 $\mu g\ m^{-3}$ averaged over a 15 minute period, though it cautions that this is provisional and will be reviewed in the future as more data are made available. This is a useful starting point for setting Action Levels around waste facilities.

7.2 Speciated Monitoring of Suspended Particulate Matter

7.2.1 Summary of the measurement technique

As explained in Section 3.3, a range of particle types may be released from different waste management activities, including specific inorganic elements and compounds, complex organic species, biologically-active particles (bioaerosols) and particles with special shapes (e.g. fibres). Although air quality criteria for PM_{10} and $PM_{2.5}$ are designed to provide protection from health effects of general particulate matter, there are occasions where it is appropriate to further speciate the particles and compare them with more specific air quality criteria.

Organic particulate pollutants sometimes measured as individual species include the toxic organic micro-pollutants (TOMPs) - dioxins, polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). It should be noted that organic contaminants in particulate matter are often partitioned between the solid or liquid phase and the gaseous phase. Regarding speciated measurements of inorganic particulates, those most frequently carried out around waste facilities are for heavy metals and metalloids.

The organic or inorganic components will usually be present at only trace levels in the suspended particulate matter. Sampling usually, therefore, involves drawing a large volume of ambient air through the collection medium (e.g. filter paper, foam filter, etc) over a number of weeks duration. Analysis of the collected sample is typically by ICP-AES, ICP-OES, ICPMS, AAS or CV-AFS for metals, or GC-MS or HPLC for organic micropollutants. The techniques, standard methods and equipment, together with their performance characteristics, are described in more detail in Technical Guidance Note M8 *Monitoring Ambient Air*.

Hexavalent chromium (Cr^{VI}) is of special concern due to its potential health impacts and has a very stringent ambient concentration limit. There are few publically available estimates of background levels of Cr^{VI} that can be used in air quality assessments (typically for thermal treatment facilities), therefore site-specific baseline studies are increasing carried out to demonstrate the available headroom for the process contribution. Analysis for Cr specifically in the hexavalent state is challenging and large air sample volumes may be required to obtain a suitably low detection limit. Currently, few laboratories have UKAS accreditation for this determination.

It should also be noted that a few metals/metalloids and their compounds (as well as TOMPs) are of sufficient volatility at ambient temperatures to make vapour-phase sampling necessary. The most notable is mercury, which has an appreciable vapour pressure at room temperature and elemental mercury is a common air pollutant in the vapour phase, as an aerosol, or adsorbed onto particles. Organically-bound mercury compounds are present largely in the vapour phase, whilst inorganic mercury compounds may be present as particles or vapour.

7.2.2 Limits, objectives and guidelines for speciated PM

There are various statutory air quality limit values, target values and objectives, and nonstatutory Environmental Assessment Levels (EALs) that relate to the various inorganic and organic particulate pollutants. These are listed in the latest version of our Horizontal Guidance Note H1, *Environmental Risk Assessment for Permits*, available for download from our website.

7.3 Bioaerosols

7.3.1 Generation of bioaerosols at waste facilities

What are bioaerosols?

Bioaerosols are microscopic airborne particles or droplets of biological origin. The sizes of the individual particles vary from fractions of a micron up 30 μm or more, but many have a tendency to form larger clumps or agglomerations, or to attach to inert dust particles. These biological aerosols are complex in nature, and may include: viruses, bacteria (including actinomycetes), fungal spores, enzymes, endotoxins, mycotoxins and glucans, dust mites, protozoa, fragments of plant material, and human and animal debris (skin cells, hair, etc) that have been shed. Bioaerosols can be subdivided into:

i) Viable components: living organisms/cells; and ii) Non-viable components: non-viable organisms plus chemicals that are parts of the organism (e.g. the cell walls, such as endotoxins).

Further information on these individual components is given in Table 7.1.

Bioaerosols from waste activities

Bioaerosols are found widely throughout the waste industry including waste collection, materials recovery facilities, mechanical biological treatment facilities, composting and the storage of waste material prior to incineration. Increased activity levels and the agitation of material such as turning of windrows during composting and the shredding of material has been shown to be associated with increased levels of bioaerosol production.

Looking more closely at composting, the process relies on the growth and activity of microorganisms. Different groups of micro-organism predominate at different phases of the composting process according to how well they are adapted to specific conditions such as temperature (see Table 7.1). Cellular waste products such as endotoxins and glucans are also present during composting. Composting relies on turning the compost regularly to increase aeration and maintain optimum composting activity by increasing porosity of the windrow pile. It is during the agitation of the material when the warm buoyant air rises from the windrow that elevated numbers of bioaerosols are released and dispersed downwind. This has caused concerns over the impact of bioaerosols on the public living around such facilities. However, there is the potential to reduce exposure to bioaerosols from such facilities by the implementation of good practice and having adequate control measures in place to minimise bioaerosol release.

While a study[40] by the Health and Safety Executive (HSE) has confirmed that large concentrations of bacteria (including actinomycetes) and fungi, and to a lesser extent endotoxin, are found close to the source of composting activities such as windrow turning, there was little evidence of a major contribution to the overall bioaerosol burden by a distance of 250 metres from such activities.

Table 7.1 Micro-organisms in compost[41 42]

Category of micro-organism	Sub-category based on thermal tolerance	Features
Fungi	Mesophilic (10-35□)	The majority of moulds present, including aspergilli, peicillia and mucor species
	Thermophilic (≥35□C)	Includes the most hazardous moulds, e.g. *Aspergillus fumigatus* (which is fairly thermo-tolerant) and *Absidia ramosa*
Bacteria	Mesophilic	The great majority of bacteria. Gram +ve and Gram –ve species (the latter includes *Salmonella* and *E.Coli*). Some specific components include: Actinomycetes – these are Gram-negative bacteria, but are filamentatous and morphologically resemble fungi; some produce spores similar to fungi. They play an important role in the decomposition of organic matter. The majority of actinomycetes present, including the Streptomycetes, are Mesophilic. Endotoxins are toxic substances (macro-moleculues) that form an integral part of bacterial cells, in particular the outer membrane of Gram –ve bacteria; they are released into the atmosphere during growth of the bacteria and after the cell dies.

	Thermophilic	Most Thermophilic species of bacteria are Gram +ve. Only a few species of adapted actinomycetes are Thermophilic.

Health effects of bioaerosols

We know that significant exposure to bioaerosols could be associated with a range of different adverse health effects such as an increased risk of respiratory illness and possibly gastrointestinal symptoms and fatigue. The type of effect is dependent on the species present and the associated exposure level, though at the present time we can‟t fully quantify the true significance of the health impact because there is a lack of dose response data for individual components. For more details on health effects refer to the IOM/Defra review[43].

7.3.2 Measurement of bioaerosols

Bioaerosols can be measured using a number of different techniques. A comprehensive summary of the different bioaerosol monitoring methods is given in our Science Report *Review of Methods to Measure Bioaerosols at Composting Sites*[44], and in the document *Guidance on the Evaluation of Bioaerosol Risk Assessments for Composting Facilities*[42], where the advantages and limitations of the different monitoring and assay techniques are discussed in detail.

Concentration of bioaerosols in air are described in terms of counts of viable (culturable) colony forming units (CFUs) or total (viable and non-viable particles) microbial cells per unit volume of air. CFU refers to those cells (whether individual or in aggregate) that are able to grow on selective nutrient media to produce visible colonies that can be counted. Some "viable" cells may not grow on selective media, in which case they are termed "viable but not culturable" (VBNC).

It is estimated that less than 10% of all bioaerosols may be culturable, and non-viable cells can still be toxic or allergenic[45]. Other techniques, such as epifluorescence microscopy and DNA based methods, allow counts to be made of the total alive and dead microbial cells.

In 2009, the Environment Agency in collaboration with the Association for Organics Recycling (AFOR) introduced a standardised protocol for measuring bioaerosols from composting sites „*A standardised protocol for the monitoring of bioaerosols at open compost facilities*‟ (2009 version)[46]. One of the reasons for this standardisation was to improve the quality of exposure information generated and allow intercomparison of data. This protocol uses an Anderson single-stage impactor to sample onto agar gel or a filtration method for the quantification of culturable microorganisms: total culturable mesophillic bacteria and *Aspergillus fumigatus*. The protocol also states that there may be an additional requirement to monitor Gramnegative bacteria at in-vessel sites. The *Guidance on the Evaluation of Bioaerosol Risk Assessments for Composting Facilities document*[42] provides information on suitable culture media for their isolation.

Current sampling approaches for the quantification of culturable microorganisms are limited to short sampling times that only give a „snapshot‟ representation of emissions. A CEN Technical Specification (DD CEN/TS 16115) has recently been published that may overcome this limitation[47]. The method describes the long term (10 minutes to 24 hours) sampling of moulds onto gelatine filters. Since the introduction of the standardised protocol in 2009 we have seen an increase in the number of in-vessel facilities that emit bioaerosols via a stack. Until recently it was not possible to monitoring bioaerosols from stacks. However, a new German VDI method (VDI 4257 Part 2 Bioaerosols and biological agents - Emission measurement - Sampling of bioaerosols and separation in liquids) was published in September 2011 that measures bioaerosol emissions from stacks using an isokinetic sampling approach into a liquid impinger.

Bioaerosol monitoring is currently in a state of development with research being conducted by the Agency and Defra. A Defra research project (Monitoring bioaerosol and odour emissions from composting facilities - WR1121) is carrying out an all-inclusive set of standard and new approaches to measure the concentration of micro-organisms around compost sites. We will use the outputs from this research and our own to produce a detailed M series guidance note on bioaerosol monitoring in 2013. Both M8 (*Monitoring Ambient Air)* and M17 will be updated to reflect any new developments.

7.3.3 Guideline limits for bioaerosols

No statutory limits have been set for ambient concentrations of bioaerosols. The absence of definitive health-based data on dose-response relationships between bioaerosols and respiratory allergy or infection makes it impossible to establish a level of exposure that poses no risk. In the absence of dose-response data the Agency takes a precautionary approach to permitting sites that emit bioaerosols, as demonstrated by our Position Statement[48] on permit applications for composting operations. That means new composting operations within 250 metres of workplaces or dwellings must carry out a Site Specific Bioaerosol Risk Assessment (SSBRA) in support of their application to demonstrate that bioaerosols can, and will, be maintained no higher than acceptable levels at the sensitive receptors. In the current (2010) version of the Position Statement, we specify these Acceptable Levels (predicted, or measured directly using Natural Resources Wales/AFOR standardised protocol) at sensitive receptors as being:

Gram-negative bacteria: 300 cfu m^{-3}

Total bacteria: 1000 cfu m^{-3}

Aspergillus fumigatus: 500 cfu m^{-3}

The first step to interpreting the results of monitoring is to compare upwind (background concentrations specific to that site) with downwind concentrations to determine the level of emission attributable to the composting facility (process contribution). The process contribution must not exceed the acceptable levels quoted above at the sensitive receptor. The operator would be expected to carry out up to four sampling campaigns a year to demonstrate bioaerosol levels are being maintained.

7.4 Fibres: Asbestos and Man-Made Mineral Fibres

7.4.1 The issue of fibres at waste facilities

At some waste facilities, e.g. landfill sites, particulate matter in the form of fibres may be encountered. This includes materials such as asbestos and man-made mineral fibres (MMMFs). Asbestos waste must be deposited in a landfill for hazardous waste, a site designed to accept asbestos only or in a separate cell in a landfill for non-hazardous waste, but only if the cell is sufficiently self-contained and the design provides a physical separation and isolates the asbestos so that it remains undisturbed[49]. To prevent the uncontrolled release of asbestos fibres there must be no drilling through asbestos cells.

There is also the legacy of asbestos/MMMF being released to air from contaminated land. We have conducted trials with the HSE to support development of guidance for assessing the risks from asbestos in contaminated soils but no published guidance is yet available; however, professional and industry bodies (CL:AIRE, the Environmental Industries Commission and the British Occupational Hygiene Society) are working together towards the development of practical and robust non-statutory industry guidance[50].

The epidemiological risk implications of fibres are due, in part, to their long, thin structure (aspect ratio) and, especially for asbestos fibres, their propensity to break down into ever finer, sharp fibres. The main health impacts from asbestos are from exposure that has occurred at work, rather than from non-occupational exposure. Workplace exposure to asbestos kills more people than any other single work-related illness. The diseases can take from 15-60 years to develop – so the person who has breathed in the fibres will not immediately aware of any change in their health. Asbestos can cause two main types of disease in humans: asbestosis (scarring of lung tissue) and cancer (particularly lung cancer and mesothelioma), as detailed in Box 7.1.

MMMFs can in some circumstances cause irritation of the skin and eyes and upper respiratory tract and such effects are discussed in further detail in HSE Guidance Note EH 46[51].

7.4.2 Summary of the measurement technique

There are no standard methods for monitoring fibres in ambient air around waste management facilities; therefore, procedures have been adopted based on modifications of published methods for occupational monitoring.

Manual sampling of fibres is undertaken in much the same way as for many other particulates, using air-sampling pumps and filters. A number of analytical end methods can then be used to identify and quantify the fibres that have been collected, as outlined in MDHS 87[52].

Box 7.1 Diseases from Asbestos Exposure

Asbestosis: A chronic lung ailment where the inhalation of fibres causes scarring and hardening of the lung tissue. Clinically similar to silicosis, the disease is progressive and rate of progression is related to exposure. There is a clear dose-response relationship and although incurable and irreversible, early diagnosis may halt the disease.

Lung Cancer: A malignant tumour of the lungs" air passages, and may spread to other parts of the body. It should be noted that there is a synergistic effect between smoking and asbestos – exposure of the two carcinogens together significantly increases the risk of developing lunch cancer. Similar to asbestosis, there appears to be a reasonable dose-response relationship.

Mesothelioma: This disease is still the dominant occupational cancer affecting cells that make up the lining around the outside of the lungs and inside the ribs (pleura) or around the abdominal organs (peritoneum). Although the risk appears to be increased with high and persistent exposure, there has been evidence that mesothelioma may be the result of relatively short exposures. The dose-response relationship is not clear and may possibly result from non-occupational exposure.

Asbestos

MDHS 87 outlines the two main methods of quantifying the asbestos that has been collected in air samples, optical microscopy and electron microscopy.

Optical microscopy is used as the routine approach for monitoring and the method given in HSE guidance HSG 248[1,53] is used basis for monitoring ambient air, although it should be noted that this method is designed for controlled conditions in premises and workplaces and dusty outdoor conditions cause problems. The procedure uses the membrane filter method, with low-flow sampling pumps and membrane filters (mixed esters of cellulose or cellulose nitrate with 0.8–1.2 µm pore size) held in electrically-conducting cylindrical cowled filter holders. Fibres collected on the cleared filter are then counted using phase contrast microscopy (PCM) to obtain the countable fibre number concentration in air. This method gives a lower detection limit of 0.01 fibres per millilitre of air (10,000 fibres per cubic metre) for a 25 mm diameter filter and a sampled air volume of 480 litres. However, this can be improved to some degree by increasing the sampled air volume, making it more suitable for measuring ambient environmental levels of asbestos.

PCM continues to be the analytical method of choice for occupational monitoring of asbestos, because of the following advantages over other methods:

- the technique is specific for countable fibres: non-fibrous particles are excluded from the count;
- the technique is relatively inexpensive;
- the analysis is quick and can be performed on-site for rapid determination of air concentrations of asbestos fibres; and
- the technique has continuity with historical epidemiological studies so that estimates of expected disease can be inferred from long-term determinations of asbestos exposures.

The main disadvantage of PCM is that it does not positively identify asbestos fibres. Other fibres that are not asbestos may be included in the count if deemed a countable fibre by HSG 248. A further disadvantage of PCM is that the smallest visible fibres are about 0.2 µm in diameter while the finest asbestos fibres may be as small as 0.02 µm in diameter. For some exposures, substantially more fibres may be present than are actually counted. Other fibres can also interfere with counting, including fibreglass, anhydrite, plant fibres, perlite veins, gypsum, some synthetic fibres, membrane structures, sponge spicules, diatoms, micro-organisms and wollastonite. Positive identification of asbestos must be performed by dispersion staining or electron microscopy techniques. Fibre counting is not suited to very dusty atmospheres, and high levels of general environmental dust can render samples unreadable by PCM.

Electron microscopy is able to detect much smaller fibres than optical microscopy. Levels of electron microscope-visible fibres per cubic metre are reported to be in the range 40-100 fibres per m^3 (0.04×10^{-3} to 0.1×10^{-3} fibres ml^{-1}) for remote areas and up to 2400 fibres per m^3 (2.4×10^{-3} fibres ml^{-1}) in urban air. At these low levels, the scanning electron microscope (SEM) / transmission electron microscope (TEM) provides the best means of analysis. Quantification is by counting of fibres, but positive confirmation of fibres as asbestos on selected areas of the filter may be made by Selected Area Electron Diffraction (SAED) or Energy Dispersive X-ray Analysis (EDAX), which are facilities available on a TEM. This makes the electron microscope method preferable when there are significant levels of nonasbestos fibres in the air. British Standard BS ISO 10312 describes the standard method[54] for measuring asbestos fibres in ambient air using TEM. The SEM method[55] of measuring inorganic fibre particles is given by BS ISO 14966.

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[1] HSG 248 consolidates and updates HSE technical guidance previously published as EH10, MDHS 39 and MDHS 77.

In summary, for monitoring around waste facilities the preferred method will usually be sampling onto membrane filters at about eight litres per minute for one hour, or two litres per minute over a four hour period to achieve a 480 litre sample volume, followed by fibrecounting by PCM in accordance with HSG 248. If difficulties with interferences are experienced with PCM, then TEM and/or EDAX should be used as the end method. One practical approach that can be taken is to divide the exposed filter paper into two halves and immediately analyse the first half by PCM; then, if necessary, the other half of the filter paper can later be analysed by scanning/transmission electron microscopy (SEM/TEM) to establish the PCM-equivalent asbestos fibres concentrations.

Several direct-reading instruments operating on the light scattering principle are used as portable fibre counters in occupational hygiene work, but their suitability for ambient applications is unproven. The instruments rely on being able to first align fibres before they pass into the optical sensor. However, they cannot match the performance of manual methods and are best used only for an indication of whether levels are increasing or decreasing[56].

Man-made mineral fibres

The UK occupational method MDHS 59[57] offers two approaches for monitoring man-made mineral fibre concentrations: sampling by cellulose ester filter followed by gravimetric determination; or sampling onto a filter followed by plasma ashing and fibre counting by polarised light microscopy. The gravimetric approach is not well suited to the ambient atmosphere because the method is non-specific and other atmospheric dusts would interfere significantly.

The fibre counting method is preferred for monitoring around waste facilities; it is similar in principle to that for asbestos and can be modified for ambient monitoring by increasing the sampled volume to provide an improved lower detection limit. As for asbestos, fibre counting is not suited to very dusty atmospheres and if difficulties with interferences are experienced with PCM, then TEM and/or EDAX should be used as the end method.

7.4.3 Guideline limits for fibres

Asbestos is a proven human carcinogen (IARC Group 1). No safe level can be proposed for asbestos because a threshold is not known to exist. Exposure should therefore be kept as low as possible[58] and asbestos should not be found above background levels at site boundaries. Further guidance will be available in the Technical Guidance Note for landfill sites, which should be available early in 2014.

Occupational exposure limits exist for MMMF (refer to the latest issue of Guidance Note EH 40[59] and to Operational Circular HSE OC 267/2[60]); but for ambient air, no EAL is currently listed in H1 - *Environmental Risk Assessment for Permits*. H1 recommends that in such cases, operators should discuss the requirement with the site inspector who, if necessary, can obtain appropriate advice.

8 Reporting Requirements

In order to allow proper checking and facilitate meaningful intercomparisons, monitoring reports providing data for site investigations should include the following information:

Front end/cover information

- The site address and name of the operator
- The type of development/process
- The planning consent reference
- Date of issue of the report
- Period covered
- Authors of the report
- Organisation submitting the report
- Evidence of quality check/authorised sign-off of the report

Introduction

- Scope and terms of reference of the monitoring and the report

Methodology

How was the measurement carried out?

- Statement on the standard published method, or in-house documented technical procedure, and the technique/principle used
- Summary of the technique and methodology used for both sampling and analysis
- Equipment type/make/models used
- Details of the monitoring locations on map that also shows the process/development

By whom?

For both the sampling and the analysis stages, needs to show:

- Who carried it out
- Belonging to which organisation (i.e. in-house or subcontracted outside)
- If the organisation carrying out the sampling and/or the analysis has UKAS or MCERTS accreditation, then this should be stated and the accreditation numbers given.

What quality accreditation is in place?

- The general QA system, if any, under which the organisation operates, e.g. ISO9001 quality management system
- Any specific accreditation that applied specifically to these tests/measurements, e.g. UKAS or MCERTS.
- A statement on the traceability of the results.

Results

- Summary of the measurement results (expressed in the correct units), together with the environmental quality standard with which it is being compared (e.g. 2% EAC day^{-1}; 200 mg m^{-2} day^{-1}; annual average PM_{10} of 40 □gm^{-3}; 35 exceedences pcy of the 24-hour 50 □gm^{-3} limit) □ Details of the lower detection limit (LDL) for each test
- Details of the uncertainty attached to each result, and an indication of the method used to estimate the uncertainty
- Statement as to whether the tests complied with the test method procedural requirements; or whether there were deviations from the procedural requirements of the test method. If so these need to be summarised.
- Observations relevant to the test and sampling period, e.g. weather, activity, damage, interference.

Inferences/Conclusion

- Conclusion on whether there has been compliance with the environmental quality standard, or not.
- Discussion on relevant factors affecting results for this period
- Statement on what the longer-term trend is, if any, taking into account monitoring results to date.

Appendix containing the raw data.

For example, for Frisbee monitoring the following would be expected:

- Sampling records/worksheets showing: the date, sample identification and clearly linking it to the sample location and the specific sampler, the name of the site operative, date/time sampling commenced and ended, and a note of any relevant observations.
- Analysis certificates/reports/records/worksheets showing: the sample identification (i.e. clear traceable link from sampling), liquor volume, pre- and post-filtration weighings (to constant weight), oven drying temperature, analytical balance identification (clearly traceable to the calibration details in the QA appendix), evidence that the daily drift-check showed balance calibration remained within acceptable limits, how the deposition rate was calculated (i.e. showing the mass, days exposed and surface area), name of the analyst and the date.

For example, for Sticky Pad monitoring the following would be expected:

- Sampling records/worksheets showing: the date, sample identification and clearly linking it to the sample location and the specific sampler, the name of the site operative, date/time sampling commenced and ended, and a note of any relevant observations.
- Analysis certificates/reports/records/worksheets showing: the sample identification (i.e. clear traceable link from sampling), reflectance meter/sensor identification (clearly traceable to the calibration details in the QA appendix), reflectance zero and/or span check, how the deposition rate was calculated (i.e. showing the reflectance, conversion to EAL, and days exposed), name of the analyst and the date.

For example, for PM_{10} monitoring by an automatic instrument the following would be expected:

- Print-out or tabulated detailed results of monitoring data and time-series plots, clearly showing the instrument identity and the site location.

Appendix containing QA information Sampling

Unless the sampling is carried out by a UKAS or MCERTS-accredited organisation, and the test is clearly within the defined scope of its accreditation, then evidence of calibration of any quality-critical sampling equipment needs to be included in the appendix.

For example, for PM_{10} monitoring by an automatic instrument the following would be expected:

- Site records/worksheets showing: the date of visits to check operation/download data, instrument identification, sampling location, the name of the site operative, functional tests/checks (e.g. span and zero checks) carried out to demonstrate continuing satisfactory operation.

Analysis

Unless the analysis is carried out by a UKAS or MCERTS-accredited organisation, and the test is clearly within the defined scope of its accreditation, then evidence of calibration of any quality-critical analytical equipment needs to be included in the appendix.

For example, for analysis of the Frisbee monitoring samples the following would be expected:

- For the analytical balance, evidence of the most recent full calibration to traceable standards.
- When the last service of the balance was carried out and when the next service is scheduled.

For example, for analysis of the Sticky Pad samples the following would be expected:

- For the reflectometer meter/sensor, evidence of the most recent full calibration to traceable standards.

For example, for PM_{10} monitoring by an automatic instrument the following would be expected:

- Evidence of the most recent full calibration to traceable standards.
- When the last service of the instrument was carried out and when the next service is scheduled.

Glossary

Absolute Area Coverage (%AAC) - the proportion of the horizontal (sticky pad) sampling surface that been dusted, irrespective of dust colour and reflective properties.

Action level – the concentration, deposition rate, soiling rate or flux of dust/particulates at which the operator will review his operational procedures to ensure that a compliance limit is not exceeded.

Aerosol – a suspension of particles in a gas.

Background monitoring – an alternative to baseline monitoring to estimate the underlying background pollution levels, carried out at a location that is (predominantly) upwind of the waste site and far enough away so that the sampler is not significantly influenced by dust from the site in question.

Baseline monitoring – to estimate the level of particulates that is present without the proposed development.

Bioaerosols - microscopic airborne particles or droplets of biological origin that may include: viruses, bacteria, actinomycetes, fungal spores, enzymes, endotoxins, mycotoxins and glucans, dust mites, protozoa, fragments of plant material, and human and animal debris (skin cells, hair, etc) that have been shed.

Black carbon - the highly biologically-reactive, sooty, elemental carbon particles thought to be responsible for much of the observed adverse health effects of particles in urban areas.

Compliance limit – the concentration, deposition rate, soiling rate or flux of dust/particulates specified in the environmental permit as the level above which pollution is likely to be occurring. It is analogous to an Emission Limit Value (ELV) applied to a point source emission.

Deposited dust – dust that is no longer in the air and which has settled out onto a surface. Deposited dust is also sometimes called amenity dust or nuisance dust, with the term nuisance applied in the general sense rather than the specific legal definition.

Deposition rate – this is the rate of dustfall, i.e. how much dust settles out of the air onto a surface in a given time.

Dust – solid particles that are suspended in air, or have settled out onto a surface after having been suspended in air. The terms dust and particulate matter (PM) are used fairly interchangeably, although in some contexts one term tends to be used in preference to the other.

Dustfall – the process by which particles settle out of the air onto a surface.

Dust flux - the quantity of particles travelling past a particular location in a given time.

Effective Area Coverage (%EAC) - soiling of a sticky pad sampler measured as staining (discoloration, which depends in part on the blackness of the dust) and measured using a reflectometer or optically scanned followed by computerised image processing.

Heavy metals and metalloids - the term "heavy metals" is imprecise but is widely used to refer to those metals (and sometimes also the metalloids) having a density greater than 6 $g.cm^{-3}$ (though some authors use a value of >5 $g.cm^{-3}$) and an atomic number greater than 20. Alternative terms are "toxic metals", "potentially toxic elements" and "trace metals".

Maximum Deposition Rates – a guideline for the protection of soils. The MDR is the quantity of pollutant (units of mg m^{-2} day^{-1}) that can be added to the soil daily over 50 years before the corresponding Soil Quality Criterion (units of mg kg^{-1}) is exceeded.

Morphology - the study of shape, size, texture and phase distribution of materials.

PM_{10} – the fraction of suspended PM that is up to 10 μm aerodynamic diameter.

$PM_{2.5}$ - the fraction of suspended PM that is up to 2.5 μm aerodynamic diameter

Primary particulates – emitted directly into the air from a source such as an engine or an industrial process.

Process contribution (PC) – the airborne or deposited particulate matter around the waste management site that is due to the facility itself. This is superimposed on top of the underlying, ambient background contribution (BC). The total environmental level is the sum of PC + BC.

Receptor - people and their properties (users of the adjacent land), materials, flora and fauna, soils and water bodies. Different receptors vary in their sensitivity to dust

Secondary particulates – particles formed from reactions between other pollutants (e.g. NO_2, SO_2, NH_3) already in the air

Suspended PM – dust that is currently in the air.

TOMPs – toxic organic micro pollutants that include dioxins and furans, polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs).

Total particulate matter (TPM) – a measure of suspended particles in the air not limited by size fraction. TPM will include the larger suspended dust particles, as well as PM_{10}, but the exact upper cut-of point will be dependent on the sampler design characteristics.

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