Guidance on the evaluation of bioaerosol risk assessments for composting facilities
## Contents

1. Introduction ............................................................................................................. 1  
   1.1. How to use this guidance ................................................................................ 2  
2. Introduction to bioaerosols...................................................................................... 4  
   2.1. Types of micro-organisms ............................................................................. 4  
   2.2. Health impacts ............................................................................................. 5  
   2.3. Sources at composting facilities.................................................................... 6  
   2.4. Sources of variation ...................................................................................... 6  
   2.5. Bioaerosol control and mitigation measures ................................................... 7  
3. Bioaerosol sampling ............................................................................................... 9  
   3.1. Sample collection methods ........................................................................... 9  
   3.2. Culture and enumeration methods ................................................................ 10  
   3.3. Interpretation of sampling results .................................................................. 12  
   3.4. Sampling frequency ...................................................................................... 13  
4. Key aspects of a risk assessment ......................................................................... 14  
   4.1. What is risk? .................................................................................................. 14  
   4.2. Problem definition ......................................................................................... 15  
   4.3. Risk screening and prioritisation ................................................................... 17  
   4.4. Summary ....................................................................................................... 18  
5. Decision flowcharts ............................................................................................... 20  
6. Checklists ............................................................................................................. 22  
7. Reference tables ................................................................................................... 25  
References ................................................................................................................... 30  
List of abbreviations ..................................................................................................... 33  
Glossary........................................................................................................................ 34
1. Introduction

In the UK, compost production increased from ca. 1 million tonnes in 2000/01 to 3.4 million tonnes by 2005/06 (Association for Organics Recycling (AFOR) 2008). This trend is set to continue in order to meet the targets set in Defra’s 2007 Waste Strategy for England (Defra, 2007). As a result, the number of composting facilities and the amount of waste processed will increase. This has led to concerns regarding potential health effects during waste processing, particularly those associated with exposure to bioaerosols (National Audit Office, 2002).

Bioaerosol is simply a general term for micro-organisms suspended in the air. These micro-organisms include fungi and bacteria, as well as their components such as mycotoxins, endotoxins and glucans. Bioaerosols are generally less than 10 µm in size and are not filtered out by hairs and specialised cells that line the nose. Due to their airborne nature and small size, many bioaerosols can penetrate the human respiratory system, resulting in inflammatory and allergic responses (Wheeler et al 2001; Swan et al, 2003).

Although bioaerosols are ubiquitous, waste and waste management operations provide environments that are conducive to their growth, particularly composting, which requires micro-organisms to support the process. Bioaerosols are therefore certain to be associated with composting, and in particular, activities such as shredding and turning, which release the micro-organisms into the air.

The Environment Agency’s current policy position on composting and potential health effects from bioaerosols (2007) is that they will:

“take into account the potential effects of bioaerosols on human health when authorising new waste composting facilities or changes to existing facilities. To do this, applicants will have to provide us with a site-specific bioaerosol risk assessment if there is a workplace or dwelling within 250 metres of the composting site boundary... The assessment must be based on clear scientific evidence and show that bioaerosols can and will be maintained at appropriate levels at any workplace or boundary of a dwelling”

The site-specific bioaerosol risk assessments provide operators with the basis for identifying operational controls on site and allow them to target controls where exposures to significant hazards are of greatest concern. Furthermore, they should reassure the regulator and local communities that facilities are being operated safely and responsibly without undue risks to operational staff, to public health or to the environment.

This document provides guidance on assessing the adequacy of a bioaerosol risk assessment. It does not provide generic guidance on how to undertake a risk assessment, as this already exists elsewhere (e.g. DETR et al., 2000). The aim is to provide a user-friendly document that will assist Environment Agency permitting staff to make informed decisions about applications for a permit or exemption for composting facilities. While the focus is on Environment Agency staff, this document will also assist those completing the risk assessments, as it will provide an understanding of what the Environment Agency expects to be included in bioaerosol risk assessments. This guidance is designed to complement the Association for Organics Recycling (2009) standard protocol ‘A standardised protocol for the monitoring of bioaerosols at open composting facilities’, which provides detailed methodologies for collecting bioaerosol concentration data. Both documents aim to
improve risk assessment quality given that many are often of poor quality or are not sufficiently comprehensive.

This guidance begins with a brief introduction to the key components of a bioaerosol risk assessment, and then provides more details on bioaerosols. Topics covered include types of bioaerosols, sampling methods and potential health effects.

1.1. How to use this guidance

The aim of this guidance is to assist Environment Agency staff in evaluating bioaerosol risk assessments submitted to support permit applications for composting facilities. This guidance will also be useful to operators and consultants completing bioaerosol risk assessments, as it will provide greater understanding of the Environment Agency’s requirements. This document is designed specifically for bioaerosol risk assessments and supports existing guidance on risk assessments, including:

- “Guidelines for Environmental Risk Assessment and Management” (DETR et al. 2000).

The key components of this guidance are the decision flowcharts, checklists and reference tables found in sections 5, 6 and 7. Sections 2 through 4 provide further detailed information on the key aspects of a bioaerosol risk assessment to support the later sections. It is important to read and understand the background information before progressing to the flowcharts.

Each of the flowcharts has a specific purpose:

- The first flowchart assists in determining whether the correct documents have been submitted for a particular composting facility.
- The second flowchart examines the different aspects of the risk assessment to determine whether the required information is present.
- The second flowchart also refers to three checklists (section 6), which each assist in evaluating:
  - the problem definition (checklist 1),
  - the risk screening process (checklist 2) and
  - the bioaerosol monitoring information (checklist 3).

Within the checklists, reference is made to the earlier sections of this document that provide detailed information. Section 7 of this document provides four summary tables on bioaerosols, including sampling techniques, bioaerosol sources and health impacts. These tables are also referenced with the relevant checklist.

The flowcharts are designed to be used in the order they are presented. If the relevant information is not present, there are two possible actions:

- a request for further information should be sent to the operator; or
• if further information is not forthcoming or in adequate, the application may be rejected.

Once this information is received, you should start at the beginning of flowchart 1 again and work through the flowcharts and checklists systematically. The purpose of this guidance is to define what is consider acceptable in a bioaerosol risk assessment.
2. Introduction to bioaerosols

2.1. Micro-organisms associated with composting

The process of composting involves firstly shredding the material, which increases the surface area and then windrows are created. The combination of these processes provides ideal conditions for micro-organisms, including bacteria and fungi, to grow, multiply and break down the organic material. The effectiveness of the composting process is dependent upon providing the correct conditions (e.g. oxygen, temperature, moisture, and particle size) to support the growth of micro-organisms, which results in increasing temperatures due to biological activity.

Temperature is directly proportional to the biological activity within the composting system, so as temperature increases, micro-organisms increase the rate at which the organic material is broken down. The composting process generally begins with medium temperatures (mesophilic phase up to 40°C) and is dominated by mesophilic micro-organisms, but then progresses to higher temperatures (the thermophilic phase over 40°C) in later stages. During the thermophilic phase, thermophilic and thermotolerant fungi and bacteria are essential for the composting process to continue. In the thermophilic phase the numbers of actinomycetes (resemble fungi but are filamentous spore forming bacteria) and fungi, particularly *Aspergillus fumigatus*, increase.

Cellular waste products such as endotoxins and glucans are also present during composting. Endotoxins are found within the cell walls of Gram-negative bacteria and are comprised of lipids, proteins and lipopolysaccharides (LPS).

Bioaerosols from composting facilities arise when micro-organisms and their reproductive structures, cells and cellular waste material (endotoxins [bacteria] and glucans [fungi]) are released into the buoyant hot air rising from the windrow and into the air stream or are dispersed when the windrow is mechanically disturbed, allowing them to be carried downwind.

2.1.1. Fungi

Fungi are eukaryotic organisms that have cells bound by rigid walls usually formed of chitin and glucans. They may be unicellular or multi-cellular and comprise of yeasts, moulds, mushrooms, puffballs, and truffles. Different fungal species are adapted to thrive at specific temperatures, and so a change in the species composition is found during different stages of composting. The most common fungi in composting are the *Penicillium* and *Aspergillus* species. *Aspergillus fumigatus* is particularly important as it has the ability to degrade cellulose and is found in high numbers ([Swan et al., 2003](#)). *A. fumigatus* grows rapidly between 30°C and 52°C. Fungal spores produced during reproduction can vary in size, typically between 2 and 50 µm. They are often small, light and therefore easily transported by air. *A. fumigatus* is also found in many other environments and the presence of large amounts of its spores in most places results in very low risk of allergic responses to this fungi.

Fungi produce secondary products during metabolism, such as mycotoxins (toxic substances produced by fungi during their growth), as well as shedding components, such as glucans. Glucans are highly-branched polymers of glucose that occur as components of the cell walls of yeasts and other fungi.
2.1.2. **Bacteria**

Bacteria are single-celled prokaryotic organisms and are the most important group during the initial stages of the composting process (Miller, 1996). Bacteria are usually between 1 and 5 µm in size, and are divided into Gram-negative bacteria (predominantly of animal origin) and Gram-positive bacteria (predominantly of plant origin).

Gram-negative bacteria are more abundant in the mesophilic phases of composting. The pathogenic Gram-negative bacteria, *Salmonella* species and *Escherichia coli*, can also be found in composting facilities (Brinton *et al.*, 2009). However, adequate process control during composting should produce temperatures high enough to kill these bacteria.

Endotoxins are toxic substances that form an integral part of bacterial cells, and in particular, the outer membrane of Gram-negative bacteria. Endotoxin consists of a family of molecules called lipopolysaccharides (LPS). The lipid portion of LPS, Lipid A, is responsible for the toxicity of endotoxin. They are released into the environment during growth of bacteria and after the cell dies. Endotoxins can also be found in other industries, such as cotton production, poultry farms and hay or grain storage.

As the compost heats up and enters the thermophilic phase, the abundance of Gram-positive bacteria increases. Thermophilic bacteria from the genus *Bacillus* are able to survive at high temperatures, where they are capable reproduce quickly.

Actinomycetes are Gram-positive bacteria, but they are distinguished from other bacteria by their distinct role in decomposition. They have a filamentous (thread-like) morphology and grow slower than other bacteria, making them more of an intermediate between fungi and bacteria. Actinomycetes prefer moist and aerobic conditions, with a neutral to slightly alkaline pH. They are most easily seen in the early stages of composting, when the self heating process has begun. They form long grey strands that resemble spider webs and give the compost a soil-like odour. They are therefore a useful indication of the stage of the composting process. The most common species in composting are the *Saccharopolyspora* spp., *Thermoactinomyces* spp., *Thermomonospora* spp. and the mesophilic *Streptomyces* spp.

2.2. **Health impacts**

The presence of airborne particles and microorganisms, their occurrence and behaviour in relation to each other with respect to size (µm [fungi, bacteria and actinomycetes] and nm [cellular fragments] scales) and aerodynamic properties allow them to be released at high numbers on site, but also potentially travel away from site, downwind. Bioaerosols are generally less than 10 µm in size and are therefore not filtered out by the hairs and specialised cells that line the nose. They can therefore penetrate deep into the lungs, causing both respiratory and gastro-intestinal symptoms (CIWM, 2002).

Exposure to bioaerosols has been associated with human health effects and symptoms usually manifest inflammation of the respiratory system, coughs and fever (Enviros, 2004) and inhalation of bioaerosol may cause or exacerbate respiratory diseases. They have been also known to case gastrointestinal illness, eye irritation and dermatitis.

Organic Dust Toxic Syndrome (ODTS) is an acute disease, which results in symptoms resembling those of influenza, such as shivering, an increase in body
temperature, dry cough, and muscle and joint pains (Rylander, 1997). Particularly relevant to waste management facilities are infections caused by Aspergillus fumigatus. Invasive aspergillosis is a particularly severe infection, which may be fatal and is primarily a concern with at risk and immuno-suppressed patients.

One of the current knowledge gaps for bioaerosols is their dose-response relationships. We currently cannot state with any certainty that a given concentration will result in a particular health impact. This is because of the number of bioaerosols as well as the complexities associated with human responses to different microorganisms. Table 7.4 provides a summary of current knowledge on this topic.

2.3. Sources at composting facilities

Bioaerosols are ubiquitous and can be found associated with houses, hospitals, industry, agriculture and waste management facilities.

The majority of composting sites in the UK (79%) operate as open-air turned windrow systems (Association for Organics Recycling, 2008). Open-air windrow composting potentially results in the dispersal of bioaerosols downwind. The release of microorganisms, and their constituent parts, into the ambient environment through composting activities such as shredding, turning and screening has been shown to cause significant episodic release of bioaerosols. However, it is important to note that current measurement techniques mean that measurements reflect only instantaneous images of bioaerosol emissions, and not long term trends.

Waste management activities have been acknowledged as a source of environmental endotoxins, causing occupational exposure, but there is little information regarding endotoxin dispersal from green waste composting, and the potential for non-occupational exposure at sensitive receptors is unknown, due to the focus of past research on bioaerosols on the culturable fraction.

Bioaerosols are also small and light. They can therefore be carried by wind currents. The heat generated by the composting process can also contribute to their dispersal, as they are carried upwards as steam rises. Turbulence within the plume, and drop-out will dilute the concentration of bioaerosols downwind of a site. However, the exact nature of this dilution is difficult to quantify, due to several uncertainties. In particular, there is limited information available regarding bioaerosol particle size and aggregation tendencies, as well as the ratio of viable to non-viable particles.

2.4. Sources of variation

Bioaerosol concentrations naturally present in the atmosphere can vary greatly. This emphasises the need for reproducible, replicated, up-to-date and standardised sampling strategies to help evaluate this variability. Sources of natural variation include season, time of day, geographic location, and local weather conditions (particularly humidity and solar radiation).

Bioaerosol concentrations at composting facilities are determined by site activity, namely shredding, screening and turning of waste material / compost. Secondary to these are meteorological factors such as wind speed, wind direction, temperature and relative humidity, which also strongly affect concentrations. Compost source material and moisture content will also affect the ability for the microorganisms to proliferate and disperse.
2.5. Bioaerosol control and mitigation measures

The process of composting relies on microbial growth and biodegradation. If microbial populations are reduced by any measures, then the composting process will be compromised and its efficiency reduced. The aerial structures of bioaerosols release reproductive cells into the air stream to improve their chances of colonising new areas. Cells are small in size, produced in high numbers and are usually aerodynamic in shape. In other words, they are designed to disperse into the air stream and travel downwind. In addition, the buoyant hot air that is released from compost contains bioaerosols and can assist in moving them into the air stream. Therefore, in order to ‘control’ bioaerosols we need to look at the factors contributing to their release. There are three main mechanisms for mitigation of bioaerosol emissions, namely reducing releases, containing emissions and enhancing dispersion (Wheeler et al., 2001). These are mainly achieved through adjusting site activity and through consideration of the meteorological conditions.

Site activities (turning, screening and shredding) and the stage of composting influence bioaerosol dispersal (Taha et al., 2005, 2006, 2007). The activity that causes by far the highest release levels is turning of material, as the movement of compost material releases bioaerosols. We therefore suggest that at times of potentially high bioaerosol spread downwind, i.e. high winds and humidity, site activity be adjusted accordingly. For example, agitation activities should not be undertaken when high winds are blowing towards sensitive receptors. Furthermore, different equipment used on site can increase or decrease bioaerosol emissions. For example, slower speed shredders will generate fewer bioaerosols (Wheeler et al., 2001) and dedicated compost turners may generate fewer bioaerosols than front end loaders (Taha et al., 2006).

Drier compost is likely to result in more dust being created. This dust can carry and assist in dispersal of bioaerosols (Wheeler et al., 2001). Therefore, maintaining appropriate moisture content of the compost can assist in reducing bioaerosol releases. However, this does require careful management as if the moisture content becomes too high, the compost may become anaerobic and odorous, and excess leachate may be produced. In addition, systems that spray water or odour control chemicals have been suggested to 'bring bioaerosols to ground', but these are poorly researched and there is currently little published information to support the use of these.

Site topography and layout is also a major factor. Sites should be designed so that the smallest surface area of the windrow is exposed to the prevailing wind and that windrows and activities should be placed at the lowest elevations on site. Bunds, tree lines or banking can also be used to increase turbulence around the site (Britter, 1998; Wheeler et al., 2001). Increased turbulence can assist in improving dispersion and reducing downwind concentrations. However, there is limited detailed information about the effects of this, so further research is still required.

There is a move towards in-vessel systems to comply with the requirements of the Animal By-Products Regulation 2005, where the compost is housed in a sealed container, and air is filtered using biofilters. Biofilters were originally designed to remove odour, but there are a very limited number of studies on the efficiency of biofilters for removal of bioaerosols and airborne microorganisms in the air passing through the filter. The effectiveness of biofilters in removing bioaerosols has been shown to reduce the presence of Aspergillus fumigatus spores by about 90%, and mesophilic bacteria by between 39-94% (Sanchez-Monedero and Stentiford, 2002, Sanchez-Monedero et al., 2003). This large range suggests that further studies should be undertaken, as there is very little other published data on their
effectiveness for bioaerosol removal. Although, it has been shown that the removal efficiency of *A. fumigatus* associated particles is higher than the removal of bacterial cells (which in turn are more variable in their removal efficiency), there is currently no real explanation for this difference.

There is also some evidence to suggest that in certain circumstances, biofilters may become a source of bioaerosols themselves. Chmielowiec-Korzeniowska *et al.* (2007) found that a significant number of micro-organisms grew within a biofilter from an industrial hatchery. This caused significantly higher levels of mesophilic actinomycetes in all outlet ducts of the biofilter and compromised the efficiency of the filter by the release of bioaerosols into the post-filter air.
3. Bioaerosol sampling

There are currently three common methods used to collect bioaerosols, namely direct impaction, filtration and liquid impingers. Summaries of these techniques are briefly described in Table 7.1, Table 7.2 and Table 7.3. The direct impaction and filtration techniques are approved methods listed in the AFOR (2009) protocol for sampling of bioaerosols. Environment Agency staff must ensure that this standardised protocol is followed by those undertaking bioaerosol monitoring. The protocol has been specifically developed for composting facilities that operate open-air turned-windrow systems composting green waste, but is equally applicable to in-vessel systems where they may still emit bioaerosols. Where the waste source potentially presents a different hazard to green waste e.g. those wastes regulated by the Animal By-product Regulations, 2005, then monitoring additional microorganisms to those listed in the standard protocol, specifically Gram-negative bacteria, may be required (see section 3.2 for suitable culture media and incubation temperature).

Meteorological data (wind speed, wind direction, temperature and relative humidity) should also be recorded during sampling, as well as taking note of on-site activities.

3.1. Sample collection methods

3.1.1. Standard Protocol Methods

Direct impaction samplers, specifically the Andersen samplers (Copley Scientific) are loaded with pre-prepared agar plates, and the sample is collected directly onto the agar plate. The Andersen sampler typically operates at a flow rate of 28.3 Lmin\(^{-1}\), and can be either a single or multiple stage sampler, although the single stage is the method stated in the standard protocol. The multiple stage sampler has the ability to separate the total concentration into particle size fractions.

The standard protocol requires the use of at least two (preferably four) single stage Andersen samplers, which have been appropriately sterilized and plugged to prevent contamination. The samplers should be fitted with a baffle of at least 15 cm high and placed on a tripod so that the top of the inlet cone is held at 1.5 – 1.8 m above the ground. The samplers should be connected to a vacuum pump calibrated to a constant flow rate of 28.3 Lmin\(^{-1}\).

The advantages of this method are that it requires minimal post-collection sample handling, it pumps at a high rate and is capable of collection bioaerosols at low concentrations. There are also a number of disadvantages with this method. For example, it cannot be used for non-culturable micro-organisms, and the plates become easily over-loaded in areas where there are high emissions. In addition, prolonged exposure may harden the agar in the plates, resulting in particles bouncing off the agar, thereby reducing overall concentrations. The samplers are also expensive and labour intensive to operate.

The filtration method uses personal aerosol filter samplers operated at a flow rate of 2.0 ±0.1 Lmin\(^{-1}\). Pumps are attached to particulate sampling heads, loaded with IOM multi-dust plastic cassettes, with tubing and a vertical orientation. Each sample cassette contains a 0.8 µm pore size polycarbonate filter. Other filters such as quartz can also be used. Sampling pumps are run for 60 min, usually in triplicate (minimum of two) simultaneously. The samplers should be placed on a tripod at 1.5 – 1.8 m
above the ground. The advantage of this system is that it is simple and relatively inexpensive, which allows for easy replication of samples. This method can be used for both culturable and non-culturable micro-organisms. Although the field work associated with this method is straightforward, the post-sampling laboratory analysis requires more work than for the direct impaction samplers. In addition, sampling for markedly longer time periods will cause micro-organisms to dry out and lose viability. A further disadvantage is that the limits of detection with this method are not as low as for the Andersen sampler.

3.1.2. Other Methods

The AFOR protocol for sampling bioaerosols must be used as a minimum for bioaerosol monitoring. If this method has not been used, please contact the Human Health Advisory Service for advice on the use of alternative methods.

Liquid impingers capture bioaerosols in a glass container containing a liquid. The flow rate is typically 12.5 L min⁻¹, with an average sampling period of 1 to 8 hours. Examples of this equipment include the AGI-30 and the BioSampler (SKC). The main advantage of this method is that it reduces the possibility of micro-organisms drying out, as they are captured in a liquid. However, prolonged sampling periods can result in the liquid evaporating. This method can be used for both culture and non-culture methods.

There is evidence that the membrane filtration method is a reliable and reproducible alternative to the direct impactors, and has been accepted for the enumeration of bioaerosols from waste processing. German standards (VDI, 2004) have recently been developed for the sampling of moulds in air using gelatine and polycarbonate membrane filters. Table 3.1 provides the German standard, which has also been adopted as the basis for the new ISO air quality standards, currently under development.

Table 3.1 Details of the German standard for filtration sampling of bioaerosols (VDI, 2004)

<table>
<thead>
<tr>
<th>German standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling method</td>
</tr>
<tr>
<td>Filter sampling, gelatine/polycarbonate filter</td>
</tr>
<tr>
<td>Sampling flow rate</td>
</tr>
<tr>
<td>2.0 ±0.1 L min⁻¹</td>
</tr>
<tr>
<td>Sampling period</td>
</tr>
<tr>
<td>10 min to 24 hours</td>
</tr>
<tr>
<td>Agar</td>
</tr>
<tr>
<td>DG18</td>
</tr>
<tr>
<td>Incubation temperature</td>
</tr>
<tr>
<td>Mesophilic fungi 25°C</td>
</tr>
<tr>
<td>Thermotolerant fungi 37°C</td>
</tr>
<tr>
<td>Aspergillus fumigatus 45°C</td>
</tr>
</tbody>
</table>

3.2. Culture and enumeration methods

After sampling, culture techniques are used to determine the number of viable micro-organisms captured in a sample. We cannot use microscopes to see this, so we need to encourage the micro-organisms to grow from the microscopic scale to a macroscopic scale forming colonies on agar plates, so that we can visualise and count (enumerate) them.

For all the sampling methods (described below), agar plates are used to culture the micro-organisms. Agar contains essential micro-nutrients for micro-organism growth.
It also allows us to differentiate between micro-organisms by selecting appropriate agar, which can inhibit the growth of other micro-organisms.

Figure 3.1 shows the steps required for each of the three sampling methods described in section 3.1. For all methods, agar plates are prepared prior to collecting the samples on-site. With the direct impaction method, the agar plates are transported back to the laboratory, incubated and then the colonies can be counted.

For the Andersen sampler, agar plates are prepared prior to the field work. The following media are used for each of the micro-organisms:

- Bacteria: half-strength nutrient agar
- *Aspergillus fumigatus*: malt extract agar.

Agar plates for culturing bacteria should be incubated at 37°C and the number of colonies counted after 2 days. Sample plates culturing *A. fumigatus* are incubated at 40°C for 2 days.

With the filtration method, filter cassettes are removed from the sampling heads and placed into a sterile container containing buffer solution (for example, NaCl 1g L\(^{-1}\) and 3 drops of Tween 80 L\(^{-1}\), made up to 1L with sterilised ddH\(_2\)O), agitated to ensure buffer covers the polycarbonate filter (to avoid cell dehydration) and stored at 4°C for transport. Within 24hrs, filters should be removed from the sampling heads, under aseptic conditions, and re-suspended in the vial by shaking for 2 min.

The suspension could contain 1 micro-organism or 1 million micro-organisms. If too many are transferred to the agar, they can overgrow and obscure each other, which makes counting difficult. This is a common problem with the direct impaction samplers. One of the advantages of the filtration method is that the solution can be diluted. The suspensions should then be diluted to a common logarithm order (10\(^{-1}\) and 10\(^{-2}\)) and aliquots of 100 µL transferred to the centre of a range of culture media on 90 mm single-vented Petri dishes. The samples should then be spread evenly over the agar using a sterile spreader. Once the liquid is absorbed the Petri dish is inverted and incubated. The agars used and incubation temperatures should be as for the Andersen sampler method.

Alternative methods for enumeration involve the use of different agars:

- *Aspergillus fumigatus*: Malt Extract Agar [MEA] (with 0.1 g L\(^{-1}\) chloramphenicol) incubated at 37 ±2 °C in the dark for 3-7 days;
- Actinomycetes (Compost Agar [CA], after Taha et al. 2007 + 0.2 g L\(^{-1}\) cyclohexamide) incubated at 42 ±2 °C in the dark for 7 days; and
- Gram-negative bacteria (MacConkey Agar [MAC] + 0.2 g L\(^{-1}\) cyclohexamide), incubated at 37 ±2 °C in the dark for 3-7 days.

After the appropriate period, the number of Colony Forming Units (CFU's) on each plate is enumerated visually and recorded as CFU m\(^{-3}\) of sampled air. This is based on the theoretical assumption that 1 microbial cell or clump of cells gives rise to 1 colony on the agar plate. Thus the number of colonies that grow is equal to the original microbial count.

It is possible to get a result known as too numerous too count (TNTC). This is when the number of Colony Forming Unit’s (CFU) is greater than 399 (bacteria) or the inability to count individual colonies due to excessive growth (fungi) on a single 90mm Petri dish. The term TNTC is also used when CFU’s grow into each other producing a 'lawn' that does not enable individual CFU’s to be counted. The term
TNTC is used as the accuracy of determining the number of CFU’s on the Petri dish is compromised. When CFU’s reach these high numbers, it is also impossible to ascertain if some CFU’s growth is preventing other colonies from growing on the plate.

3.3. Interpretation of sampling results

Once you have the bioaerosol concentration in CFU m\(^{-3}\), the first step in interpreting the results is to compare with background concentrations specific to that site. Background concentrations refer to the concentrations of bioaerosols emitted from sources other than the composting facility and should preferably be concentrations sampled before the site was operational. In the absence of pre-operational bioaerosol concentrations, the sampling results should be compared to upwind samples. Downwind concentrations will be determined to assess the level of emission directly from the composting facility. These should not exceed the suggested threshold levels of 300, 1000 and 500 CFU m\(^{-3}\) for gram-negative bacteria, total bacteria and *Aspergillus fumigatus* respectively.

If the downwind measured concentrations exceed background concentrations or the suggested threshold limits, then three steps should be undertaken in the following order:

- The site and environmental conditions that existed during the sampling process should be examined for any anomalies, for example, unusually high tonnages being processed or high winds.
• The sampling process should be repeated to take into account the variability’s associated with bioaerosol sampling techniques.

• Finally, mitigation measures, such as the construction of bunds or planting of trees, should be discussed with the operator.

If you are still uncertain about interpreting the results, please contact the Human Health Advisory Service for advice on the use of alternative methods.

3.4. Sampling frequency

The frequency of sampling for bioaerosols should be determined by the level of risk from a particular site. With new sites, the level of bioaerosol emissions will initially be unknown, so more frequent sampling should be undertaken at new sites, until the emissions are understood. Typically, a three stage sampling regime will be proposed for bespoke permitted sites with a sensitive receptor within 250m of the site boundary:

• Stage 1: Background sampling should be undertaken before a site begins operating, to understand the level of bioaerosols before site activity.

• Stage 2: New sites should monitor quarterly for the first year of operations, to provide some indication of the level of variance in emissions.

• Stage 3: Under normal operating conditions, bioaerosol monitoring should be undertaken twice a year. This may be discussed with the Environment Agency on a site-specific basis.

It is anticipated that most sites will remain within Stage 3. However, under the following circumstances monitoring should return to Stage 2 and then progress through Stage 3 as appropriate:

• Sensitive receptors identified close to the site (i.e. within 250m)

• Any increase in the tonnage/amount of material being processed

• Any changes to the site operations, including new equipment or changes in feedstock

• High concentration of bioaerosols is detected during routine sampling

Sampling practices should follow the AFOR protocol, with samples taken upwind, downwind and at the nearest sensitive receptor.

In addition, there may be other concerns associated with a composting site. These include complaints from neighbours or politically sensitive sites. Frequently, complaints may be due to other emissions, especially odours. Other concerns may include the location of particularly sensitive receptors (e.g. a school or hospital) close to the site but beyond the 250m (e.g. 255m) trigger limit for bioaerosol risk assessments. In this situation, it may be prudent to undertake bioaerosol monitoring.
4. Key aspects of a risk assessment

4.1. What is risk?

The most common definition of risk is the probability of suffering (environmental) harm (consequences) from a hazard. The definition of risk depends on the context, for example, the people concerned, and what they are concerned about protecting. Risk therefore has social, technical and financial components.

Managing risk allows us to examine what might go wrong (the consequence) and the likelihood of it going wrong (the probability). Once we have a clearer understanding of the risk, we can prioritise preventative action or mitigate the consequences. Risk assessments can therefore demonstrate understanding of the issues and build confidence in the eyes of stakeholders.

We cannot manage the risks associated with all hazards, so undertaking a risk assessment allows us to prioritise those hazards that could result in the greatest harm. Risk assessments are also a statutory requirement that assists in regulatory decisions.

The starting point for every risk assessment is to identify the different aspects, namely the hazards, sources of those hazards, sensitive receptors and the pathways between the source and the receptors.

Figure 4.1 shows the different stages in undertaking a risk assessment and detailed guidance is available elsewhere (DETR et al., 2000; IEMA, 2006). The key stages are:

- Hazard identification: What sources of hazard(s) are present and what are their properties? Is this substance toxic (or situation hazardous) and how toxic (hazardous) is it?
- Exposure assessment: Evaluate the plausibility of the hazard being realised at the receptor - by which mechanisms, allowing an assessment of the probability, magnitude and duration of exposure. Who (or what) is exposed, how long and often?
- Risk estimation: Of what relative scale is the probability and extent of possible harm? How big a risk is this?
- Risk characterisation: How significant is the risk and what are the uncertainties? Is this something I need to worry about and if so, how much should I worry?
4.2. Problem definition

It is important to start by clearly setting out the problem, including what aspects the risk assessment will address and which it will not. This determines the scope, level of detail and focus. In particular, the temporal and spatial scales, contaminants to be assessed, persons at risk and the endpoint should be described. In other words, this process establishes the baseline and the environmental setting.

The problem definition should be logical and transparent. A clear and logical problem statement is useful should results be challenged or questioned later. The order of presentation is important. It should define the source of the hazard, the pathway and the receptors, and the processes that link them. If any one of these is missing, there is possibly no need for a risk assessment. For bioaerosol risk assessment a good understanding of the composting process, the environmental setting and the regulatory context (Environment Agency policy) are required. In particular, it should identify other sources of the same emission, sensitive receptors and stakeholders.

The problem definition should also state any limitations, uncertainties and assumptions. This should clearly state what has not been done and why, as well as what is not known and why. This may arise from a lack of knowledge, failure to consider boundaries of the risk assessment or failure to consider direct or indirect effects. It may be useful to involve stakeholders at this point, as they have local knowledge that may be useful. This prevents repeating analysis again later should anything come to light that was now discerned in the early stages. It is impossible to eliminate all uncertainties. It is therefore important to identify the key uncertainties and to state was has been done to resolve them. Part of this process involves stating the limitations to your own study, and justifying the gaps.
There are currently still many uncertainties associated with bioaerosols, including the ratio of viable to non-viable, differences between sampling procedures, bioaerosol dispersal (particle size and aggregation, which affect how far downwind bioaerosols can travel) and dose-response relationships. We currently cannot eliminate all these uncertainties as more research is needed, however, risk assessors should be aware of them and acknowledge them.

The simplest risk assessment method is to use a conceptual model (for example, Figure 4.2), which answers the essential questions of what is at risk and what is it at risk from? All stages of risk, including the risk of an initiating event, the risk of exposure and the risk of harm, should be examined. Using the Source-Pathway-Receptor model will assist in answering these questions. For example, at a composting facility three areas should be examined, namely the source of any emissions (i.e. the facility), those at risk (the sensitive receptor, such as the housing in Figure 4.2) and finally the pathway (the prevailing winds in Figure 4.2) between the source and the receptor.

Figure 4.2 Example conceptual model for a composting facility (after Environment Agency, 2004)

In particular, a bioaerosol risk assessment problem definition should describe:

- Processing technology, e.g. windrow, in-vessel, or static pile and equipment used
- Feedstock, tonnages processed and seasonal variations
- Site layout, including any screens, bunds, or trees around the site
- What is beyond the site boundaries
- Sources of bioaerosols from composting
- Local wind direction data
- Location of sensitive receptors
- Brief summary of health risks associated with bioaerosols
Other sources of bioaerosols in vicinity

Other emissions, e.g. odour

However, it is important to remember that the risk assessment is not a repeat of the working plan of the site nor is it a description of how to do a risk assessment (i.e. the theory).

4.3. Risk screening and prioritisation

The purpose of the risk screening exercise is to determine whether the composting facility represents, or potentially represents a risk by identifying the potential links between sources, pathways and receptors. It is essentially a qualitative assessment that prioritises the risks; however it should still be site specific.

In order to prioritise the risks, it is important to define the dose for each emission. The dose is defined by determining the concentration (or potency), the duration of exposure and the frequency of exposure. Acute exposures are those that have a short duration (typically a few hours), while chronic exposures refer to longer durations (measured in days). The number of receptors at risk and their vulnerability should also be taken into account when prioritising risks. For example, old and young people, or those who are immuno-compromised, tend to be more vulnerable.

The probability of harm examines the likelihood of someone being exposed, which assists in assessing the scale of the consequences of the harm being realised. It is important at this stage that all assumptions are included to justify the reasoning. In particular, the risk assessment should show the scenarios that have been examined, including both normal operations and the consequences of process failure (e.g. shredder breaks down and new arrivals cannot be processed). The probability of harm can be described as:

- High – exposure is probable, direct exposure likely with no/few barriers between source and receptor;
- Medium – exposure is fairly probable, barriers less controllable;
- Low – exposure unlikely, barriers exist to mitigate; or
- Very low – exposure very unlikely, effective and multiple barriers.

The consequences of the hazard considers the nature of the source, the hazard and the receptor. For bioaerosol risk assessments, this should show some appreciation of the health risks as well as possible nuisances such as odour from composting that may annoy the public. The consequences can be described as:

- High – severe consequences, evidence that exposure may result in serious damage
- Medium – significant consequences, evidence that exposure may result in damage that is not severe and is reversible
- Low – minor consequences, damage not apparent, reversible adverse changes possible
- Very low – negligible consequences, no evidence for adverse changes

By examining the probability and consequences together, you can determine the magnitude of the risk (Figure 4.3). For example, the exposure to bioaerosols emitted from a composting facility for a sensitive receptor within 250m would be considered...
medium. The consequences of exposure could be considered as high, therefore the magnitude of the risk are high. For sensitive receptors located further away, the probability of exposure would be low, so the magnitude of the risk would be medium. This information can be used to prioritise risks for further examinations, and can also define risk management options. High risks will need additional assessment and active management, while medium risks are likely to require further assessment and may require either active management or monitoring. Low and very low risk will only require periodic review.

![Risk Matrix]

**Figure 4.3 Determining the magnitude of the risk, with reference to the probability of harm and the consequences of the hazard (after Environment Agency, 2004).**

In summary, this stage should identify and justify the risks that will not be investigated further, and the risks that require action. This information will provide a justification for the prioritisation of resources for further investigation.

**4.4. Summary**

Risk assessments are not the decision, but are the processes that lead to informed decisions. All risk problems have a common structure and it is important to go through the process systematically. The key is to ensure that the problem has been defined correctly, taking into account the environmental health objectives. It is also useful to initially complete a qualitative assessment following the tiered approach, and use this analysis to direct and define further quantitative work. Common problems and mistakes include:

- Problem definition is poor or absent
- Risk assessment is not site specific
- Not stating the limitations/uncertainties
- Not using diagrams (conceptual models, maps, site layout)
For bioaerosol risk assessments, common problems found include:

- Absent or inadequate description of sampling techniques, including organisms sampled and culture techniques
- Assumptions not stated
- Other potential sources of bioaerosols not identified
- Background information not supplied
- Information presented not relevant and site specific
- Little or no appreciation of health risks associated with bioaerosols provided.

This document aims to provide guidance to avoid these issues.
5. Decision flowcharts

Flowchart 1: Confirmation of documentation acceptability

Is the site exempt from an environmental permit?

- Yes
  - Does the site process less than 10 tons at any one time?
    - Yes
      - No further documentation necessary
    - No
      - Is the Pollution Risk Assessment complete?
        - Yes
          - No further documentation necessary
        - No
          - Ask the operator to complete the risk assessment
          - Refer to Flowchart 2
          - Ask the operator to complete a site-specific bioaerosol risk assessment

- No
  - Are there sensitive receptors within 250m?
    - Yes
      - No further documentation necessary
    - No
      - Has the operator completed a site-specific bioaerosol risk assessment?
        - Yes
          - No further documentation necessary
        - No
          - Ask the operator to complete a site-specific bioaerosol risk assessment

Refer to Flowchart 2
Flowchart 2: Appraisal of Risk Assessment Content

Has the operator defined the problem? Refer to Checklist 1.

- Yes
- No

Has the operator screened the risks? Refer to Checklist 2.

- Yes
- No

Ask the operator to provide further information.

Has the operator monitored for bioaerosols using the AFOB Standard Protocol?

- Yes
- No

Ask the operator to provide further information.

Is all the information present? Refer to Checklist 3.

- Yes
- No

Ask the operator to provide bioaerosol monitoring data.

Are there any unacceptable risks or high levels of bioaerosols?

- Yes
- No

Ask the operator to provide further information.

Does the operator have adequate controls, management procedures or mitigation methods?

- Yes
- No

Accept risk assessment. Stipulate appropriate monitoring regime.

Contact the Human Health Advisory Service.

Accept risk assessment. Stipulate appropriate monitoring regime.

Suggest improvements for resubmission.
6. Checklists

Checklist 1: Problem Definition (refer to Section 4.2)

<table>
<thead>
<tr>
<th>Essential attributes</th>
<th>Yes/No</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Has the operator or consultant described Environment Agency policy on bioaerosols and risk assessment?</td>
<td></td>
</tr>
<tr>
<td>2 Has the operator or consultant demonstrated that they understand what bioaerosols are (see section 2)?</td>
<td></td>
</tr>
<tr>
<td>3 Does the operator or consultant provide a summary of health risks from bioaerosols (see section 2.2 and Table 7.4)?</td>
<td></td>
</tr>
<tr>
<td>4 Has the operator or consultant described other sources of bioaerosols in vicinity (see Table 7.5)?</td>
<td></td>
</tr>
<tr>
<td>5 Has the operator or consultant shown they understand the uncertainties and the lack of dose-response relationships associated with bioaerosols?</td>
<td></td>
</tr>
<tr>
<td>6 Has the operator or consultant discussed any other potential emissions, e.g. odour, from their activities?</td>
<td></td>
</tr>
<tr>
<td>7 Has the operator or consultant described the processing technology and equipment that is or will be used on the site?</td>
<td></td>
</tr>
<tr>
<td>8 Has the operator or consultant described the feedstock that they will process and the tonnages?</td>
<td></td>
</tr>
<tr>
<td>9 Has the operator or consultant described the site layout and included a scaled diagram?</td>
<td></td>
</tr>
<tr>
<td>10 Does this description cover details of any screens, bunds, misting sprays or trees around the site?</td>
<td></td>
</tr>
<tr>
<td>11 Has the operator or consultant described the pathways between the source and receptors, e.g. the prevailing winds?</td>
<td></td>
</tr>
<tr>
<td>12 Has the operator or consultant provided local wind direction data?</td>
<td></td>
</tr>
<tr>
<td>13 Has the operator or consultant described what is beyond the site boundaries?</td>
<td></td>
</tr>
<tr>
<td>14 Does this include the location of and distance to sensitive receptors? Is there a scaled map that shows this?</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Desirable attributes</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>16 Is all information site specific and relevant?</td>
<td></td>
</tr>
<tr>
<td>17 Has the operator or consultant described their own competencies or qualifications for undertaking a bioaerosol risk assessment?</td>
<td></td>
</tr>
<tr>
<td>18 Has the operator or consultant consulted any receptors (stakeholders)?</td>
<td></td>
</tr>
</tbody>
</table>
**Checklist 2: Risk Screening (refer to Section 4.3)**

<table>
<thead>
<tr>
<th>Essential attributes</th>
<th>Yes/No</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Has the operator or consultant described what is at risk (sensitive receptors, e.g. offices, schools homes)?</td>
<td></td>
</tr>
<tr>
<td>2 Has the operator or consultant described what it is at risk from (the hazard)?</td>
<td></td>
</tr>
<tr>
<td>3 Has the operator or consultant described what might happen (the consequences)?</td>
<td></td>
</tr>
<tr>
<td>4 Has the operator or consultant described how it might happen (pathways)?</td>
<td></td>
</tr>
<tr>
<td>5 Has the operator or consultant described how large the consequences might be?</td>
<td></td>
</tr>
<tr>
<td>6 Has the operator or consultant described how probable the consequences are?</td>
<td></td>
</tr>
<tr>
<td>7 Has the operator or consultant described the significance of the probabilities and consequences?</td>
<td></td>
</tr>
<tr>
<td>8 Has the operator or consultant described the criteria used to assess their significance?</td>
<td></td>
</tr>
<tr>
<td>9 Has the operator or consultant described the certainty of the assessment?</td>
<td></td>
</tr>
<tr>
<td>10 Has the operator or consultant described the most significant risk?</td>
<td></td>
</tr>
<tr>
<td>11 Has the operator or consultant described their assumptions and justified these?</td>
<td></td>
</tr>
<tr>
<td>12 Is all information site specific and relevant?</td>
<td></td>
</tr>
</tbody>
</table>
### Checklist 3: Bioaerosols (refer to Section 2)

<table>
<thead>
<tr>
<th>Essential attributes</th>
<th>Yes/No</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Has the operator or consultant listed the sources of bioaerosols from their composting process?</td>
<td></td>
</tr>
<tr>
<td>2 Has the operator or consultant explained the causes of variation?</td>
<td></td>
</tr>
<tr>
<td>3 Has the operator or consultant identified other sources of bioaerosols in the vicinity (refer to Table 7.5)?</td>
<td></td>
</tr>
<tr>
<td>4 Has the operator or consultant discussed bioaerosol dispersal?</td>
<td></td>
</tr>
<tr>
<td>5 Has the operator or consultant used the Association for Organics Recycling standard protocol for sampling? If not, please contact the Human Health Advisory Service advice on alternative methods.</td>
<td></td>
</tr>
<tr>
<td>6 Has the operator or consultant monitored background concentrations?</td>
<td></td>
</tr>
<tr>
<td>7 Is background either upwind for an existing site or pre-operations for a new site?</td>
<td></td>
</tr>
<tr>
<td>8 How far upwind (greater than 25m)?</td>
<td></td>
</tr>
<tr>
<td>9 Has the operator or consultant stated the local conditions during sampling (sampling location, including height and relationship to buildings, activities on-site, and weather conditions)?</td>
<td></td>
</tr>
<tr>
<td>10 Has the operator or consultant taken these into account in designing their sampling strategy?</td>
<td></td>
</tr>
<tr>
<td>11 Has the operator or consultant provided details of equipment used and sampling times (refer to Table 7.3)?</td>
<td></td>
</tr>
<tr>
<td>12 Has the operator or consultant provided details of the calibration of equipment?</td>
<td></td>
</tr>
<tr>
<td>13 Has the operator or consultant provided details of the storage of samples, transport method, time of transport, and any delays in analysis?</td>
<td></td>
</tr>
<tr>
<td>14 Has the operator or consultant provided details of laboratory procedures, including agar used and culture techniques (refer to Table 7.1)</td>
<td></td>
</tr>
<tr>
<td>15 Has the operator or consultant provided details of the laboratory certification?</td>
<td></td>
</tr>
<tr>
<td>16 Has the operator or consultant provided details of the level of replication of sampling, variability between samples, or a statement of errors or error bars?</td>
<td></td>
</tr>
<tr>
<td>17 Has the operator or consultant stated the uncertainties associated with the data?</td>
<td></td>
</tr>
<tr>
<td>18 Is all information site specific and relevant?</td>
<td></td>
</tr>
</tbody>
</table>
7. Reference tables

Tables 7.1 – 7.3 are designed to provide a quick reference guide to the possible methods used for bioaerosol sampling. Table 7.1 shows the culture methods used for the different micro-organisms and Table 7.2 shows the methods used to quantify non-viable cells. Table 7.3 provides a guide to the different on-site sampling methods. Table 7.4 gives an indication of suggested threshold levels and possible health impacts, while Table 7.5 shows indicative concentrations captured from other sources of bioaerosols.

The AFOR standard protocol for sampling bioaerosols should be used as a minimum for bioaerosol monitoring. If this method has not been used, please contact the Human Health Advisory Service for advice on the use of alternative methods.
<table>
<thead>
<tr>
<th>Bioaerosol component</th>
<th>AFOR Standard protocol</th>
<th>AFOR methodology</th>
<th>Recommended Methodology</th>
<th>Dilution series recommended</th>
<th>Species Identification</th>
<th>Enumeration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Fungi</td>
<td>×</td>
<td>n/a</td>
<td>MEA, 25 ±2 °C in dark for 5-7 days</td>
<td>10⁻¹, 10⁻², 10⁻³</td>
<td>n/a</td>
<td>Count CFU’s where 10-100 per plate (before overgrowth) report as CFU m⁻³</td>
</tr>
<tr>
<td>Total Bacteria</td>
<td>✓</td>
<td>Half-strength NA, 20 min sampling (Andersen), incubate at 37 °C</td>
<td>NA, 37 ±2 °C in dark for 2 days</td>
<td>10⁻¹, 10⁻², 10⁻³</td>
<td>n/a</td>
<td>Count where between 30-399 per plate report as CFU m⁻³</td>
</tr>
<tr>
<td>Aspergillus fumigatus</td>
<td>✓</td>
<td>MEA, 30 min sampling time (Andersen) 40 ±2 °C</td>
<td>MEA, 40 ±2 °C in dark for 2 days (spread plate)</td>
<td>10⁻¹, 10⁻²</td>
<td>White spreading colonies with green center</td>
<td>Count CFU’s where 10-100 per plate (before overgrowth) report as CFU m⁻³</td>
</tr>
<tr>
<td>Gram negative bacteria</td>
<td>×</td>
<td>n/a</td>
<td>MAC, 37 ±2 °C in dark for 3-7 days (pour plate)</td>
<td>10⁻¹, 10⁻² (10⁻³ if heavy load)</td>
<td>Cream or Pink in colour circular to oval colonies in shape</td>
<td>Count where between 30-300 per plate report as CFU m⁻³</td>
</tr>
<tr>
<td>Actinomycetes</td>
<td>×</td>
<td>n/a</td>
<td>CA, 42 ±2 °C in dark for 7 days (spread plate)</td>
<td>10⁻¹, 10⁻²</td>
<td>Gram positive bacteria with filamentous morphology</td>
<td>Count where between 30-300 per plate report as CFU m⁻³</td>
</tr>
</tbody>
</table>
### Table 7.2 Bioaerosol Sampling (non-viable cells)

<table>
<thead>
<tr>
<th>Bioaerosol component</th>
<th>Description</th>
<th>AFOR standard protocol</th>
<th>Methods</th>
<th>Why analyse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endotoxin</td>
<td>Gram negative bacteria cell waste product in nm scale</td>
<td>x</td>
<td>Limulus amoebocyte lysate assay</td>
<td>Endotoxin can cause inflammatory reactions in humans</td>
</tr>
<tr>
<td>Phenotypic diversity</td>
<td>Microbial diversity measure (profiling)</td>
<td>x</td>
<td>PLFA Analysis (biochem)</td>
<td>Non-viable qualitative fingerprint of microbial diversity</td>
</tr>
<tr>
<td>Genotypic diversity</td>
<td>Microbial diversity measure (profiling)</td>
<td>x</td>
<td>DGGE, T-RFLP (molecular)</td>
<td>Non-viable qualitative measure of genetic diversity</td>
</tr>
</tbody>
</table>

### Table 7.3 Bioaerosol Sampling Technologies

<table>
<thead>
<tr>
<th>Sampling method</th>
<th>Examples</th>
<th>Method of capture</th>
<th>Sampling time</th>
<th>Sampling volume</th>
<th>Analysis</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluid Impinger</td>
<td>AGI-30 / Biosampler</td>
<td>Direct Into liquid</td>
<td>1-8 hrs</td>
<td>12.5 l min⁻¹</td>
<td>Viable &amp; non-viable cells</td>
<td>Minimal dehydration as cells are sampled into liquid</td>
<td>Fragile glass sampler, expensive, uncommon use</td>
</tr>
<tr>
<td>Direct Impactor</td>
<td>Andersen sampler / Merck</td>
<td>Direct onto culture media</td>
<td>20-30 min</td>
<td>28.3 l min⁻¹</td>
<td>Viable cells only</td>
<td>No further dilutions – direct incubation</td>
<td>Rapid overloading of sampling media in areas with a high microbial load, culturable cells only</td>
</tr>
<tr>
<td>Membrane filter sampler</td>
<td>SKC personal sampling pump</td>
<td>Onto polycarbonate filter</td>
<td>30-45 min</td>
<td>2.2 l min⁻¹</td>
<td>Viable &amp; non-viable cells</td>
<td>Adopted by European standard, cost</td>
<td>Possible loss of viability due to dehydration on longer sampling times</td>
</tr>
</tbody>
</table>
Table 7.4 Bioaerosol Health Impacts: Available suggested dose-response and threshold exposure data for bioaerosols (after Pankhurst et al. 2008)

<table>
<thead>
<tr>
<th>Bioaerosol</th>
<th>Suggested dose-response/threshold</th>
<th>Result if suggested dose-response exceeded</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bacteria (cfu/m³)</strong></td>
<td>10,000</td>
<td>Not stated</td>
<td>Macher, 1999; Lavoie et al., 2006</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>Not stated</td>
<td>Wheeler et al., 2001*</td>
</tr>
<tr>
<td><strong>Fungi (cfu/m³)</strong></td>
<td>5 × 10⁴</td>
<td>Work related respiratory disorders at continuous exposures over 10⁵</td>
<td>Dutkiewicz, 1997</td>
</tr>
<tr>
<td><strong>Background</strong></td>
<td>Not stated</td>
<td></td>
<td>Macher, 1999; Lavoie et al., 2006</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>Not stated</td>
<td>Wheeler et al., 2001*</td>
</tr>
<tr>
<td><strong>Actinomycetes (cfu/m³)</strong></td>
<td>2 × 10⁴</td>
<td>Work related respiratory disorders at continuous exposures over 10⁵</td>
<td>Dutkiewicz, 1997</td>
</tr>
<tr>
<td><strong>Aspergillus fumigatus (spore/m³)</strong></td>
<td>10⁵-10⁶</td>
<td>Sensitisation if exposed repeatedly</td>
<td>Milner et al., 1994</td>
</tr>
<tr>
<td></td>
<td>10⁸</td>
<td>Hypersensitivity Pneumonitis</td>
<td>Milner et al., 1994</td>
</tr>
<tr>
<td><strong>Gram-negative bacteria (cfu/m³)</strong></td>
<td>1 × 10⁴</td>
<td>Work related respiratory disorders at continuous exposures over 10⁵</td>
<td>Dutkiewicz, 1997</td>
</tr>
<tr>
<td></td>
<td>2 × 10⁴</td>
<td>Work related respiratory disorders at continuous exposures over 10⁵</td>
<td>Dutkiewicz, 1997</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>Not stated</td>
<td>Wheeler et al., 2001*</td>
</tr>
<tr>
<td><strong>Endotoxins</strong></td>
<td>1-2 × 10² (ng/m³)</td>
<td>Not stated</td>
<td>Dutkiewicz, 1997</td>
</tr>
<tr>
<td></td>
<td>50 (eu/m³)</td>
<td>Based on no-effect-level of 90 eu/m³ in clinical trials</td>
<td>Liebers et al., 2006</td>
</tr>
<tr>
<td></td>
<td>1000-2000 (ng/m³)</td>
<td>Organic dust toxic syndrome</td>
<td>Milner et al., 1994</td>
</tr>
<tr>
<td></td>
<td>100-200</td>
<td>Bronchostriction</td>
<td>Milner et al., 1994</td>
</tr>
<tr>
<td></td>
<td>20-50</td>
<td>Mucous membrane irritation</td>
<td>Milner et al., 1994</td>
</tr>
</tbody>
</table>

*The Environment Agency’s adopted reference levels are based on Wheeler et al., (2001).*
Table 7.5 Comparison of bioaerosols from different sources to those found from composting with indicative concentrations (after Pankhurst et al. 2008)

<table>
<thead>
<tr>
<th>Bioaerosol</th>
<th>Source</th>
<th>Quantity</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fungi (cfu/m³)</strong></td>
<td>Indoors (UK homes)</td>
<td>28 - &gt;35,000</td>
<td>Swan et al., 2003</td>
</tr>
<tr>
<td></td>
<td>Grain harvesting</td>
<td>$10^4$-$10^7$</td>
<td>Swan et al., 2003</td>
</tr>
<tr>
<td></td>
<td>Cattle sheds</td>
<td>$10^4$-$10^5$</td>
<td>Swan et al., 2003</td>
</tr>
<tr>
<td></td>
<td>Horse stables</td>
<td>$10^3$-$10^4$</td>
<td>Swan et al., 2003</td>
</tr>
<tr>
<td></td>
<td>Pig houses</td>
<td>$10^4$-$10^5$</td>
<td>Swan et al., 2003</td>
</tr>
<tr>
<td></td>
<td>Poultry houses</td>
<td>$10^3$</td>
<td>Swan et al., 2003</td>
</tr>
<tr>
<td></td>
<td>Textile mills</td>
<td>105</td>
<td>Swan et al., 2003</td>
</tr>
<tr>
<td></td>
<td>Paper mills</td>
<td>$10^2$</td>
<td>Swan et al., 2003</td>
</tr>
<tr>
<td></td>
<td>Waste collection</td>
<td>$10^4$-$10^5$</td>
<td>Nielsen et al., 1997</td>
</tr>
<tr>
<td></td>
<td>Composting facility</td>
<td>$10^3$ - $10^4$</td>
<td>Wheeler et al., 2001</td>
</tr>
<tr>
<td><strong>Aspergillus fumigatus (cfu/m³)</strong></td>
<td>Outdoor air</td>
<td>0-690</td>
<td>Millner et al., 1994</td>
</tr>
<tr>
<td></td>
<td>Garden waste collection</td>
<td>10³</td>
<td>Nielsen et al., 1997</td>
</tr>
<tr>
<td></td>
<td>Composting facility</td>
<td>10⁶</td>
<td>Clark et al., 1983</td>
</tr>
<tr>
<td></td>
<td>Composting turning activity</td>
<td>$10 - 16 \times 10^6$</td>
<td>Taha et al., 2005</td>
</tr>
<tr>
<td></td>
<td>50m from composting facility</td>
<td>200-1000</td>
<td>Kothary et al., 1984</td>
</tr>
<tr>
<td></td>
<td>250m from composting facility</td>
<td>50</td>
<td>Kothary et al., 1984</td>
</tr>
<tr>
<td><strong>Bacteria (cfu/m³)</strong></td>
<td>Grain harvesting</td>
<td>$10^4$-$10^8$</td>
<td>Swan et al., 2003</td>
</tr>
<tr>
<td></td>
<td>Cattle sheds</td>
<td>$10^3$-$10^5$</td>
<td>Swan et al., 2003</td>
</tr>
<tr>
<td></td>
<td>Horse stables</td>
<td>10⁵</td>
<td>Swan et al., 2003</td>
</tr>
<tr>
<td></td>
<td>Pig houses</td>
<td>$10^4$-$10^5$</td>
<td>Swan et al., 2003</td>
</tr>
<tr>
<td></td>
<td>Poultry houses</td>
<td>10⁵</td>
<td>Swan et al., 2003</td>
</tr>
<tr>
<td></td>
<td>Textile mills</td>
<td>10⁶</td>
<td>Swan et al., 2003</td>
</tr>
<tr>
<td></td>
<td>Paper mills</td>
<td>$10^3$-$10^6$</td>
<td>Swan et al., 2003</td>
</tr>
<tr>
<td></td>
<td>Waste collection</td>
<td>$10^4$-$10^5$</td>
<td>Nielsen et al., 1997</td>
</tr>
<tr>
<td></td>
<td>Composting facility</td>
<td>$10^3$ - $10^6$</td>
<td>Wheeler et al., 2001</td>
</tr>
<tr>
<td></td>
<td>200m from composting facility</td>
<td>0-1</td>
<td>Gilbert et al., 2002</td>
</tr>
<tr>
<td><strong>Actinomycetes (cfu/m³)</strong></td>
<td>Composting turning activity</td>
<td>$20 - 36 \times 10^6$</td>
<td>Taha et al., 2005</td>
</tr>
<tr>
<td></td>
<td>Composting shredding activity</td>
<td>&lt; $5\times10^4$</td>
<td>Lacey, 1997</td>
</tr>
</tbody>
</table>
References


Association for Organics Recycling (AFOR), 2008. The State of Composting and Biological Waste Treatment in the UK 2005/06. The Association for Organics Recycling: Wellingborough, UK.


Macher J. (ed.), 1999. Bioaerosols assessment and control. Cincinnati, Ohio: American Conference of Governmental Industrial Hygienists (ACGIH); 322 pp


List of abbreviations

CA - Compost Agar
CEN – European Committee for Standardisation
CFU’s - Colony Forming Unit’s
CIWM – Chartered Institute of Wastes Management
dd – double distilled
Defra – Department for Environment, Food and Rural Affairs
DGGE - Denaturing Gradient Gel Electrophoresis
IOM – Institute of Occupational Medicine
MAC - MacConkey Agar
MEA - Malt Extract Agar
NA - Nutrient Agar
PLFA - Phospholipid Fatty Acid
Spp. - species
Glossary

**Actinomycetes** – A specific group of bacteria that are capable of forming very small spores.

**Aerosol** – A suspension in a gaseous medium of solid particles, liquid particles or solid and liquid particles having a negligible falling velocity.

**Aspergillus fumigatus** – Species of fungus with spores that can cause allergic reactions in some people.

**Bacteria** – A group of micro-organisms with a primitive cellular structure, in which the genetic material is not retained within an internal membrane (nucleus).

**Bioaerosols** – Micro-organisms suspended in air.

**Chronic pulmonary effects** – Long-term disruption to the lung’s ability to supply oxygenated blood to the heart.

**Colony forming units (cfu)** – Unit of measure for micro-organism numbers that relies on bacteria to grow to form colonies on nutrient plates that can be subsequently counted.

**COPD** – Chronic Obstructive Pulmonary Disease: disorders characterised by abnormal tests of expiratory flow unchanged over periods of several months.

**Endotoxin** – Certain (toxic) substances found within bacterial cells and which are released only on cell lysis.

**Eukaryote** – Organisms with complex cells and a nucleus.

**Fungi** – A group of micro-organisms with a more complicated cellular structure than bacteria, in which the hereditary genetic material is retained within an internal membrane, forming a nucleus.

**Glucans** – Polysaccharides composed of D-glucose in either straight or branched chains with glycosidic linkages.

**Gram-negative bacteria** – A group of bacteria that can be identified by their inability to hold the crystal violet stain due to fundamental differences in cell biology.

**Gram-positive bacteria** – A group of bacteria that can be identified by their ability to hold the crystal violet stain due to fundamental differences in cell biology.

**Hazard** – A substance or situation with the potential to cause harm.

**Inhalable dust** – Dust that can be inhaled into the body through the nose and throat but may be captured before entering the lungs. Respirable dust is the smaller fraction of dust that can penetrate to the lungs.

**Mesophilic** – The temperature range most conducive to the maintenance of optimum digestion by mesophilic bacteria 20 – 45 °C.

**Micro-organism** – An organism too small to see with the naked eye that is capable of living on its own.

**Mycotoxins** – Toxic substances produced by fungi.
**ODTS** – Organic Dust Toxic Syndrome: fever, flu-like symptoms, headaches, excessive tiredness and joint pain, and gastrointestinal problems; symptoms usually disappear within a day.

**Organic dusts** – airborne particulates of vegetable, animal or microbial origin.

**Organic matter** – Chemical substances of animal or vegetable origin, consisting of hydrocarbons and their derivatives.

**Pathogen** – Any organism capable of producing disease through infection.

**Pathogen kill** – High temperature period of composting (>55 °C) during which organisms capable of producing disease or infection are destroyed.

**Prokaryote** – organisms without a cell nucleus, and are in most cases unicellular, although can occasionally be multi-cellular.

**Risk** - the probability of suffering harm or loss under specific circumstances, has magnitude.

**Sensitive receptor** – any building, other structure or installation, in which at least one person normally lives or works, other than a building, structure or installation within the same ownership or control as the operator/owner of the composting facility.

**Streptococci** – Group of Gram-positive bacteria, many of which are linked to parasites and pathogens of animals, particularly of the respiratory tract.

**Thermophilic** – The process or organisms that occur at temperatures above 45 °C.

**Toxicity** – the potential of a material to produce injury in biological systems.

**Viability** – Ability of micro-organisms to survive.