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Bioaerosol emissions from waste composting and the potential for workers' exposure

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Bioaerosol emissions from waste composting and the potential for workers' exposure

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Composting organic waste is an important component of the waste management process in the UK and the strategy to reduce waste to landfill, and as a result there has been an increase in the number of commercial composting operations. Microbiological activity is fundamental to the composting process, therefore any handling of composting material is likely to make airborne significant quantities of those micro-organisms (referred to as bioaerosols). Workers mechanically handling compost on these sites may therefore be at risk of considerable exposure to bioaerosols depending on their work task, their proximity to the bioaerosol source and the control measures put in place. In addition, because the work is largely done out of doors, there is the potential for bioaerosols generated to disperse some distance from the point source. Consequently, there is concern that people living or working in the vicinity of waste composting sites (sensitive receptors) may also be exposed to these bioaerosols.

Bioaerosols were sampled at sites representative of commercial scale waste composting in the UK. The samples taken were linked to specific activities likely to generate compost bioaerosols, such as turning and screening, and samples were collected from as close as possible to the source of emission. The dispersion of bioaerosols from compost handling activities was estimated by collecting bioaerosol samples at several points downwind increasing in distance from the emission site up to 250m. Upwind background samples were used as a benchmark. The sampling took place during both winter and summer periods to provide an insight into the differences in bioaerosol generation that may exist.

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CONTENTS

EXECUTIVE SUMMARY

Objectives

Composting organic waste is an important component of the waste management process in the UK and the strategy to reduce waste to landfill, and as a result there has been an increase in the number of commercial composting operations. Microbiological activity is fundamental to the composting process, therefore any handling of composting material is likely to make airborne significant quantities of those micro-organisms (referred to as bioaerosols). Workers mechanically handling compost on these sites may therefore be at risk of considerable exposure to bioaerosols depending on their work task, their proximity to the bioaerosol source and the control measures put in place. In addition, because the work is largely done out of doors, there is the potential for bioaerosols generated to disperse some distance from the point source. Consequently, there is concern that people living or working in the vicinity of waste composting sites (sensitive receptors) may also be exposed to these bioaerosols.

Bioaerosols were sampled at sites representative of commercial scale waste composting in the UK. The samples taken were linked to specific activities likely to generate compost bioaerosols, such as turning and screening, and samples were collected from as close as possible to the source of emission. The dispersion of bioaerosols from compost handling activities was estimated by collecting bioaerosol samples at several points downwind increasing in distance from the emission site up to 250m. Upwind background samples were used as a benchmark. The sampling took place during both winter and summer periods to provide an insight into the differences in bioaerosol generation that may exist.

Main Findings

The results confirmed that, close to the source of composting processes, large concentrations of bacteria, actinomycetes and fungi, and to a lesser extent endotoxin and dust, may be aerosolised. Bacteria and fungi frequently in excess of 100,000 (10^5) cfu/m^3 of air and sometimes in excess of 1 million (10^6) cfu/m^3 air were measured immediately adjacent to the release area (windrow turning). There was a general trend of decreasing bioaerosol with distance from the source. This is most prominent at 50m distance from the source compared to the immediate area of release (samples taken outside vehicle cabs), and at 10m distance. By 50m and 100m distances downwind of the process, bioaerosol concentrations were substantially reduced by comparison to those levels measurements at source.

For ease of interpretation, the bioaerosol emission data were subdivided into exposure bands for the four main bioaerosol components for individual sites and for site activities. A ‘risk zone’ approach was also applied to the overall emission data for each of the four main bioaerosol components, to summarise the likelihood of exposure to bioaerosols at different distances from composting activities. In summary:

- Bioaerosol concentrations at 50m upwind of site operations were within a range considered to be ‘typical’ background levels, with the large majority (84%+) of samples yielding less than 1,000 cfu/m^3 air of bacteria, actinomycetes, fungi and *Aspergillus fumigatus*.

- Close to compost handling activities, if workers are not protected from exposure, they may be exposed to concentrations of airborne bacteria and fungi that frequently exceed

100,000 (10^5) cfu/m^3 and occasionally (28% of bacterial samples and 10% of fungal samples) exceed 1 million cfu/m^3 air sampled.

- Downwind of compost handling activities, although at some sites the bioaerosol levels at times were higher than upwind even at 100 to 250m distance, still the majority of samples yielded fewer than 1,000 cfu/m^3 air. At least 93% of bacteria and 98% of *Aspergillus fumigatus* bioaerosol concentrations were less than 5,000 cfu/m^3 air, and could be considered to be within the range of 'typical' background levels.

- There was little evidence therefore that the composting operations studied made a major contribution to the overall bioaerosol burden by a distance of 250m from activities.

Recommendations

Bioaerosol emissions from commercial waste composting activities will continue to be a health concern for workers on site and to near neighbours. This study has provided evidence of the potential for compost site workers to be exposed to large concentrations of bioaerosols, and some previous epidemiological studies have examined the effect of such levels of exposure to compost bioaerosols and shown the potential for allergic respiratory ill health.

The data from this study has demonstrated that compost bioaerosol emissions rapidly decline with distance from source and that at site boundaries are within what could be considered as 'typical' background levels. Only limited information exists on the effects of long term exposure to bioaerosols at or slightly above typical environmental levels, and the threshold dose that may trigger respiratory response. Continued research in this area is necessary to resolve such questions.

Bioaerosol sampling methods were compared. The industry guidance method most commonly used at present to collect bioaerosols on compost sites provides useful data but has some practical limitations, while two more practical filter based collection methods may provide comparable bioaerosol data. Filtration sampling may be a practical advantage and the use of such methods may warrant further investigation.

The 'risk zone' approach described in this report provides a simple method which can be adopted for site operators and regulators to assess the potential for occupational exposure to compost bioaerosols. Included in this was an estimate of the likelihood of exposure to significant concentrations of bioaerosol components. Such an approach can be used to apply practical and proportionate exposure mitigation measures on waste composting sites.

1 INTRODUCTION

1.1 THE COMPOSTING PROCESS AND ITS COMMERCIAL IMPORTANCE

The UK produces around 330 million tonnes of waste every year. As a consequence of the European Landfill Directive (Council Directive 1999/31/EC), as translated into the Landfill (England and Wales) Regulations 2002, there is an obligation to reduce the quantities of biodegradable municipal solid waste (MSW) sent to landfill to 35% of 1995 levels by 2020 (www.environment-agency.gov.uk). A waste management strategy has been developed in which a hierarchy of preferences for waste management is, in descending order:

- Waste reduction at source;
- Materials recovery;
- Composting;
- Incineration;
- Landfill.

Composting organic waste is therefore an important component of the waste management process in the UK, resulting in an increase in the number of commercial composting operations, with several more at the planning stage either as new facilities or to increase capacity at existing facilities.

Composting is a natural biological process of decomposition. In the right environmental conditions, the micro-organisms naturally present in vegetation multiply and metabolise organic matter, turning it into a stabilised product with a high nutrient content capable of being used as a soil conditioner. During the commercial composting process, heat produced by microbial activity is controlled to sanitise the organic matter, and under the right conditions kills weed seeds and plant and animal pathogens.

In a typical commercial operation, organic waste is delivered to the composting site where it is initially shredded and screened into smaller particles. This increases the surface area available to microbiological decomposition. The resulting material is then transferred to a maturation area (windrow) or to an in-vessel system of maturation.

Windrows are elongated piles of compost, shaped like a haystack in cross section and up to a hundred metres or more in length dependent on the size of the site. The site of the windrows is often referred to as a maturation pad/ area. It is necessary to turn the compost regularly to increase aeration and maintain optimum composting activity by increasing porosity of the pile, redistributing material to enhance process uniformity, and breaking up clumps to improve product consistency. A variety of specialised turning machines are available.

Horizontal and vertical reactors are commonly referred to as in-vessel systems as differentiated from open systems such as windrows and static piles. Because of the higher capital and operation costs associated with these contained systems, residence time in the reactors is rarely adequate for the production of mature compost. Instead, in-vessel composting technologies are often used at the early stages of composting when odours and process control are most critical. The in-vessel system provides closer control of temperature conditions, which is important to eliminate pathogenic micro-organisms as mentioned previously, and these systems therefore are

used to meet the requirements of the Animal By-Products Regulations 2005 (Statutory Instrument 2347/2005) for composting of low risk animal by-products such as catering waste. The material is then moved into a windrow or static pile system for the later stages of decomposition.

After the composting process has been completed by either of the above methods, it is usually then mechanically screened into various size fractions dependent on its final use. High grade compost may be used as a soil conditioner if it meets defined quality standards PAS100, the industry standard specification for compost produced from source-separated waste, with accreditation as being 'fit for unrestricted use as a fully recovered product'. Lower grade compost is often used as cover for landfill.

1.2 POTENTIAL HEALTH RISKS ASSOCIATED WITH WASTE COMPOSTING

The waste disposal industry is a cause for concern for HSE because studies have shown that the number of accidents and fatal incidents are greatly in excess of the national average for the UK workforce (Bomel, 2004). The most frequent causes of accidents are manual handling injuries including cuts from sharps, slips and trips, and being struck by objects, including being struck by vehicles. However, there are also health concerns including musculo-skeletal damage from manual handling, and allergic respiratory ill health from exposure to bioaerosols. The risks for kerbside collection and handling of domestic waste have been reviewed for HSE by HSL, resulting in the development of a risk assessment tool for industry (Turner *et al*, 2008). As described above, the process of waste composting, either using green waste or mixed waste, encourages the multiplication of micro-organisms indigenous to the organic material used. This multiplication leads to heat generation, which in turn encourages the growth of thermophilic species such as actinomycetes (spore forming bacterial species) and in some cases thermotolerant fungal species such as *Aspergillus fumigatus*. Some of these thermophilic and thermotolerant species are recognised as being the causative agents of allergic respiratory disease such as extrinsic allergic alveolitis (e.g., Farmer's Lung disease, Mushroom Worker's Lung disease), allergic rhinitis and occupational asthma, following excessive exposure (Swan *et al*, 2003). In addition, the thermotolerant fungus *Aspergillus fumigatus* is recognised as an opportunist respiratory pathogen of immunocompromised persons. Any handling of composting materials may generate aerosols of these micro-organisms, referred to as bioaerosols.

Workers on composting sites, whose job it is to handle the compost at the various stages, from feedstock handling, to turning heaps to encourage the composting process, to final screening and grading, may therefore be at risk of considerable exposure to bioaerosols depending on their work task, their proximity to the bioaerosol source and the control measures put in place. In addition, because the work is largely done out of doors, there is the potential for bioaerosols generated to disperse some distance from the point source. Consequently, there is concern that people living or working in the vicinity of waste composting sites (sensitive receptors) may also be exposed to these bioaerosols. In a previous HSL report (Swan *et al*, 2003) relevant publications on this subject were reviewed. However, only limited information exists regarding the potential for bioaerosols in significant numbers to be dispersed from composting processes, or the risk to health. A current project is being undertaken by Institute of Occupational Medicine, Edinburgh, for Defra (http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=15140#Description) in which the aim is to review the clinical evidence for respiratory ill health from bioaerosols dispersed from composting processes. To date, as a

precautionary approach the Environment Agency have stipulated a 250 m zone around waste composting operations within which, if there is a sensitive receptor, a detailed health risk assessment must be made.

1.3 HSE FUNDED STUDY ON BIOAEROSOLS FROM COMPOSTING

The study described in this report was funded by HSE, with additional funding by the Environment Agency. The Environment Agency funded component was aimed at providing data to estimate potential dispersion of bioaerosols off site. This included laboratory scale trials in which representative samples of compost were collected from operational sites. Microbial activity was determined and the potential for release of bioaerosol was estimated. The potential use of molecular based techniques to provide a profile or 'fingerprint' of a bioaerosol to attribute emission to source was evaluated. These data were reported in detail in an Environment Agency report (Crook *et al*, 2008) and are summarised briefly in this report.

The aim of the HSE component of the project was to measure bioaerosol emissions from a representative range of commercial UK composting facilities, including the typical range of work activities on each site. Dust and bioaerosol measurements included workers' potential exposure, emissions from compost handling operations and dispersion of emissions to points downwind of operations. Measurements were supported by work task observations and have been evaluated for their potential use in computational dispersion modelling of emissions.

The purpose of these measurements was to provide data with which HSE can develop a risk assessment tool for compost working that takes into account proximity to bioaerosol emissions, so that proportionate exposure controls can be applied.

2 MATERIALS AND METHODS

2.1 DESCRIPTION OF THE COMPOST SITES INCLUDED IN THIS STUDY

With assistance from Environment Agency staff, a number of green waste composting sites were identified, representing the range of methods currently used in the UK. Site operators were approached by HSL and agreement obtained to visit sites to obtain compost samples and to monitor bioaerosol emissions. The overall process is summarised in Figure 1, and the sites visited are described below.

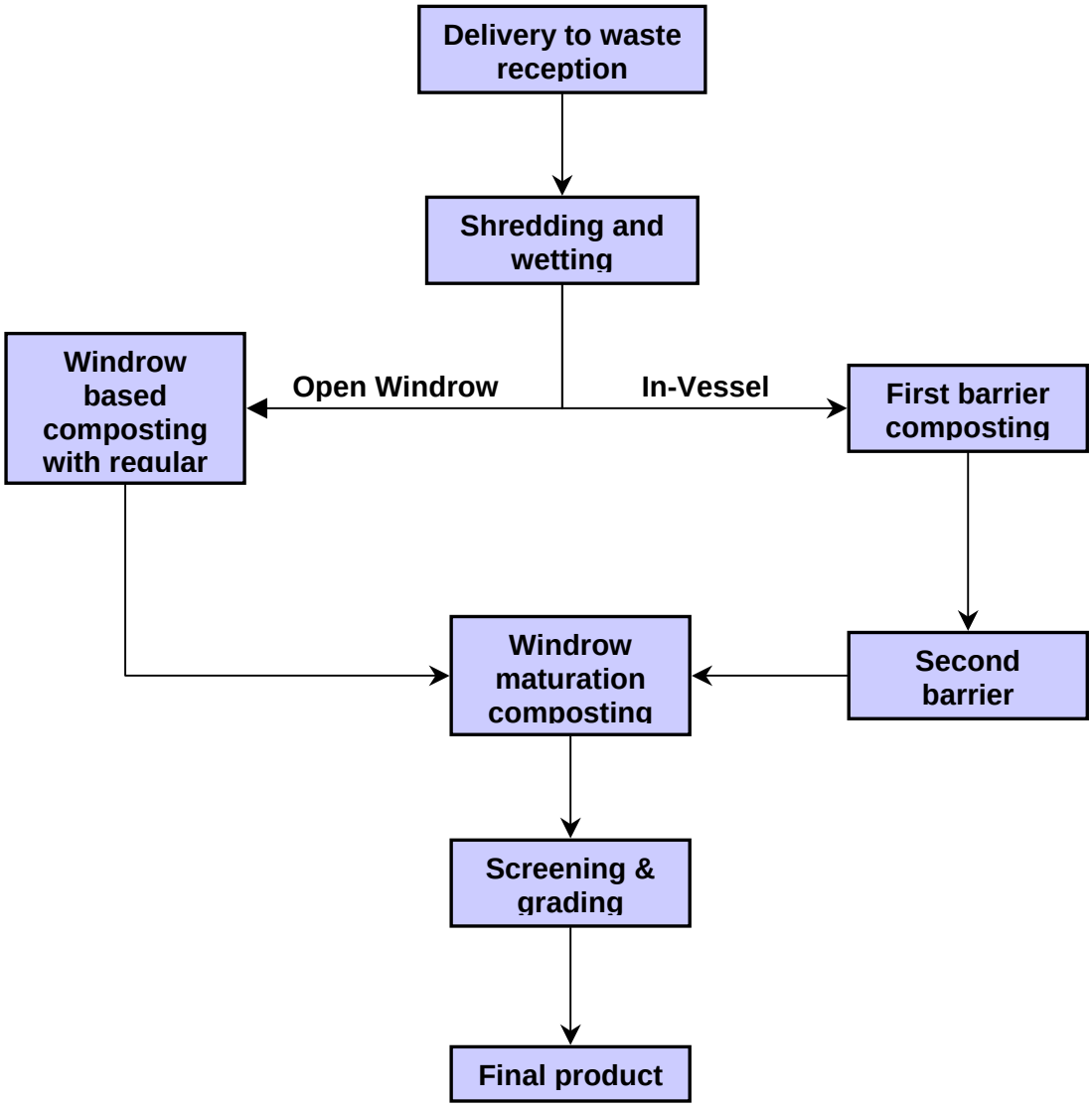


Figure 1. Schematic summary of composting process

2.1.1 SITE A

Site A is a commercial provider of recycling and waste management services in the UK. Their facility is a composting facility accepting household green waste site from kerbside collection, civic amenity sites and a small number of landscape gardening companies. The site is located on a disused landfill site between a busy dual carriage way and B road, as shown in the schematic diagram in 8.1. The site uses an open-air windrow system. On site activities therefore include green waste shredding, compost turning and screening. At the start of the process, shredding of waste is done externally on a concrete pad. Typically, one new windrow per week is created on site, which are then turned on a weekly basis to aerate the compost and maintain optimum composting conditions. Windrows are turned by mechanical shovel, this involves lifting the compost to maximum height of the mechanical shovel and then dropping it with a jerking motion, to form a new windrow. At the time of sampling, which was typical of site activity, they had 19 windrows ranging in age from 4 days to 19 weeks. As composting progresses, microbiological activity declines as the compost enters a maturation phase leading to the final fully composted product. The final product is mechanically screened, i.e., passed through a mesh, to achieve compost product of a specified size and to remove oversize material, then it is loaded by mechanical shovel into lorries for delivery to bagging plants. The site is staffed by three workers who mainly work together on each of the above tasks.

2.1.2 SITE B

This composting plant is an in-vessel composting (IVC) system. A schematic diagram is shown in 8.2. The facility was partially funded by Defra. The composting equipment used is the Hybelt system supplied by Cambridge Recycling Services (CRS) (http://www.crservices.co.uk/). Integral to the system is that it operates to parameters set by the Animal ByProducts Regulations (ABPR), i.e., that temperatures of 60°C are achieved for two days twice over during the entire process to ensure destruction of animal pathogens. This is achieved by placing two physical barriers in the process, so that the compost cannot pass each barrier until it has achieved the temperature conditions. The plant currently processes 15,000 t/a kerbside collected organic waste and civic amenity green waste with space for planned expansion to 40,000 t/a.

Source separated household waste and civil amenity site green waste is shredded and moisture added. The resulting mixture is passed over a 200 mm screen to remove any oversized material. The sieved material is transferred using loading shovels to the first barrier composting bays (IVC). Here the temperature of the decomposing waste is continually monitored using probes inserted into the material which notify the operator when this has been passed for the first time. The material is then moved to a second barrier composting bay. Again the processing waste is monitored until it passes the second barrier. Aerobic conditions are maintained using a mechanical air handling unit to force air through the composting material. Air enters through pipes situated in the floors of the composting bays. It is removed for recirculation back through the air system, or is vented to atmosphere after it has been passed through an odour control system to remove noxious smells. The process has been optimised so that after this second barrier period the material is known to be decomposed sufficiently to meet ABPR regulations and is moved onto the open maturation area. Here the compost is turned regularly to maintain aerobic conditions and allowed to mature to produce a compost that can be used for land restoration or amenity use.

The Composting Facility achieved full ABPR approval from Defra in February 2005. The sieved material is left for approximately two weeks in-vessel followed by two weeks standing

outside, then is transferred to the maturation pad where it undergoes 45 weeks of maturation in one large windrow which is turned weekly. The resulting compost then passes through a final screen before being distributed to the end user.

2.1.3 SITE C

This composting facility, again an in-vessel system, was designed and built by CRS. A schematic diagram is shown in 8.3. It processes a wide variety of kerbside collected organic wastes and has a design capacity of up to 25,000 tonnes per year. It is designed to meet ABPR regulations, similar to Site B, with the use of a two barrier temperature regulated system and a one-way flow system through the composting tunnels.

Waste is delivered into an enclosed reception building by refuse collection vehicles. After unloading, the material is checked for obvious and removable contamination, then moved by mechanical shovel into a pre-treatment line for shredding. Water is added to the waste to optimise moisture content for rapid composting, this water being recycled from other parts of the process plant, including leachate and rainwater as required.

The composting vessels operating to the first temperature control barrier on this site have a door at front and rear so that the waste can be loaded into one end and emptied at the other, ensuring one way flow of waste through the plant and reducing the risk of cross contamination. Once a vessel has been loaded it is then assigned a batch number, and the doors closed whilst the material heats up to thermophilic temperatures. The composting tunnels are equipped with a floor aeration system which blows air in through pipes on the floor and removes air from above the waste in the tunnel. To monitor the composting process and to ensure compliance with the regulations, temperature probes are inserted through the roof of the tunnel for contiunuous monitoring. After the waste has achieved 60°C for two days, it is transferred to the second barrier composting tunnels where the composting continues for a second period again to achieve temperatures in excess of 60°C for two days. After this second barrier period the conditions have been optimised such that material is then known to be decomposed sufficiently to meet ABPR regulations and can be moved onto the open maturation area. Here the compost is turned regularly to maintain aerobic conditions and allowed to produce a mature compost, remaining on the maturation pad for approximately 2 weeks before processing

2.1.4 SITE D

Site D is a waste management company servicing local communities and industries. The company operates nine waste management facilities, receiving locally generated waste, and manages 23 Household Waste Recycling Centres on behalf of the County Council and a City Council. It also provides a range of specialist waste management services for business and domestic customers including secondary aggregate production, wood recycling, cardboard, paper, glass, plastic and metal, composting, electricity generation and liquid waste management.

A schematic diagram of Site D is shown in 8.4. The site accepts household green waste from kerbside collection and civic amenities such as recycling centres. The site also composts wastewater from drains and industrial wastewater such as car wash and cosmetic production wastewater. This is mixed into the compost at the early stages of the process. The site also receives waste wood, shredded outside near the maturing compost. The site is located on a disused area of a working landfill site and uses an open-air windrow system, with initial shredding of waste being done outside. It has approximately 10 windrows on the first part of

the maturation and shredding area and a second stage approximately 300m away. At the second stage the compost is matured for long periods to reach PAS100 ('fit for unrestricted use') standards. On site activities during site visits included green waste and wood shredding, compost turning and screening. Windrows were turned by mechanical shovel, the compost being lifted to the maximum height of the mechanical shovel and dropped to form a new windrow. The composting site had four employees who operated the mechanical shovels, screeners and shredders.

2.1.5 Site E

This site composts a mixture of municipal and household green waste, handling 65,000 green bins per week. Composting is done by open windrows to PAS 100 standard, the screened product at 40mm being used for landfill landscaping and at 10mm as a peat replacement in bagged commercial compost. On site activities during site visits included shredding green waste, using a telehandler to turn windrows, and loading containers with screened finished compost.

2.1.6 Site F and Site F MBT plant

This is a site for a national provider of waste management services. The MBT site is adjacent to a landfill site and also incorporates an open windrow compost site. The waste arriving at the MBT site is pre-treated at a transfer station to remove metals and waste over 50mm diameter. The waste is predominantly garden and food waste with some plastic and glass.

The site operates a 2 barrier in-vessel composting (IVC) system. This is followed by maturation and drying of the compost in open windrows covered with an open sided roofed barn type structure. The matured compost is then usually milled to form a fine powder, although due to technical problems this was not being done at the time of the sampling visits.

The compost site, located on a currently working landfill site, is an open windrow system receiving municipal green waste, and green waste from household collection. Green waste is shredded, and windrows turned using a mechanical shovel to lift the compost to maximum height then dropping with a jerking motion to form a new windrow. The site is overseen by the owners but the process is operated by subcontractors. Typically there were two employees operating mechanical shovels, windrow turners etc.

2.2 BIOAEROSOL MONITORING AND ANALYSES

Site visits for sampling were undertaken regularly from winter 2005 to summer 2007. Environmental (static, or fixed point) samplers and personal (in the workers' breathing zone) air samples for bioaerosols were collected during various activities at the compost sites. The static samplers were placed as close as possible to the activity being monitored and also where possible at 50m intervals downwind of the activity, up to a maximum of 250m. Control samples were also taken 50m upwind of the activity. Methods used were as follows.

2.2.1 Andersen samplers

Andersen cascade impaction samplers were used for the collection of airborne micro-organisms (Fig 2). This sampler collects airborne particles by impaction onto the surface of agar plates placed under six stacked sieve plates each with 400 holes of defined size. These are progressively smaller from top to bottom, so that particles collected are separated into six size ranges. Stages 1 and 2 collect particles >7µm aerodynamic diameter, equating to nasal deposition, stages 3 and 4 collect particles 3 -7µm, equating to bronchial deposition and stages 5 and 6 collect particles <3µm, equating to alveolar deposition. Suction for Andersen samplers was by vacuum pumps powered by generators and run at the required volume of 28.3l/min. The Andersen sampler is a commonly used bioaerosol sampler. As a single stage version it is recommended for use in the Composting Association guidelines for bioaerosol monitoring (Composting Association, 1999), although for this study we chose to use the six stage version to obtain particle size data.

Compost bioaerosols were collected onto ½ strength Nutrient agar and Malt agar as described in the Composting Association guidelines. The samplers were positioned as close to the Partisol samplers (see below) as possible in order to compare the results of the samplers. The samplers were run for 3 to 10 minutes dependent on the distance from the task and the task being performed.

Figure 2. Andersen sampler showing six stages

2.2.2 Partisol samplers

Partisol samplers (models 2000 and 2005) are static samplers designed to collect PM_{10} (particles less than 10µm) particulate matter onto 47mm filters at a flow rate of 16.7 l/min, giving a total volume of $1m^3$/hour (Fig 3). Partisol samplers are used for air pollution monitoring in the UK Automatic Urban Air Quality Network (http://www.airquality.co.uk/archive/autoinfo.php) and, because of this cross-reference of sampling methods, they were selected to test their use for monitoring compost bioaerosols. The Partisol 2000 and 2005 sampler operate in the same way but the 2005 model includes an automatic filter change mechanism, which allows timed

sequential sampling and is important where sample filters may become overloaded. The samplers have an integrated vacuum pump and were powered either by heavy-duty batteries or portable generators.

On the compost sites, the samplers were positioned as close to the work task as possible without risk of damage to equipment. This limited the distance to the task to between 10 and 50m. The samplers were run simultaneously in the described positions for one to four hours dependent on the length of task monitored. Where possible, for comparison the samplers were also run when no activity was being performed. However this was not always possible due to continuous working on some of the sites.

Fig 3: Partisol sampler in operation on compost site

2.2.3 IOM samplers

The IOM Personal Inhalable Sampler is a conductive plastic sampling head that collects airborne particles onto the surface of a filter housed in a reusable 25-mm filter cassette. When attached to a personal sampling pump operating at 2l/min and clipped near a worker's breathing zone, the IOM effectively traps particles up to 100µm in aerodynamic diameter and closely simulates the manner in which airborne workplace particles are inhaled through the nose and mouth (Fig 4). IOM samplers are recommended samplers for workplace measurement of Total Inhalable Dust (TID) by weighing as a single unit the cassette and filter before and after sampling (HSE, 2000). In addition to this purpose, in this study they were also used to sample airborne micro-organisms and endotoxins in the breathing zone of the workers, and were also used as static samplers close to activities where Partisol samplers could not be utilised. The filters used in this study were Quartz filters, (Whatman QM-A), determined by HSL and others in previous studies to be optimum for retrieval of captured micro-organisms and endotoxins (Kenny *et al*, 1998; Reynolds *et al*, 2002).

Fig 4. IOM filtration sampler

2.3 BIOAEROSOL SAMPLE ANALYSIS

2.3.1 Endotoxin analysis

Filters from the IOM samplers were placed in pyrogen free tubes and the collected deposits were extracted by shaking at room temperature for 2 hours in 10ml of endotoxin free 50mM Tris buffer (Cambrex). The resulting suspension was then divided to provide samples for endotoxin analysis and microbial enumeration (see below). Samples for endotoxin analysis were then centrifuged at 1000 g for 10 minutes to remove particles, and dilutions of the supernatant were prepared for analysis.

Samples were analysed using the Kinetic-QCL automated system (Bio-Whittaker Inc., Walkersville, Maryland, USA). This system is widely accepted in the pharmaceutical industry for endotoxin free product validation in accordance with the United States' FDA, but is also widely used for assaying endotoxin in workplace samples (Reynolds *et al*, 2005; Liebers *et al*, 2007). It is a quantitative kinetic assay based on a commercial 96 well plate assay system, with assays performed in a temperature controlled plate reader. It is validated for detection of Gram-negative bacterial endotoxin, the presence of which in a sample activates a proenzyme in the Limulus Amebocyte Lysate (LAL) reagent. This results in a colour (chromatic) change, and the concentration of endotoxin in the sample is calculated automatically from the rate of colour change, compared to controls of known concentrations. Results are expressed as endotoxin units (EU)/ml, which is a measure of the biologically available endotoxin in the sample. From other assay methods, endotoxin concentration may be expressed as nanogram (ng)/ml, and for cross reference 10 EU is the equivalent of 1 ng (assay manufacturers data). Each sample was analysed with a negative and positive control.

2.3.2 Enumeration of culturable micro-organisms

A sub-sample of the extracts prepared from filters for endotoxin analysis was used for microbial analysis. A dilution series was prepared from the initial extraction suspension in ¼ strength Ringers solution and was used to inoculate agar plates.

Total mesophilic fungi were isolated on Malt extract agar and Dichloran glycerol agar (DG18) incubated at 25^0C for up to 10 days. DG18 is a lower water availability agar medium and was used to inhibit spreading of fast growing fungi. Total thermotolerant fungi were isolated on Malt extract agar, incubated at 40^0C for up to 10 days. Total mesophilic bacteria and bacteria capable of growth at human body temperature were isolated on Nutrient agar incubated at 25^0C and 37^0C respectively. Thermophilic bacteria and actinomycetes were isolated on R8 agar and incubated at 55^0C for 7 days.

The ½ strength Nutrient agar and Malt agar plates from the Andersen sampler were incubated at 37^0C for 7 days and 40^0C for 2 days respectively as recommended by the Composting Association Guidelines.

Following incubation, emerging colonies on agar plates were counted and, using the known volume of air sampled, numbers calculated as colony forming units (cfu)/m^3. Predominant bacteria and fungi were isolated into pure culture and identified.

2.3.3 Enumeration of total microbial numbers

Total microbial cell numbers from filter samples were counted by direct epifluorescence filter technique (DEFT; Palmgren *et al*, 1986). Sub-samples of extracts prepared from filters were concentrated onto the surface of black (to reduce background interference) 0.2 um pore size polycarbonate membrane filters. Cells thus immobilised were then stained with acridine orange fluorescent dye, filters mounted on a slide in microscope immersion oil and observed under UV light with a fluorescence microscope. Acridine orange reacts with cell DNA such that metabolising cells fluoresce orange. Fluorescing cells observed in randomly selected microscope fields at x1000 magnification were counted and the total number of cells in the original sample calculated, to derive a value for total cell numbers /m^3 air sampled.

2.4 IDENTIFICATION OF MICRO-ORGANISMS

2.4.1 Bacterial Identification

DNA Isolation: Portions of predominant bacterial colonies cultured from poultry dust bioaerosols were suspended in 100µl H_2O and lysed using lysozyme (100µl, 50mg/ml in UV de-ionised water [UDIW]), each mixture was incubated for 30 minutes at 37^oC, with gentle mixing after 15 minutes. The lysate was then processed with the Qiagen Qiaquick Tissue Lysis kit (Qiagen Ltd., Dorking, Surrey) using modifications to the manufacturer's instructions as optimised in-house at HSL(details on request). The DNA was eluted into 150 µl of warmed elution buffer, and was used as template for polymerase chain reaction (PCR) with no further purification.

PCR amplification of the 16S rRNA gene from extracted DNA: Each DNA sample was used as a template in the polymerase chain reaction (PCR). The DNA-based analysis here focused on the identification of the bacterial components from each sample. The primers used for all initial PCR amplifications have been selected on the experience of previous investigations at HSL into workplace and environmental micro-organisms. These and other primers were synthesised by Alta Bioscience, University of Birmingham.

A polymerase chain reaction (PCR) that selectively amplified the first 520 base pairs of the bacterial 16S rRNA gene was carried out with primers and reaction conditions following standard HSL protocols. The resulting PCR products were stained with ethidium bromide (0.5µg ml^{-1}) and visualised under UV after electrophoresis on 1.5% agarose gel. PCR products were cleaned using a microspin S400 spin columns prior to automated sequence analysis. Resulting sequences were then compared to the online NCBI database to characterise the micro-organism (http://www.ncbi.nlm.nih.gov/BLAST). Sequence analysis of these regions of the 16S rRNA genes provides an accurate microbial identification to the genus level, and species level identification can often be made with a high degree of confidence.

2.4.2 Fungal identification

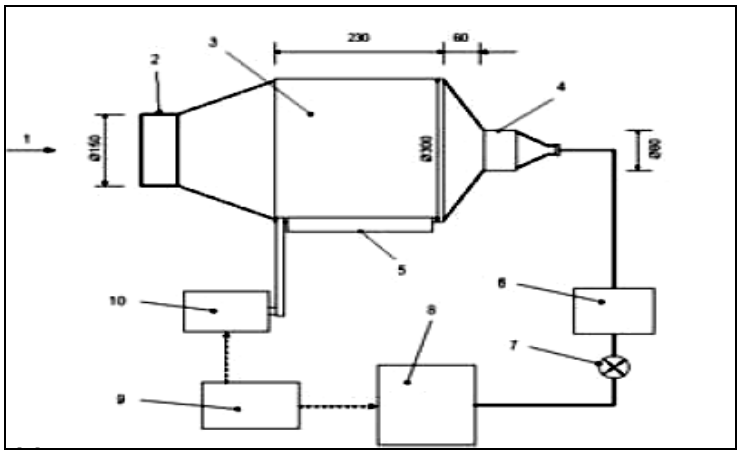
Fungal colonies were identified by gross morphology, microscopic examination and DNA analysis. Where DNA analysis was required, DNA was isolated as described for bacteria and primers targeting specific regions of the rRNA gene were used following standard HSL protocols for fungal PCR amplification.

2.5 DUSTINESS TESTING

2.5.1 Method

The dustiness of a material is the mass of dust generated per mass of material undergoing testing. This has been used as a means of estimating the potential for a solid material to generate potentially harmful dust when handled in the workplace, as an empirical risk assessment method. A European Standard method has been developed by HSL, in collaboration with others, for measuring the dustiness of materials expressed as a ‘dustiness index’ (BOHS, 1985; Mark, 2005).

Figure 5 is a schematic of a dustiness drum as described in the EU standard and used to determine the dustiness indices of solid materials. It consists of a dust generator and a dust sampler. The generator includes a drum with conical ends with eight vanes fitted internally to its walls, enabling dispersion of the material within the drum as it is rotated along a horizontal axis at 6 rpm. A dust filter placed at one end of the drum filters inflowing air, while on the outlet end a vacuum pump extracts air at a constant rate of 38l/min through dust collection filters.



KEY

1 -Air flow	2 -Inlet stage
3 -Dust generating section	4 -Dust collection stage
5 -Rollers	6 -Mass flow meter
7 -Control valve	8 -Vacuum pump
9 -Timer	10- Drive motor

FIGURE 5. Schematic of a rotating dustiness drum. (Source: Mark, 2005)

2.5.2 Determining the microbial dustiness of compost

The term 'microbial dustiness' has been used to refer to the generated number of airborne micro-organisms per mass of the material undergoing testing, and has been used previously to estimate microbial release from composted materials (Breum *et al*., 1997; 1999).

In the current project, the number of micro-organisms released from known quantities of waste compost were measured as a means of determining numerical values that could be used to estimate bioaerosol emission from compost facilities. The purpose of this was to provide data that could be used in computational dispersion models. These are particularly relevant to downwind dispersion of compost bioaerosols and the potential for exposure of 'sensitive receptors', i.e., those at risk of ill health resulting from exposure.

These data were obtained mainly for the Environment Agency funded component of this project. Brief details of the technique used are described below for general information. Full details, and the results from this work, are available in the Environment Agency report (Crook et al, 2008).

Bulk material samples at various stages of the composting process were collected from three sites and known volumes used in dustiness tests. Material made airborne was collected onto filters and microbiological analyses done to determine total and culturable numbers of micro-organisms and endotoxin.

2.6 PROFILING THE MICROBIAL POPULATION OF COMPOST

2.6.1 Background

Molecular biology techniques can be applied to the analysis of microbial populations in natural habitats (Giovanni *et al*., 1990, Ward *et al*., 1990, Amann *et. al*., 1995). Therefore it may be possible to apply such techniques to the characterisation of bioaerosol emitted from compost facilities and, if successful, this could be used to identify dispersed sources.

The aim of this phase of work was to develop a method to 'fingerprint' compost bioaerosols. If successful, such an approach would be a valuable tool in attributing source to bioaerosol emissions, especially where more than one potential source was present. For example, in a rural area a waste composting site generating bioaerosols may give cause for concern, but there may be other bioaerosol sources such as from farming. If it is feasible to characterise and profile the range of species present in a bioaerosol sample, it would be possible to compare a sample taken close to composting operations with ones taken further away. This would determine whether the samples taken at distance are being augmented by bioaerosols from other sources, and the distance at which predominant compost derived microbial species are lost from the bioaerosol emission.

These data were obtained mainly for the Environment Agency funded component of this project. The main method evaluated was denaturing gradient gel electrophoresis (DGGE), supported by PCR cloning. Full details, and the results from this work, are available in the Environment Agency report (Crook et al, 2008).

3 RESULTS

3.1 BIOAEROSOL SAMPLING – INDIVIDUAL SITES

Bioaerosol sampling was undertaken at various sites, details of which are given in Section 2.1. For bioaerosol results, the lower limit of detection (LOD) is a function of the volume of air sampled and the dilution factors for any subsequent sample handling. The LOD will therefore differ according to the sampling time, as follows.

For Andersen samples, where inoculation is directly onto agar plates, the LOD is one colony-forming unit (cfu) from the volume of air sampled. At an air sampling rate of 28.3 l/min, sampling times between three and 10 minutes were used, so for example:

- For a three-minute sampling period, the LOD is one colony-forming unit (cfu) in 85 litres, or 12 cfu/m^3.
- For a 10-minute sampling period, the LOD is 4 cfu/m^3.

For filtration samples, cells collected on filters were re-suspended into 10 ml buffer and 0.1 ml volumes of diluted or undiluted suspension used to inoculate duplicate agar plates. Therefore, the LOD is:

- 1 cfu on one of the replicate plates (= 0.5) x 10 (accounting for the 0.1 ml inoculum) x 10 (accounting for the volume used to obtain an undiluted resuspension from the filter) = 50 cfu from the volume of air sampled.

At an air sampling rate of 1 m^3 per hour for the Partisol sampler, sampling times between one and four hours were used, so for example:

- For a one-hour sampling period, the LOD therefore is 50 cfu/m^3 and
- For a four-hour sampling period, the LOD is 13 cfu/m^3.

At an air sampling rate of 2.0 l/min for the IOM sampler:

- For a one-hour sampling period the LOD is 417 cfu/m^3 and

For a four-hour sampling period, the LOD is 104 cfu/m^3.

3.1.1 Bioaerosol Sampling at Site A (Sample visit 1)

Bioaerosol sampling visit 1 was carried out in December 2005. The main site activity taking place was green waste shredding. Some screening of final product was also being carried out, however this was downwind of the shredding and was not considered at the time of sampling to be likely to interfere with the bioaerosol from shredding. Due to the wind direction, sampling was only located at 50m upwind and 50 to 125m downwind of the shredding activity. The results of the dust and microbial dust concentrations are given in full in Appendix 1.

The results showed that bioaerosol concentrations were mostly low, with a maximum detected concentration of 2,119 cfu/m^3, but that there was a general trend of increase in concentration with distance from the shredding activity for most parameters measured which was contrary to what may be expected. Endotoxin and thermophilic bacteria were below the detection limits of the method. The concentration of fungi at 50m would be expected to be greater than at 125m, but this was not the case. Contrary to our assumptions, other site activity may have contributed to the overall bioaerosol concentration. Also, the compost site is on sloping ground which, combined with the wind direction, meant that the sampling positions were lower in height than the shredding activity, and this may have allowed bioaerosols to remain airborne longer. In summary:

- Dust levels were <1mg/m^3 of air and decreased with distance from the bioaerosol source.

- Concentrations of micro-organisms were lower upwind compared to downwind.

- During shredding activity, concentrations of fungi were lower upwind compared to downwind, but when no shredding was taking place the upwind concentration of fungi was similar to the maximum downwind, 229 cfu/m^3 of air compared to 324 cfu/m^3 of air.

- The upwind value when no activity was taking place, 229 cfu fungi /m^3 of air, was greater than the upwind value of 96 cfu fungi /m^3 of air measured during shredding, showing the variable nature even of a background value.

- Fungal counts during shredding activity were greater at a distance of 125m compared to 50m from the waste being handled, with mesophilic fungi and *A. fumigatus* at concentrations up to 2,095 and 2,119 cfu/m^3 of air respectively at the 125m sampling site, compared to 158 and 45 cfu/m^3 of air respectively at the 50m sampling site.

- Total microbial counts measured by direct microscopy also increased with distance to 125m.

3.1.2 Bioaerosol Sampling at Site A (Sample visit 2)

A second bioaerosol sampling visit to Site A was carried out in January 2006. The main activity sampled was turning of the compost windrows. Some screening of final product was also being carried out. As on the previous visit, this was downwind of the shredding and should not have interfered with the sampling. Due to the ground conditions vehicle access was restricted and samplers were only located at 50m upwind and 50 to 100m downwind of the turning activity. The results of the dust and microbial dust concentrations are given in full in Appendix 1.

In general, the concentrations of the parameters measured follow an expected trend of decreasing with distance from the bioaerosol source. The Andersen samplers gave slightly higher counts than the Partisol samplers. The concentrations of all parameters were lower when no activity was being performed. For example, the maximum yield of airborne bacteria and fungi at 50m downwind when no turning activity was taking place was 138 cfu/m^3 for each parameter, compared to 4,169 and 2,100 cfu/m^3 respectively when turning was taking place (Appendix 6.2). In summary:

- Dust levels were < 1mg/m^3 of air at all sampling positions both during turning and no activity.

- Workers' greatest exposure to bacteria and fungi while turning and screening compost were both 24,912 cfu/m^3 air sampled. The fungi included up to 3495 cfu/m^3 *Aspergillus fumigatus*.

- Concentrations of airborne mesophilic fungi measured using Partisol samplers peaked at 2,100 cfu/m^3 50m from turning activity, dropping to 1,802 cfu/m^3 at 100m downwind from turning activity, compared to 176 cfu/m^3 upwind.

- *A. fumigatus* concentrations measured using the Partisol samplers were similar at both 50m and 100m downwind of turning, 2,069 and 2,189 cfu/m^3 respectively. Andersen samplers yielded larger numbers and showed a decrease with distance from turning, airborne concentration being 4,205 cfu/m^3 at 50m distance and 3,734 cfu/m^3 at 100m distance downwind.

- Using Partisol samplers, bacteria isolated at 25^0C and 37^0C and actinomycetes were detected at levels of up to 1,636, 4,169 and 495 cfu/m^3 of air respectively at 50m downwind of turning operations. This had dropped to 321, 1,513 and 354 cfu/m^3 of air respectively by 100m downwind. Upwind, bacterial concentrations isolated at both at 25^0C and 37^0C were 88 cfu/m^3 of air, with no actinomycetes detected.

- Using Andersen samplers, fewer bacteria were isolated downwind at 37^0C, peaking at 2406 cfu/m^3 at 50m downwind and dropping to 2146 cfu/m^3 at 100m. Bacterial concentrations measured upwind with Andersen samplers were greater than with Partisol samplers, 293 cfu/m^3 compared to 88 cfu/m^3.

- Endotoxin concentration was < 1 EU/m^3 at all the static sampling sites.

3.1.3 Bioaerosol Sampling at Site B (Sampling visit 1)

Bioaerosol sampling visit 1 was carried out in December 2005. The main activity sampled was turning of the compost windrows. Adjacent shredding and screening of household waste should not have interfered with the sampling. Due to the ground conditions vehicle access was restricted and sampling was only located at 50m upwind and 50 to 125m downwind of the turning activity. The results of the dust and microbial dust concentrations are given in full in Appendix 1.

3.1.3.1 Sampling during turning of windrows

From the Partisol sampler data there is a general trend of decrease in concentration from the 50m site to the 120m site for bacteria 37^0C, actinomycetes, and *A. fumigatus* and an increase in concentration for bacteria 25^0C and mesophilic fungi. Although the differences between the sites were minimal, endotoxin levels were all below 3 EU/m^3 of air and dust levels were all below 1mg/$m^3$of air. Mesophilic fungi were found to be in concentrations of up to 348 but *A. fumigatus* was below the level of detection. Concentrations of micro-organisms were lower upwind compared to downwind and when no tasks were being performed.

3.1.3.2 Sampling during shredding and initial screening of green waste at the site B

Bioaerosol sampling visit was carried in December 2005 on the same day as the sampling of windrow turning. The main activity sampled was the shredding and screening of green waste. Some turning of compost was also being carried out adjacent to these activities which was not considered at the time of sampling to be likely to interfere with the sampling. Due to the ground conditions vehicle access was restricted and sampling was only located at 50m upwind and 50 to 125m downwind of the turning activity.

From the Partisol sampler data there is a general trend of decrease in concentration from the 50m site to the 120m site for mesophilic fungi (25 Malt) bacteria 25^0C and *A. fumigatus* and an increase in concentration for bacteria 37^0C mesophilic fungi (DG18) and Actinomycetes. *Aspergillus fumigatus* yield with the Andersen impactor however was considerably greater at 120m downwind (644 cfu/m^3) compared to 50m downwind (21 cfu/m^3).

Although the differences between the sites are minimal, in summary:

- Dust levels were all below 1mg/$m^3$of air.
- Mesophilic fungi and *A. fumigatus* were in concentrations of up to 466 and 644 cfu/m^3 of air.
- Bacteria at 25, 37^0C and actinomycetes were detected at levels of up to 45, 121 and 25 cfu/m^3 of air respectively.
- Endotoxin levels were all below 1 EU/m^3 of air.

Concentrations of micro-organisms were lower upwind compared to downwind when no tasks were being performed, indicating some natural bioaerosol generation even when no work activity took place.

Comparisons between concentrations of bacteria and fungi detected using Andersen and Partisol showed no clear trend of greater yield with one sampler compared to the other.

Personal exposure measurements were taken on three workers, two driving vehicles and one undertaking site housekeeping work. This last worker had the highest potential exposure to fungi, with a personal sampler recording 52,536 cfu/m^3 of fungi and 5,625 cfu/m^3 of *A. fumigatus*. Bacterial concentrations were greatest for a driver, at 51,724 cfu/m^3 of air. It was noted that the vehicle was missing a window, therefore exposure to the outside atmosphere was not controlled.

3.1.4 Bioaerosol Sampling at Site B (Sampling visit 2)

A bioaerosol sampling visit was carried out in August 2006. The main activity sampled was the movement of compost from the first barrier (clamp) to the second barrier (clamp) and shredding of green waste. These two tasks were performed at the same time and were in line of each other during sampling. Also during the sampling when shredding was not being performed some clamp work was still ongoing. Because of this the sample at 10m from the shredding is the only sample of just shredding. The other samples are a mixed set of data for both tasks. Samples were taken from 10m to 250m for shredding and 10m to 210m for barrier exchange. Weather

conditions were warm (14-21^{0}C) and dry with wind speeds from 1.6 – 6.6 m/sec, mean 3.4 m/sec. The results of the dust and microbial dust concentrations are given in full in Appendix 1.

From the Partisol amd Andersen sampler data there is a general trend of decrease in concentration from the 10m site to the 250m site for bacteria, actinomycetes, mesophilic fungi and *A. fumigatus*. However, in some cases there is an increase at the 140/150m sampling point. In summary:

- Dust levels were < 1mg/m^3 of air at all sampling positions except for fixed point samplers placed on the front of vehicle cabs handling waste. One personal sampler inside a cab yielded 8.9 mg/m^3.

- Concentrations of micro-organisms from the fixed point Partisol samplers (PM_{10}) and Andersen samplers yielded concentrations of airborne fungi as high as 44,132 cfu/m^3 of air 10m downwind of waste shredding activities and 36,615 cfu/m^3 at 50m downwind, declining to a maximum of 7,361 cfu/m^3 250m downwind. *A. fumigatus* concentrations were as high as 43,818 cfu/m^3 at 50m downwind but showed a particularly high count of 222,048 cfu/m^3 of air at the 140/150m sampling point with the Partisol sampler, reflected but at a smaller count with the Andersen sampler. This suggested a sustained elevated bioaerosol detected with the sampler operating for a longer period also picked up to some extent by the short sampling period of the Andersen sampler.

- Concentrations of micro-organisms from the fixed point Partisol samplers (PM_{10}) and Andersen samplers yielded concentrations of airborne bacteria up to 696,279 cfu/m^3 of air at 50m downwind declining to a maximum of 18,501 at 250m. By comparison, upwind values were 772 cfu/m^3.

- Concentrations of fungi from the personal and fixed point filter (IOM) samplers were as high as 103,586 cfu/m^3 of air inside cabs and 1.46 million cfu/m^3 of air outside cabs. *A. fumigatus* concentrations were as high as 224,161 cfu/m^3 of air inside cabs and 1.43 million cfu/m^3 of air outside cabs.

- Concentrations of bacteria from the personal and fixed point filter (IOM) samplers were as high as 3.6 million cfu/m^3 of air inside cabs and 4.2 million cfu/m^3 of air outside cabs. Thermophilic actinomycete concentrations were as high as 286,245 cfu/m^3 of air inside cabs and 1.17 million cfu/m^3 of air outside cabs.

- Endotoxin concentrations were up to 10.2 EU/m^3 at the static sampling sites and up to 6641 EU/m^3 on vehicle cabs loading compost.

3.1.5 Bioaerosol Sampling at Site C (Sampling visit 1)

A bioaerosol sampling visit was carried out in February 2006. The main activity sampled was turning of the windrows on the maturation pad. The compost on the maturation pad originated from the IVC and at this stage was approximately two weeks into the maturation process. The compost remained on the maturation pad for approximately two further weeks before processing. Some screening of compost close to the maturation pad and green and household waste screening (indoors) was also being carried out adjacent to these activities, but should not have interfered with the sampling. IOM samplers were also placed on the front of the loading and turning machines. Sampling was located at 50m upwind and 10, 50,150 and 250m downwind of the turning activity. The results of the dust and microbial dust concentrations are given in full in Appendix 1.

The Partisol sampler data indicated that, in general, bioaerosol concentrations decreased from the 10m sampling point to the 150m point. At the 250m sampling point there was a small increase in microbial concentrations in all but mesophilic fungi isolated on DG18 medium, but all concentrations were considerably smaller than at the 10m sampling point.

From the downwind Partisol samplers, mesophilic fungi and *A. fumigatus* were found to be in concentrations of up to 1,681 and 9,545 cfu/m^3 of air. Bacteria at 25, 37^{0}C and actinomycetes were detected at levels of up to 3,318, 7,409 and 11,818 cfu/m^3 of air respectively. These peak levels were detected at the 10m sample site, while at the 50m site concentrations had decreased greatly.

From the IOM sample (total inhalable dust) on the front of the turning machine, mesophilic fungi were found to be in concentrations of up to 15,173 cfu/m^3 of air. Bacteria at 25^{0}C, 37^{0}C and actinomycetes were detected at levels of up to 420,520, 591,000 and 3,757 cfu/m^3 of air respectively.

Concentrations of micro-organisms were lower upwind compared to downwind and when no tasks were being performed. The comparison between concentrations of bacteria and fungi detected using Andersen and Partisol showed no clear trend of greater yield with one sampler compared to the other.

Endotoxin levels from the Partisol samples (PM_{10}) were all below 1 EU/m^3 of air and dust levels were all below 1mg/$m^3$of air. However, the results from the IOM samplers on the machinery indicate much higher concentrations of dust and endotoxin particularly on the turning machine where concentrations of 25.6 mg/m^3 and 262 EU/m^3 were detected.

3.1.6 Bioaerosol Sampling at Site C (Sampling visit 2)

A bioaerosol sampling visit was carried out in August 2006. The main activities sampled were screening of compost from windrows on the maturation pad. The screened compost was being loaded into an open backed trailer for transportation to a landfill tipping face for use as cover. During the sampling period, unloading of the second barrier of the IVC to the maturation pad took place. Partisol samplers were located at 50m upwind, and downwind at 10m, 50m and 150m. Partisol samples were also taken at these distances from site when no work was being done. Weather conditions were warm and fine with wind speed ranging from 0.9 to 5.2 m/sec, mean 1.5 m/sec.

From the Partisol and Andersen sampler data there was no clear trend of decrease in concentration from the 10m site to the 150m site for bacteria, mesophilic fungi and *A. fumigatus*, although there appeared to be a steady decline in numbers of actinomycetes. In summary:

- Dust levels were less than 1 mg/m^3 of air at all sampling positions except for fixed point samplers placed on the front of vehicle cabs handling waste. Fixed point samplers on the front of cabs handling waste yielded as much as 10.76 mg/m^3.

- Concentrations of micro-organisms from the fixed point Partisol samplers (PM_{10}) yielded similar concentrations of airborne fungi (1875 and 1887 cfu/m^3 of air) 10m downwind of the waste screening site whether work was being done or not. By comparison, upwind yields were 758 cfu/m^3 of air when screening was being done but 1083 cfu/m^3 with no activity. Airborne fungal concentrations declined to 1663 cfu/m^3 at 50m downwind and 1119 cfu/m^3 of air at 150m downwind when activities were

taking place. With no activity, fungal concentration declined to 1589 cfu/m^3 of air at 50m and 1341 cfu/m^3 at 150m downwind. The higher overall levels with no activities taking place indicated a continuing bioaerosol source from other site activities.

- *Aspergillus fumigatus* concentrations were no greater than 219 cfu/m^3 at 50m downwind as measured by Andersen sampler and 641 cfu/m^3 of air at 10m downwind as measured by the Partisol sampler.

- When screening was being done, concentrations of airborne bacteria measured with the fixed point Partisol samplers (PM_{10}) yielded similar concentrations of airborne bacteria at 10m and 50m downwind (1923 and 2430 cfu/m^3 of air) declining to 180 cfu/m^3 at 150m which was similar to the upwind value of 177 cfu/m^3. Airborne bacteria measured by Andersen samplers showed a higher background value of 715 cfu/m^3 upwind, also higher yields of 4755 and 4456 cfu/m^3 of air at 10m and 50m downwind, while at 150m downwind the airborne bacteria were measured at an even greater concentration of 8175 cfu/m^3.

- With no activity taking place, a background sample taken 50m upwind had an elevated value of 1000 cfu/m^3 of air, which was reduced to 858 cfu/m^3 of air at 10m downwind, but was as high as 2567 and 2561 cfu/m^3 of air at 50m and 150m downwind. This supported the fungal data indicating a continuing bioaerosol source from other site activities.

- Concentrations of fungi from the personal and fixed point filter (IOM) samplers were as high as 3403 cfu/m^3 of air inside cabs and 14,820 cfu/m^3 of air outside cabs. In one case during transportation of screened waste, *A. fumigatus* concentrations were as high as 497,382 cfu/m^3 of air inside a tractor cab. As the sampler located outside this cab yielded 1041 cfu/m^3 *A. fumigatus*, this suggested excessive contamination of the sampler. A fixed point sampler located in a bay housing household waste (but with no handling activity) yielded 517,751 cfu/m^3 of air total fungi and 295,858 cfu/m^3 of air *A. fumigatus.*

- Concentrations of bacteria from the personal and fixed point filter (IOM) samplers were as high as 138,889 cfu/m^3 of air inside cabs and 1.5 million cfu/m^3 of air outside the same cab during compost screening. The same samples yielded 113,757 cfu/m^3 of thermophilic actinomycetes inside the cab and 377,577 cfu/m^3 of air outside the cab.

- Endotoxin concentrations were negligible at open sites, up to 23.1 EU/m^3 in personal samplers for cab drivers and up to 1144 EU/m^3 on vehicle cabs loading compost.

3.1.7 Bioaerosol Sampling at Site D (Sampling visit 1)

One bioaerosol sampling visit was carried out in early March 2006. The main activities sampled were the turning of the windrows and shredding of waste wood. Due to the wind direction at the time of sampling it would be difficult to distinguish between these two activities. Sampling was located at 50m upwind and 10, 50, 150 and 250m downwind of the activities. IOM samplers were also located on the loading and turning machinery to monitor bioaerosol levels in the immediate vicinity of the activities. The results of the dust and microbial dust concentrations are given in full in Appendix 1.

Partisol sampler data indicated a general trend of decrease in concentration from the 10m site to the 150m site for micro-organisms.

From the downwind Partisol samplers, in summary:

- Mesophilic fungi and *A. fumigatus* were found to be in concentrations of up to 414 and 67 cfu/m^3 of air.

- Bacteria at 25, 37^{0}C and actinomycetes were detected at levels of up to 816, 3,080 and 1,155 cfu/m^3 of air respectively. These peak levels were detected mainly at the 10m sampling site.

From the IOM sample (Total Inhalable Dust) on the front of the turning machine:

- Mesophilic fungi and *A. fumigatus* were found to be in concentrations of up to 9,944 and 186 cfu/m^3 of air.

- Bacteria at 25^{0}C, 37^{0}C and actinomycetes were detected at levels of up to 105,948, 100,372 and 50,186 cfu/m^3 of air, respectively.

Concentrations of micro-organisms were lower upwind compared to downwind and when no tasks were being performed. The comparison between concentrations of bacteria and fungi detected using Andersen and Partisol were generally higher for the Andersen sampler. However, the Andersen samplers were only run for short periods of time to avoid overloading of the agar plates whereas the Partisol samplers were run for up to 3 hours and therefore give a more representative figure of concentrations over the full working shift.

Endotoxin levels from the Partisol samples (PM_{10}) were all below 5 EU/m^3 of air and dust levels were all below 1 mg/m^3 of air. However, as may be expected because of their close proximity to dust and bioaerosol generation the results from the IOM samplers on the main turning machine indicated much higher concentrations of dust and endotoxin, particularly on the turning machine where concentrations of 6.7 mg/m^3 and 53 EU/m^3 respectively were detected.

3.1.8 Bioaerosol Sampling at Site D (Sampling visit 2)

A further bioaerosol sampling visit was carried out in late March 2006. Again, the main activities sampled were the turning of the windrows and shredding of waste wood. Due to the wind direction at the time of sampling it would be difficult to distinguish between these two activities. Sampling was located at 50m upwind and 10, 50, 150 and 250m downwind of the activities. IOM samplers were also located on the loading and turning machinery to monitor bioaerosol levels in the immediate vicinity of the activities. Wind speed ranged from 0.2 to 2.7 m/sec, mean 1.56 m/sec. The results of the dust and microbial dust concentrations are given in full in Appendix 1.

From the Partisol and Andersen sampler data there is a general trend of decrease in concentration from the 10m site to the 250m site for bacteria, actinomycetes, mesophilic fungi and *A. fumigatus*. In summary:

- Dust levels were < 1mg/m^3 of air at all sampling positions except for fixed point samplers placed on the front of vehicle cabs handling waste. One personal sampler outside a cab yielded 16.2 mg/m^3, but no more than 2.3 mg/m^3 inside.

- Concentrations of micro-organisms from the fixed point Partisol samplers (PM_{10}) and Andersen samplers yielded concentrations of airborne fungi only as high as 1,155 cfu/m^3 of air 10m downwind of compost turning activities, declining to 18 cfu/m^3 at

250m downwind, compared to 66 cfu/m^3 upwind. *A. fumigatus* concentrations were 577 cfu/m^3 at 10m downwind and reduced to 18 cfu/m^3 of air at the 250m sampling point with the Andersen sampler. Upwind concentrations were 11 cfu/m^3.

- Concentrations of micro-organisms from the fixed point Partisol samplers (PM_{10}) and Andersen samplers yielded concentrations of airborne bacteria up to 12,638 cfu/m^3 of air at 10m downwind declining to a maximum of 203 cfu/m^3 at 250m. By comparison, upwind values were a maximum of 452 cfu/m^3.

- Concentrations of fungi from the personal and fixed point filter (IOM) samplers were as high as 10,249 cfu/m^3 of air inside cabs and 62,984 cfu/m^3 of air outside cabs. *A. fumigatus* concentrations were as high as 2,490 cfu/m^3 of air inside cabs and 2,212 cfu/m^3 of air outside cabs.

- Concentrations of bacteria from the personal and fixed point filter (IOM) samplers were as high as 9,630 cfu/m^3 of air inside cabs and 105,948 cfu/m^3 of air outside cabs. Thermophilic actinomycete concentrations were as high as 6,130 cfu/m^3 of air inside cabs and 50,186 cfu/m^3 of air outside cabs.

- Endotoxin concentrations were up to 4.9 EU/m^3 at the static sampling sites and up to 153.6 EU/m^3 on vehicle cabs turning compost.

3.1.9 Bioaerosol Sampling at Site D (Sampling visit 3)

A third bioaerosol sampling visit was carried out at this site in July 2006. The main activities sampled were turning of windrows by mechanical shovel. During sampling, shredding of wood was also taking place. This was adjacent to windrow turning and may have contributed to downwind bioaerosol levels. Other activities included moving of material for shredding. Samplers were located at 50m upwind and 10, 50, 150 and 250m downwind of activities, with personal samplers on workers in loading and turning machinery or fixed outside the cabs of these vehicles. Weather conditions were dry and fine with wind speeds ranging from 0.3 to 4.7 m/sec, mean 1.5 m/sec.

The results of the dust and microbial dust concentrations are given in full in Appendix 1. From the Partisol and Andersen sampler data there is a general trend of decrease in concentration from the 10m site to the 250m site for bacteria, mesophilic fungi and *A. fumigatus*. In summary:

- Dust levels were < 1mg/m^3 of air at all sampling positions except for fixed point samplers placed on the front of vehicle cabs handling waste which yielded up to 15.5 mg/m^3.

- Concentrations of micro-organisms from the fixed point Partisol samplers (PM_{10}) and Andersen samplers yielded concentrations of airborne fungi as high as 21,591 cfu/m^3 of air 10m downwind of compost turning activities, declining to 5,546 cfu/m^3 250m downwind compared to 2,418 cfu/m^3 upwind. *A. fumigatus* concentrations were as high as 5,000 cfu/m^3 at 10m downwind, declining rapidly to 58 cfu/m^3 of air at 250m downwind compared to 12 cfu/m^3 upwind.

- Airborne bacterial concentrations from the fixed point Partisol samplers (PM_{10}) and Andersen samplers yielded concentrations of up to 17,045 cfu/m^3 of air at 10m

downwind declining to 486 cfu/m^3 at 250m. By comparison, upwind values were 1702 cfu/m^3.

- Concentrations of fungi from the personal and fixed point filter (IOM) samplers were as high as 52,795 cfu/m^3 of air inside cabs and 383,959 cfu/m^3 of air outside cabs. *A. fumigatus* concentrations were as high as 62,888 cfu/m^3 of air inside cabs and 254,237 cfu/m^3 of air outside cabs.

- Concentrations of bacteria from the personal and fixed point filter (IOM) samplers were as high as 127,329 cfu/m^3 of air inside cabs and 666,667 cfu/m^3 of air outside cabs. Thermophilic actinomycete concentrations were as high as 14,286 cfu/m^3 of air inside cabs and 334,356 cfu/m^3 of air outside cabs.

- Endotoxin concentrations were up to 10.3 EU/m^3 at the static sampling sites and up to 521 EU/m^3 on vehicle cabs handling green waste.

3.1.10 Bioaerosol Sampling at Site E (Sampling visit 1)

Bioaerosol sampling was undertaken in December 2006. The main activities sampled were turning of the compost windrows. Other activities sampled included relocation of windrows using a mechanical shovel and loading of a shredding machine using a telescopic bulk material handling machine. The Partisol samples were taken during turning of the windrows using the windrow turning machine in late afternoon. The samplers were placed as close as possible to the machine, i.e., at 10m distance, then at 50m and 120m downwind. The distance samples could be taken downwind was restricted due to the location of a busy industrial site. Weather conditions were fine and overcast with wind speeds ranging from 3 to 6.7 m/sec (mean 4.7 m/sec).

The results of the dust and microbial dust concentrations are given in full in Appendix 1.

The concentrations of the parameters measured showed an inconsistent pattern when comparing upwind and various downwind sampling points. The Andersen samplers and Partisol samplers gave similar counts. In summary:

- Dust levels were < 1mg/m^3 of air at all sampling positions except for a fixed point sampler placed on the front of the telehandler cab during shredded waste handling.

- Concentrations of micro-organisms from the fixed point Partisol samplers (PM_{10}) yielded concentrations of airborne fungi no greater than 240 cfu/m^3 of air.

- Concentrations of micro-organisms from the fixed point Partisol samplers (PM_{10}) yielded concentrations of airborne bacteria no greater than 475 cfu/m^3 of air.

- Andersen sampler results yielded concentrations of airborne fungi or *A. fumigatus* no greater than 42 cfu/m^3 of air and bacteria no greater than 497 cfu/m^3.

- Concentrations of fungi from the personal and fixed point filter (IOM) samplers were as high as 2214 cfu/m^3 of air inside cabs and 9132 cfu/m^3 of air outside cabs. *A. fumigatus* concentrations were as high as 418 cfu/m^3 of air inside cabs and 5949 cfu/m^3 of air outside cabs.

- Concentrations of bacteria from the personal and fixed point filter (IOM) samplers were as high as 11,142 cfu/m^3 of air inside cabs and 25,708 cfu/m^3 of air outside cabs. Thermophilic actinomycete concentrations were as high as 10,446 cfu/m^3 of air inside cabs and 17,785 cfu/m^3 of air outside cabs.

- Endotoxin concentrations were < 1 EU/m^3 at all the static sampling sites and up to 40.9 EU/m^3 on vehicle cabs loading compost.

3.1.11 Bioaerosol Sampling at Site E (Sampling visit 2)

A further bioaerosol sampling visit was undertaken at this site in January 2007. On this occasion the main activities were screening and handling composted waste and turning windrows. This visit provided the opportunity to cover a larger range of work tasks, including personal samplers in workers' breathing zones and fixed point samplers outside vehicle cabs to compare potential total exposure with workers actual exposure. The static samplers were placed as close as possible to the activity being monitored and also where possible at 50m intervals downwind of the activity, up to a maximum of 200m. Control samples were also taken 20-50m upwind of the activity. Weather conditions were cold and fine with wind speeds from 0.8 to 5.5 m/sec, mean 2.9 m/sec.

The results of the dust and microbial dust concentrations are given in full in Appendix 1.

From the Partisol and Andersen sampler data there is a general trend of decrease in concentrations from the 10m down wind site to the 200m downwind site for bacteria, fungi and thermophilic actinomycetes, but with some fluctuation. At 100m downwind when there was no operation there was a single high count which suggested a high background general bioaerosol. In summary:

- Dust levels were all below 1mg/$m^3$of air except for one point on the front of a loader .

- During compost turning, mesophilic fungi and *A. fumigatus* were found to be in concentrations of up to 133 and 26 cfu/m^3 of air respectively at 50m downwind from the work area (Partisol data). However, this was similar to the upwind concentrations for mesophilic fungi. During screening, numbers peaked at 100m downwind at 182 cfu/m^3 of air. With no operational activities, a peak value of 423 fungi cfu/m^3 of air was recorded upwind of the site.

- Personal samplers on vehicle drivers during compost handling yielded fungal concentrations up to 761 cfu/m^3 of air, with 2241 cfu/m^3 of air recorded outside cabs.

- During compost turning work, mesophilic bacteria were found to be in concentrations of up to 450 cfu/m^3 of air at 10m downwind from the work area (Partisol data). This decreased to levels of 70 cfm/m^3 at the 150m downwind site (Partisol data). During screening, numbers peaked at 100m downwind at 850 cfu/m^3 of air. With no operational activities, a peak value of 2256 bacteria cfu/m^3 of air was recorded.

- Personal samplers on vehicle drivers during compost handling yielded bacterial concentrations up to 73,181 cfu/m^3 of air, and thermophilic actinomycetes at 49,069 cfu/m^3 of air inside the same cab, with 12,845 cfu/m^3 total bacteria of air recorded outside cabs.

- Actinomycetes were found to be at a concentration of up to 771 cfu/m^3 of air at 50m downwind during turning. This decreased to lower levels at 95 cfu/m^3 , and none detected at the 100 and 150m downwind site respectively.

- Endotoxin analyses were not done on this occasion.

3.1.12 Bioaerosol Sampling at Site F (Sampling visit 1)

A bioaerosol sampling visit was carried out in October 2006. The main activities sampled were turning of compost windrows and shredding of green waste. These two tasks were performed simultaneously and adjacent to each other, therefore contributing bioaerosols from each could not be distinguished. Turning of windrows and loading of the shredder was done using mechanical shovels. Samplers were located at 50 m upwind and 10, 50, 120 and 250m downwind. Personal samplers were placed on the front of mechanical shovel cabs and on drivers of the vehicles. Weather conditions were dry and overcast and wind speeds ranged from 0.3 to 4.2 m/sec with a mean of 1.2 m/sec.

The results of the dust and microbial dust concentrations are given in full in Appendix 1.

From the Partisol sampler data there was a general trend of decrease in concentrations from the 10m site to the 250m site for bacteria, actinomycetes, mesophilic fungi and *A. fumigatus*. In general concentrations of micro-organisms were when no tasks were being performed were lower than when turning was in progress. In summary:

- Mesophilic fungi and *A. fumigatus* were found to be in concentrations of up to 144,124 and 199,557 cfu/m^3 of air respectively at 10m downwind from the work area during turning and shredding (Partisol data). This decreased to levels similar to the upwind concentrations at 150 and 250m downwind for mesophilic fungi, but *A. fumigatus* levels remained higher than background at 4512 cfu/m^3 at 120m and 1118 cfu/m^3 at 250 downwind, compared to 95 cfu/m^3 upwind.

- Mesophilic bacteria were found to be in concentrations of up to 99,778 cfu/m^3 of air at 10m downwind from the work area, rapidly declining by 50m (Partisol data). By 120m downwind the numbers were similar to background upwind values.

- Actinomycetes were found to be at a concentration of up to 18,293 cfu/m^3 of air at 10m downwind, but were below the level of detection at more distant points.

- Dust concentrations were all <1 mg/m^3.

- Endotoxin measurements were no greater than 2.1 EU/m^3.

For personal exposure measurements and on vehicle cabs:

- The personal exposure to airborne fungi was up to 375,000 cfu/m^3 and 465,278 cfu/m^3 *A. fumigatus* for the driver of a shovel loading a shredder, while outside the same cab 324,586 cfu/m^3 fungi and 131,215 cfu/m^3 *A. fumigatus* was measured.

- The personal exposure to airborne bacteria was up to 98,611 cfu/m^3, while outside cabs up to 283,149 cfu/m^3 was measured.

- The personal exposure to airborne actinomycetes was up to 55,556 cfu/m^3, while outside cabs up to 43,508 cfu/m^3 was measured.

- The above data indicate little protection being afforded on this occasion by the vehicle cab.

- Dust concentrations were no greater than 1.75 mg/m^3 inside or outside vehicle cabs.

- Endotoxin concentrations were no greater than 10.3 EU/m^3 inside or outside vehicle cabs.

3.1.13 Bioaerosol Sampling at Site F (Sampling visit 2)

A second bioaerosol sampling visit was carried out in November 2006. The main activities sampled were turning of the compost windrows. This was performed in two stages. Firstly, mature windrows were turned, followed by turning a windrow which had recently been created from waste from the in-vessel system. The only other activity taking place was tidying up of windrows using a mechanical shovel. Samplers were located at 10m upwind and 10, 50, 120 and 250m downwind. Personal samplers were placed on the front of the turning machine and the mechanical shovel, and on drivers of the vehicles. Weather conditions were dry and overcast; wind speeds were ranged from 0.3 to 4.2 m/sec with a mean of 1.2 m/sec.

The results of the dust and microbial dust concentrations are given in full in Appendix 1.

From the Partisol sampler data there was a general trend of decrease in concentrations from the 10m site to the 250m site for bacteria, actinomycetes, mesophilic fungi and *A. fumigatus*. In general concentrations of micro-organisms were when no tasks were being performed were lower than when turning was in progress. In summary:

- Mesophilic fungi and *A. fumigatus* were found to be in concentrations of up to 117 and 29 cfu/m^3 of air respectively at 10m down wind from the work area (Partisol data). This decreased to levels similar to the upwind concentrations at 120 and 250m down wind.

- Mesophilic bacteria were found to be in concentrations of up to 5,430 cfu/m^3 of air at 10m downwind from the work area and a similar concentration at 50m (Partisol data). This decreased at 120 and 250m downwind from the work area, but remained higher than the upwind concentrations at 1,710 cfu/m^3 of air compared to 357 cfu/m^3 of air.

- Actinomycetes were found to be at a concentration of up to 5,460 cfu/m^3 of air at 10m downwind. This decreased to lower levels at 150 and 250m downwind, but still remained slightly higher than the 10m upwind concentration.

- Dust concentrations were all <1 mg/m^3.

- Endotoxin measurements were all below the level of detection.

For personal exposure measurements and on vehicle cabs:

- The personal exposure to airborne fungi was up to 13,400 cfu/m^3, while outside cabs up to 9,810 cfu/m^3 was measured.

- The personal exposure to airborne bacteria was up to 1.94 million cfu/m^3, while outside cabs up to 8.64 million cfu/m^3 was measured.

- The personal exposure to airborne actinomycetes was up to 66,500 cfu/m^3, while outside cabs up to 164,000 cfu/m^3 was measured.

- Dust concentrations were as high as 23.4 mg/m^3 outside vehicle cabs.

- Endotoxin concentrations were as high as 26.2 EU/m^3 outside vehicle cabs.

3.2 COMPARISON OF BIOAEROSOL DATA FROM ALL SITES AND STRATIFICATION OF BIOAEROSOL DATA

3.2.1 Overview

The bioaerosol data from all site visits in the study are summarised below. The aim is to provide comparisons, where possible, between changes in bioaerosol concentration with distance from composting activities, and to identify activities common to all sites where high level exposure may occur. Comparisons are also made between bioaerosol concentrations inside and outside vehicle cabs, and between samples taken in winter and summer.

In order to assist these comparisons, bioaerosol emission data from composting activity has been stratified according to concentration into eight groups ranging from <1000 cfu/m^3 to <1 million cfu/m^3, with colour coding from green (low concentration) to red (highest concentrations) to aid differentiation and to develop an exposure banding or 'traffic light' approach to potential exposure levels. The colour coded and stratified data are as follows:

- **<1000 cfu/m^3**
- **1,000-5,000 cfu/m^3**
- **5,000 – 10,000 cfu/m^3**
- **10,000 – 50,000 cfu/m^3**
- **50,000 – 100,000 cfu/m^3**
- **100,000 – 500,000 cfu/m^3**
- **500,000 – 1,000,000 cfu/m^3**
- **>1,000,000 cfu/m^3**

It must be emphasised that these exposure bands are proposed only as a means of stratifying the bioaerosol concentrations and are not necessarily related to any exposure-response health effect.

3.2.2 Exposure banding of bioaerosol data for individual sites

The following tables (Tables 1 – 8) summarise data for airborne concentrations of total and thermophilic bacteria, fungi and *Aspergillus fumigatus* in the above exposure bands.

Table 1. Total number of bioaerosol samples from each site with counts <1000 cfu/m^3

SITE	Total Bacteria	Thermophilic bacteria	Total fungi	Asp fumigatus
SITE A Visit 1	No result	7	6	6
SITE A Visit 2	6	5	4	2
SITE B Visit 1	15	10	11	16
SITE B Visit2	6	2	0	4
SITE C Visit 1	9	4	5	6
SITE C Visit 2	5	6	1	10
SITE D Visit 1	11	10	10	18
SITE D Visit 2	8	5	7	11
SITE D Visit 3	5	1	0	4
SITE E Visit 1	9	5	5	12
SITE E Visit 2	25	15	17	33
SITE F Visit 1	14	9	8	11
SITE F Visit 2	12	9	11	19
TOTAL	**125**	**88**	**85**	**152**

Table 2. Total number of bioaerosol samples from each site with counts from 1,000-5,000 cfu/m^3

SITE	Total Bacteria	Thermophilic bacteria	Total fungi	Asp fumigatus
SITE A Visit 1	0	0	1	1
SITE A Visit 2	5	0	3	6
SITE B Visit 1	0	1	2	0
SITE B Visit 2	1	4	2	6
SITE C Visit 1	2	4	2	1
SITE C Visit 2	8	2	11	3
SITE D Visit 1	5	4	3	1
SITE D Visit 2	7	2	0	3
SITE D Visit 3	3	0	2	4
SITE E Visit 1	3	1	4	2
SITE E Visit 2	5	0	2	0
SITE F Visit 1	1	0	2	5
SITE F Visit 2	1	0	2	0
TOTAL	**41**	**18**	**36**	**32**

Table 3. Total number of bioaerosol samples from each site with counts from 5,000 – 10,000 cfu/m^3

SITE	Total Bacteria	Thermophilic bacteria	Total fungi	Asp fumigatus
SITE A Visit 1	0	0	0	0
SITE A Visit 2	1	2	1	0
SITE B Visit 1	1	0	0	1
SITE B Visit 2	3	1	7	3
SITE C Visit 1	1	2	3	2
SITE C Visit 2	2	2	2	0
SITE D Visit 1	0	0	1	0
SITE D Visit 2	2	1	1	0
SITE D Visit 3	2	2	4	0
SITE E Visit 1	1	2	2	1
SITE E Visit 2	0	3	0	0
SITE F Visit 1	0	0	0	0
SITE F Visit 2	2	1	2	0
TOTAL	**15**	**16**	**23**	**7**

Table 4. Total number of bioaerosol samples from each site with counts from 10,000 – 50,000 cfu/m^3

SITE	Total Bacteria	Thermophilic bacteria	Total fungi	Asp fumigatus
SITE A Visit 1	0	0	0	0
SITE A Visit 2	1	0	1	0
SITE B Visit 1	0	2	0	0
SITE B Visit 2	2	6	3	2
SITE C Visit 1	5	1	2	0
SITE C Visit 2	2	3	1	0
SITE D Visit 1	2	0	0	0
SITE D Visit 2	2	2	4	0
SITE D Visit 3	2	1	1	0
SITE E Visit 1	2	3	0	0
SITE E Visit 2	1	1	0	0
SITE F Visit 1	0	4	1	0
SITE F Visit 2	0	1	1	2
TOTAL	**19**	**24**	**14**	**4**

Table 5. Total number of bioaerosol samples from each site with counts from 50,000 – 100,000 cfu/m^3

SITE	Total Bacteria	Thermophilic bacteria	Total fungi	Asp fumigatus
SITE A Visit 1	0	0	0	0
SITE A Visit 2	0	0	0	0
SITE B Visit 1	1 (1)	0	1 (1)	0
SITE B Visit 2	2 (2*)	1 (1*)	2 (1)	1 (1)
SITE C Visit 1	1 (1**)	1 (1)	0	0
SITE C Visit 2	0	0	0	0
SITE D Visit 1	0	0	0	0
SITE D Visit 2	1	1	1	0
SITE D Visit 3	0	1	1 (1)	1 (1)
SITE E Visit 1	0	0	0	0
SITE E Visit 2	1 (1)	0	0	0
SITE F Visit 1	4 (2) (1*)	2 (2)	0	0
SITE F Visit 2	0	3 (2)	0	0
TOTAL	**10**	**9**	**5**	**2**

All of the above samples were taken from outside the cabs of vehicles handling compost except (n) driver of vehicle; (n*) static downwind of compost screening; (n**) worker outside vehicle in shredder bay

Table 6. Total number of bioaerosol samples from each site with counts from 100,000 – 500,000 cfu/m^3

SITE	Total Bacteria	Thermophilic bacteria	Total fungi	Asp fumigatus
SITE A Visit 1	0	0	0	0
SITE A Visit 2	0	0	0	0
SITE B Visit 1	0	0	0	0
SITE B Visit 2	2 (1)	3 (2)	2 (1)	5 (2)(1*)
SITE C Visit 1	0	1 (1)	1 (1**)	0
SITE C Visit 2	2 (2)	2 (1)	0	2 (1)
SITE D Visit 1	1 (1)	0	1	1
SITE D Visit 2	1	0	0	0
SITE D Visit 3	2 (1)	2	3	2
SITE E Visit 1	0	0	0	0
SITE E Visit 2	0	0	0	0
SITE F Visit 1	1	0	3 (1) (1*)	3 (1) (1*)
SITE F Visit 2	3 (2)	2	0	0
TOTAL	**12**	**10**	**10**	**13**

All of the above samples were taken from outside the cabs of vehicles handling compost except (n) driver of vehicle; (n*) static downwind of compost screening; (n**) worker outside vehicle in shredder bay.

Table 7. Total number of bioaerosol samples from each site with counts from 500,000 – 1,000,000 cfu/m^3

SITE	Total Bacteria	Thermophilic bacteria	Total fungi	Asp fumigatus
SITE A Visit 1	0	0	0	0
SITE A Visit 2	0	0	0	0
SITE B Visit 1	0	0	0	0
SITE B Visit 2	1 (1)	1	0	1
SITE C Visit 1	1	1	0	0
SITE C Visit 2	1 (1)	1	1	0
SITE D Visit 1	0	0	0	0
SITE D Visit 2	0	0	0	0
SITE D Visit 3	2	0	0	0
SITE E Visit 1	0	0	0	0
SITE E Visit 2	0	0	0	0
SITE F Visit 1	0	0	0	0
SITE F Visit 2	0	0	0	0
TOTAL	**5**	**3**	**1**	**1**

All of the above samples were taken from outside the cabs of vehicles handling compost except (n) driver of vehicle.

Table 8. Total number of bioaerosol samples from each site with counts >1,000,000 cfu/m^3

SITE	Total Bacteria	Thermophilic bacteria	Total fungi	Asp fumigatus
SITE A Visit 1	0	0	0	0
SITE A Visit 2	0	0	0	0
SITE B Visit 1	0	0	0	0
SITE B Visit 2	4 (1)	1	2	1
SITE C Visit 1	0	0	0	0
SITE C Visit 2	2	0	1	0
SITE D Visit 1	1	0	0	0
SITE D Visit 2	0	0	0	0
SITE D Visit 3	0	0	0	0
SITE E Visit 1	0	0	0	0
SITE E Visit 2	0	0	0	0
SITE F Visit 1	0	0	0	0
SITE F Visit 1	3 (1)	0	0	0
TOTAL	**10**	**1**	**3**	**1**

All of the above samples were taken from outside the cabs of vehicles handling compost except (n) driver of vehicle.

3.2.3 Exposure banding of bioaerosol components at individual sites

Tables 9 - 12 summarise the data for each of the main bioaerosol components measured (total bacteria, thermophilic actinomycete bacteria, total fungi and *Aspergillus fumigatus*) stratified into exposure bands for each individual site included in the study.

Table 9. Bioaerosol measurements (cfu/m^3) of total bacteria in exposure bands for all sites

SITE	<1000	1,000-5,000	5,000 – 10,000	10,000 – 50,000	50,000 – 100,000	100,000 – 500,000	500,000 – 1,000,000	>1,000,000	Total
SITE A Visit 1	No result	0	0	0	0	0	0	0	**0**
SITE A Visit 2	6 (46.2)	5	1	1	0	0	0	0	**13**
SITE B Visit 1	15 (88.2)	0	1	0	1	0	0	0	**17**
SITE B Visit 2	6 (28.5)	1	3	2	2	2	1	4	**21**
SITE C Visit 1	9 (47.4)	2	1	5	1	0	1	0	**19**
SITE C Visit 2	5 (22.7)	8	2	2	0	2	1	2	**22**
SITE D Visit 1	11 (55.0)	5	0	2	0	1	0	1	**20**
SITE D Visit 2	8 (38.1)	7	2	2	1	1	0	0	**21**
SITE D Visit 3	5 (31.3)	3	2	2	0	2	2	0	**16**
SITE E Visit 1	9 (60.0)	3	1	2	0	0	0	0	**15**
SITE E Visit 2	25 (78.1)	5	0	1	1	0	0	0	**32**
SITE F Visit 1	14 (70.0)	1	0	0	4	1	0	0	**20**
SITE F Visit 2	12 (57.1)	1	2	0	0	3	0	3	**21**

Data in ( ) = % of total for that site. The only samples taken upwind which yielded >1,000 cfu/m^3 were at Site C visit 2; Site D visit 2; Site D visit 3; Site F visit 1.

Table 10. Bioaerosol measurements (cfu/m^3) of thermophilic actinomycetes in exposure bands for all sites

SITE	<1000	1,000-5,000	5,000 – 10,000	10,000 – 50,000	50,000 – 100,000	100,000 – 500,000	500,000 – 1,000,000	>1,000,000	Total
SITE A Visit 1	7 (100)	0	0	0	0	0	0	0	**7**
SITE A Visit2	5 (79.6)	0	2	0	0	0	0	0	**7**
SITE B Visit 1	10 (76.9)	1	0	2	0	0	0	0	**13**
SITE B Visit 2	2 (10.5)	4	1	6	1	3	1	1	**19**
SITE C Visit 1	4 (28.6)	4	2	1	1	1	1	0	**14**
SITE C Visit 2	6 (37.5)	2	2	3	0	2	1	0	**16**
SITE D Visit 1	10 (71.4)	4	0	0	0	0	0	0	**14**
SITE D Visit 2	5 (45.5)	2	1	2	1	0	0	0	**11**
SITE D Visit 2	1 (14.3)	0	2	1	1	2	0	0	**7**
SITE E Visit 1	5 (45.5)	1	2	3	0	0	0	0	**11**
SITE E Visit 2	15 (78.9)	0	3	1	0	0	0	0	**19**
SITE F Visit 1	9 (60.0)	0	0	4	2	0	0	0	**15**
SITE F Visit 2	9 (56.3)	0	1	1	3	2	0	0	**16**

Data in ( ) = % of total for that site. No upwind samples yielded >1000 cfu/m^3.

Table 11. Bioaerosol measurements (cfu/m^3) of total fungi in exposure bands for all sites

SITE	<1000	1,000-5,000	5,000 – 10,000	10,000 – 50,000	50,000 – 100,000	100,000 – 500,000	500,000 – 1,000,000	>1,000,000	Total
SITE A Visit 1	6 (85.7)	1	0	0	0	0	0	0	**7**
SITE A Visit 2	4 (44.4)	3	1	1	0	0	0	0	**9**
SITE B Visit 1	11 78.6)	2	0	0	1	0	0	0	**14**
SITE B Visit 2	0 (0)	2	7	3	2	2	0	2	**18**
SITE C Visit 1	5 (38.5)	2	3	2	0	1	0	0	**13**
SITE C Visit 2	1 (5.9)	11	2	1	0	0	1	1	**17**
SITE D Visit 1	10 (66.7)	3	1	0	0	1	0	0	**15**
SITE D Visit 2	7 (53.8)	0	1	4	1	0	0	0	**13**
SITE D Visit 3	0 (0)	2	4	1	1	3	0	0	**11**
SITE E Visit 1	5 (45.5)	4	2	0	0	0	0	0	**11**
SITE E Visit 2	17 (89.5)	2	0	0	0	0	0	0	**19**
SITE F Visit 1	8 (57.1)	2	0	1	0	3	0	0	**14**
SITE F Visit 2	11 (68.8)	2	2	1	0	0	0	0	**16**

Data in ( ) = % of total for that site. The only samples taken upwind which yielded >1,000 cfu/m^3 were Site B visit 2; Site C visit 2; Site D visit 3.

Table 12. Bioaerosol measurements (cfu/m^3) of *Aspergillus fumigatus* in exposure bands for all sites

SITE	<1000	1,000-5,000	5,000 – 10,000	10,000 – 50,000	50,000 – 100,000	100,000 – 500,000	500,000 – 1,000,000	>1,000,000	Total
SITE A Visit 1	6 (85.7)	1	0	0	0	0	0	0	**7**
SITE A Visit 2	2 (25.0)	6	0	0	0	0	0	0	**8**
SITE B Visit 1	16 (94.1)	0	1	0	0	0	0	0	**17**
SITE B Visit 2	4 (17.4)	6	3	2	1	5	1	1	**23**
SITE C Visit 1	6 (66.7)	1	2	0	0	0	0	0	**9**
SITE C Visit 2	10 (62.5)	3	0	0	0	2	1	0	**16**
SITE D Visit 1	18 (90.0)	1	0	0	0	1	0	0	**20**
SITE D Visit 2	11 (78.6)	3	0	0	0	0	0	0	**14**
SITE D Visit 3	4 (36.4)	4	0	0	1	2	0	0	**11**
SITE E Visit 1	12 (80.0)	2	1	0	0	0	0	0	**15**
SITE E Visit 2	33 (100)	0	0	0	0	0	0	0	**33**
SITE F Visit 1	11 (57.9)	5	0	0	0	3	0	0	**19**
SITE F Visit 2	19 (90.5)	0	0	2	0	0	0	0	**21**

Data in ( ) = % of total for that site. No upwind samples yielded >1000 cfu/m^3.

3.2.4 Exposure banding of bioaerosol components compared to site activity

At each site and for each bioaerosol component the greatest number of samples yielded <1,000 cfu/m^3 air, with progressive decline in the number of samples yielding higher concentrations. Those yielding higher concentrations were mostly near to or downwind of composting operations with the exception of a few upwind samples as listed above.

Table 13 summarises data from all the site visits, in exposure bands, for each of the four main bioaerosol components measured. More than half the bacterial bioaerosol samples (52.7%), 48% of total fungi and 71% of *Aspergillus fumigatus* samples yielded fewer than 1,000 cfu/m^3. Around two thirds of bacterial and fungal samples and 86% of *Aspergillus fumigatus* samples yielded less than 5,000 cfu/m^3.

Table 13. Summary of bioaerosol sample components in exposure bands from all sites

	Total Bacteria	Thermophilic bacteria	Total fungi	Asp fumigatus
<1000	125 (52.7)	88(52.1)	85 (48.0)	152 (71.7)
1,000-5,000	41 (17.3)	18 (10.7)	36 (20.3)	32 (15.1)
5,000 – 10,000	15 (6.3)	16 (9.5)	23 (13.0)	7 (3.3)
10,000 – 50,000	19 (8.0)	24 (14.2)	14 (7.9)	4 (1.9)
50,000 – 100,000	10 (4.2)	9 (5.3)	5 (2.8)	2 (0.9)
100,000 – 500,000	12 (5.1)	10 (5.9)	10 (5.6)	13 (6.1)
500,000 – 1,000,000	5 (2.1)	3 (1.8)	1 (0.6)	1 (0.5)
>1,000,000	10 (4.2)	1 (0.6)	3 (1.7)	1 (0.5)
TOTAL	**237**	**169**	**177**	**212**

( ) = percentage of total.

Tables 14 to 17 summarise each of the four main bioaerosol components in exposure bands and subdivided into work activities or sample location for all sites

Table 14. Bioaerosol measurements (cfu/m^3) of total bacteria in exposure bands for sample locations at all sites

Sample location	<1000	1,000-5,000	5,000 – 10,000	10,000 – 50,000	50,000 – 100,000	100,000 – 500,000	500,000 – 1,000,000	>1,000,000	Total
Upwind of site activities	34 (89.5)	4 (10.5)	0	0	0	0	0	0	**38**
10m downwind of site activities	15 (51.7)	6 (20.7)	3 (10.3)	3 (10.3)	2	0	0	0	**29**
50m downwind of site activities	22 (64.7)	10 (29.4)	1 (2.9)	1 (2.9)	0	0	0	0	**34**
50-100m downwind of site activities	6 (66.7)	3 (33.3)	0	0	0	0	0	0	**9**
100 - 250m downwind of site activities	43 (82.7)	5 (9.6)	3 (5.8)	0	1 (1.9)	0	0	0	**52**
Outside cabs during site activities	0	2 (8.0)	1 (4.0)	4 (16.0)	2 (8.0)	5 (20.0)	4 (16.0)	7 (28.0)	**25**
Inside cabs during site activities	1 (2.9)	5 (14.3)	6 (17.1)	9 (25.7)	4 (11.4)	7 (20.0)	1 (2.9)	2 (5.7)	**35**
Personal exposure for workers outside cabs during site activities	0	1 (33.3)	0	1 (33.3)	1 (33.3)	0	0	0	**3**

Table 15. Bioaerosol measurements (cfu/m^3) of thermophilic actinomycetes in exposure bands for sample locations at all sites

Sample location	<1000	1,000-5,000	5,000 – 10,000	10,000 – 50,000	50,000 – 100,000	100,000 – 500,000	500,000 – 1,000,000	>1,000,000	Total
Upwind of site activities	23 (95.8)	1 (4.2)	0	0	0	0	0	0	**24**
10m downwind of site activities	9 (56.3)	3 (18.8)	1 (6.3)	3 (18.8)	0	0	0	0	**16**
50m downwind of site activities	19 (82.6)	1 (4.3)	2 (8.7)	1 (4.3)	0	0	0	0	**23**
50-100m downwind of site activities	5 (100)	0	0	0	0	0	0	0	**5**
100 - 250m downwind of site activities	27 (87.1)	2 (6.5)	0	1 (3.2)	1 (3.2)	0	0	0	**31**
Outside cabs during site activities	1 (3.6)	4 (14.3)	3 (10.7)	8 (28.6)	2 (7.1)	6 (21.4)	2 (7.1)	2 (7.1)	**28**
Inside cabs during site activities	1 (2.9)	6 (17.6)	7 (20.6)	10 (29.4)	5 (14.7)	4 (11.8)	1 (2.9)	0	**34**
Personal exposure for workers outside cabs during site activities	0	0	2 (50.0)	1 (25.0)	1 (25.0)	0	0	0	**4**

Table 16. Bioaerosol measurements (cfu/m^3) of total fungi in exposure bands for sample locations at all sites

Sample location	<1000	1,000-5,000	5,000 – 10,000	10,000 – 50,000	50,000 – 100,000	100,000 – 500,000	500,000 – 1,000,000	>1,000,000	Total
Upwind of site activities	21 (84.0)	4 (16.0)	0	0	0	0	0	0	**25**
10m downwind of site activities	10 (55.6)	4 (22.2)	1 (5.6)	2 (11.1)	0	1 (5.6)	0	0	**18**
50m downwind of site activities	17 (70.8)	4 (16.7)	2 (8.3)	1 (4.2)	0	0	0	0	**24**
50-100m downwind of site activities	3 (75.0)	1 (25.0)	0	0	0	0	0	0	**4**
100 - 250m downwind of site activities	23 (69.7)	4 (12.1)	6 (18.2)	0	0	0	0	0	**33**
Outside cabs during site activities	2 (7.1)	5 (17.9)	6 (21.4)	4 (14.3)	2 (7.1)	6 (21.4)	0	3 (10.7)	**28**
Inside cabs during site activities	5 (15.2)	12 (36.4)	6 (18.2)	5 (15.2)	3 (9.1)	2 (6.1)	0	0	**33**
Personal exposure for workers outside cabs during site activities	0	1 (25.0)	1 (25.0)	0	0	1 (25.0)	1 (25.0)	0	**4**

Table 17. Bioaerosol measurements (cfu/m^3) of *Aspergillus fumigatus* in exposure bands for sample locations at all sites

Sample location	<1000	1,000-5,000	5,000 – 10,000	10,000 – 50,000	50,000 – 100,000	100,000 – 500,000	500,000 – 1,000,000	>1,000,000	Total
Upwind of site activities	34 (100)	0	0	0	0	0	0	0	**34**
10m downwind of site activities	18 (69.2)	4 (15.4)	2 (7.7)	1 (3.8)	0	1 (3.8)	0	0	**26**
50m downwind of site activities	27 (79.4)	5 (14.7)	1 (2.9)	1 (2.9)	0	0	0	0	**34**
50-100m downwind of site activities	6 (66.7)	2 (22.2)	1 (11.1)	0	0	0	0	0	**9**
100 - 250m downwind of site activities	39 (83.0)	6 (12.8)	1 (2.1)	0	0	1 (2.1)	0	0	**47**
Outside cabs during site activities	8 (32.0)	7 (28.0)	1 (4.0)	1 (4.0)	0	6 (16.0)	1 (4.0)	1 (4.0)	**25**
Inside cabs during site activities	14 (48.3)	7 (14.3)	1 (3.4)	1 (3.4)	2 (6.9)	4 (13.8)	0	0	**29**
Personal exposure for workers outside cabs during site activities	2 (66.7)	0	0	0	0	1 (33.3)	0	0	**3**

3.2.5 Bioaerosol concentrations at distant points downwind of compost handling activities

The following interpretation of the data (Table 18) examines samples taken at points 50m and 150+m downwind of composting activities, stratified according to concentration of the bioaerosol component measured.

Table 18. Summary of bioaerosol data at 50m and 100+m downwind of all sites (number and %age compared to total number of samples from all sites)

Location of sample	Bioaerosol concentration	Total Bacteria	Thermophilic bacteria	Total fungi	Asp fumigatus
Samples collected at 50m downwind of compost handling activities	**<1000 cfu/m^3**	22/34 (64.7%)	19/23 (82.6%)	17/24 (70.8%)	27/34 (79.4%)
	1,000-5,000 cfu/m^3	10/34 (29.4%)	1/23 (4.3%)	4/24 (16.7%)	5/34 (14.7%)
	5,000 – 10,000 cfu/m^3	1/34 (2.9%)	2/23 (8.7%)	2/24 (8.3%)	1/34 (2.9%)
	10,000 – 50,000 cfu/m^3	1	1	1	1
	50,000 – 100,000 cfu/m^3	0	0	0	0
	100,000 – 500,000 cfu/m^3	0	0	0	0
Samples collected at 100m+ downwind of compost handling activities	**<1000 cfu/m^3**	43/52 (82.7%)	27/31 (87.1%)	23/33 (69.7%)	39/47 (83.0%)
	1,000-5,000 cfu/m^3	5/52 (9.6%)	2/31 (6.5%)	4/33 (12.1%)	6/47 (12.8%)
	5,000 – 10,000 cfu/m^3	3/52 (5.8%)	0/31	6/33 (18.2%)	1/47
	10,000 – 50,000 cfu/m^3	0	1	0	0
	50,000 – 100,000 cfu/m^3	1	1	0	0
	100,000 – 500,000 cfu/m^3	0	0	0	1

In summary from the above:

- All but 2 (94%) of total bacteria samples at 50m downwind from compost handling and all but 4 (92%) of total bacteria samples at 100+m downwind yielded less than or equal to 5,000 cfu/m^3.

- All but 3 (86%) of actinomycete samples at 50m downwind from compost handling and all but 2 (93%) of actinomycete samples at 100+m downwind yielded less than or equal to 5,000 cfu/m^3.

- All but 3 (87.5%) of total fungal samples at 50m downwind from compost handling and 27/33 (82%) of total fungal samples at 100+m downwind yielded less than or equal to 5,000 cfu/m^3.

- All but 2 (94%) of *A. fumigatus* samples at 50m downwind from compost handling and all but 1 (96%) of *A. fumigatus* samples at 100+m downwind yielded less than or equal to 5,000 cfu/m^3.

3.2.6 Exposure banding of bioaerosol data inside and outside vehicle cabs

Workers are likely to be at greatest risk of potentially high bioaerosol exposure levels during work activities nearest to compost handling. In most cases this work is done using different types of vehicle to handle compost. The vehicle cab is likely to afford some mitigation from exposure to bioaerosols released by the compost being handled. Bioaerosol samples were taken using personal samplers on workers inside cabs, with similar samplers placed on the outside of their cabs. This provided a measure of the total bioaerosol in the work area compared to potential worker exposure as mitigated by being inside the vehicle cab. Table 19 summarises data from all sites for each of the main bioaerosol components measured, stratified into exposure bands and comparing inside and outside cabs.

Table 19. Comparison of bioaerosol measurements (cfu/m^3) in exposure bands inside and outside vehicle cabs during compost handling

BIOAEROSOL COMPONENT	<1000	1,000-5,000	5,000 – 10,000	10,000 – 50,000	50,000 – 100,000	100,000 – 500,000	500,000 – 1,000,000	>1,000,000	Total
Total bacteria inside cabs	1 (2.8)	5 (13.9)	6 (16.7)	9 (25.0)	5 (13.9)	7 (19.4)	2 (5.6)	1 (2.8)	**36**
Total bacteria outside cabs	0	2 (7.1)	2 (7.1)	6 (21.4)	2 (7.1)	5 (17.9)	4 (14.3)	7 (25.0)	**28**
Thermophilic actinomycetes inside cabs	1 (2.8)	6 (16.7)	10 (27.8)	10 (27.8)	4 (11.1)	4 (11.1)	1 (2.8)	0	**36**
Thermophilic actinomycetes outside cabs	1 (3.6)	4 (14.3)	3 (10.7)	8 (28.6)	3 (10.7)	6 (21.4)	1 (3.6)	2 (7.1)	**28**
Total fungi inside cabs	5 (14.7)	14 (41.2)	6 (17.6)	4 (11.8)	3 (8.8)	2 (5.9)	0	0	**34**
Total fungi outside cabs	2 (7.1)	5 (17.9)	6 (21.4)	4 (14.3)	2 (7.1)	5 (17.9)	0	4 (14.3)	**28**
Aspergillus fumigatus inside cabs	16 (48.5)	9 (27.3)	1 (3.0)	1 (3.0)	2 (6.1)	4 (12.1)	0	0	**33**
Aspergillus fumigatus outside cabs	8 (33.3)	7 (29.2)	1 (4.2)	1 (4.2)	0	5 (20.8)	1 (4.2)	1 (4.2)	**24**

Nos in brackets = percentage of total number.

As may be expected, for each bioaerosol component there was a larger proportion of counts in the higher exposure bands from samples taken outside cabs. This became apparent upwards of the 100,000 to 500,000 cfu/m^3 band.

Another approach, summarised in Table 20 where samples could be taken both inside and outside cabs at the same time, is to examine the reduction in exposure afforded by being in a vehicle cab during activities at the various sites. Data calculated as follows:

$$\text{Proportion by which exposure reduced} = \frac{\text{bioaerosol value measured outside the cab}}{\text{bioaerosol value measured outside the cab}}$$

Table 20. Reduction in exposure as influenced by vehicle cabs on compost sites

SITE	Work activity	Total Bacteria	Thermophilic bacteria	Total fungi	Asp fumigatus
SITE E Visit 1	Compost loading shovel	1.65	2.19	4.12	15.42
	Waste shredding	2.31	1.17	3.85	14.23
SITE E Visit 2	Loading shredder	2.00	73.57	0.46	-
	Moving shredded waste	3.67	1.29	5.32	-
SITE B Visit 2	Waste reception	1.18	2.19	13.23	12.88
	Waste shredding	5.45	1.50	14.48	104.35
	Loading IVC clamps	7.49	0.99	1.87	0.56
	Moving composted waste	5.61	42.02	14.14	10.46
SITE C Visit 1	Compost turning	29.64	0.05	2.36	-
	Compost loading	0.72	96.75	1.31	-
	Loading screener	1.30	0.02	4.77	-
SITE C Visit 2	Screening compost	11.13	3.32	4.67	2.44
	Unloading IVC clamp	128.73	1.13	871.28	-
	Moving screened waste	7.87	0.01	2.37	0.01
SITE D Visit 1	Shredding wood	1.07	3.24	9.12	7.33
	Turning compost	419.02	601.81	46.30	213.63
SITE D Visit 2	Turning compost	11.00	13.90	106.92	-
	Shredding wood	4.12	1.68	6.15	0.70
	Turning compost	29.87	66.13	45.76	3.88
SITE D Visit 2	Moving green waste	4.52	23.40	4.53	3.41
	Moving green waste	80.78	10.67	44.88	0.99
	Turning compost	82.91	51.04	141.58	-
SITE F Visit 1	Turning compost	0.94	0.26	0.29	0.43
	Moving green waste	2.87	0.78	0.87	0.28
SITE F Visit 2	Turning compost	40.19	2.15	0.61	0.84
	Turning compost	0.12	2.54	0.60	-
Total & range		0.12 – 419.02 n = 26	0.01 – 601.81 n = 26	0.29 – 871.28 n = 26	0.01 – 213.63 n= 17
Median value		4.52	2.19	4.67	3.41

The reduction in exposure by working in a vehicle was therefore highly variable, although the median value for those samples taken was similar at about a four-fold reduction for both total bacterial and fungi.

3.2.7 Seasonal differences in bioaerosol concentrations

Repeat visits were made to three sites at different times of the year, therefore enabling a general comparison to be made between bioaerosol emissions during winter and summer. Data are summarised in Tables 21 – 24 for those sites where this comparison could be made.

Table 21. Bioaerosol measurements (cfu/m^3) of total bacteria in exposure bands comparing summer and winter data at three sites

SITE	<1000	1,000-5,000	5,000 – 10,000	10,000 – 50,000	50,000 – 100,000	100,000 – 500,000	500,000 – 1,000,000	>1,000,000	Total
SITE B Winter	15 (88.2)	0	1	0	1	0	0	0	**17**
SITE B Summer	6 (28.5)	1	3	2	2	2	1	4	**21**
SITE C Winter	9 (47.4)	2	1	5	1	0	1	0	**19**
SITE C Summer	5 (22.7)	8	2	2	0	2	1	2	**22**
SITE D Winter	11 (55.0)	5	0	2	0	1	0	1	**20**
SITE D Winter	8 (38.1)	7	2	2	1	1	0	0	**21**
SITE D Summer	5 (31.3)	3	2	2	0	2	2	0	**16**

Table 22. Bioaerosol measurements (cfu/m^3) of thermophilic actinomycetes comparing summer and winter data at three sites

SITE	<1000	1,000-5,000	5,000 – 10,000	10,000 – 50,000	50,000 – 100,000	100,000 – 500,000	500,000 – 1,000,000	>1,000,000	Total
SITE B Winter	10 (76.9)	1	0	2	0	0	0	0	**13**
SITE B Summer	2 (10.5)	4	1	6	1	3	1	1	**19**
SITE C Winter	4 (28.6)	4	2	1	1	1	1	0	**14**
SITE C Summer	6 (37.5)	2	2	3	0	2	1	0	**16**
SITE D Winter	10 (71.4)	4	0	0	0	0	0	0	**14**
SITE D Winter	5 (45.5)	2	1	2	1	0	0	0	**11**
SITE D Summer	1 (14.3)	0	2	1	1	2	0	0	**7**

Table 23. Bioaerosol measurements (cfu/m^3) of total fungi in exposure bands comparing summer and winter data at three sites

SITE	<1000	1,000-5,000	5,000 – 10,000	10,000 – 50,000	50,000 – 100,000	100,000 – 500,000	500,000 – 1,000,000	>1,000,000	Total
SITE B Winter	11 78.6)	2	0	0	1	0	0	0	**14**
SITE B Summer	0 (0)	2	7	3	2	2	0	2	**18**
SITE C Winter	5 (38.5)	2	3	2	0	1	0	0	**13**
SITE C Summer	1 (5.9)	11	2	1	0	0	1	1	**17**
SITE D Winter	10 (66.7)	3	1	0	0	1	0	0	**15**
SITE D Winter	7 (53.8)	0	1	4	1	0	0	0	**13**
SITE D Summer	0 (0)	2	4	1	1	3	0	0	**11**

Table 24. Bioaerosol measurements (cfu/m^3) of *Aspergillus fumigatus* in exposure bands comparing summer and winter data at three sites

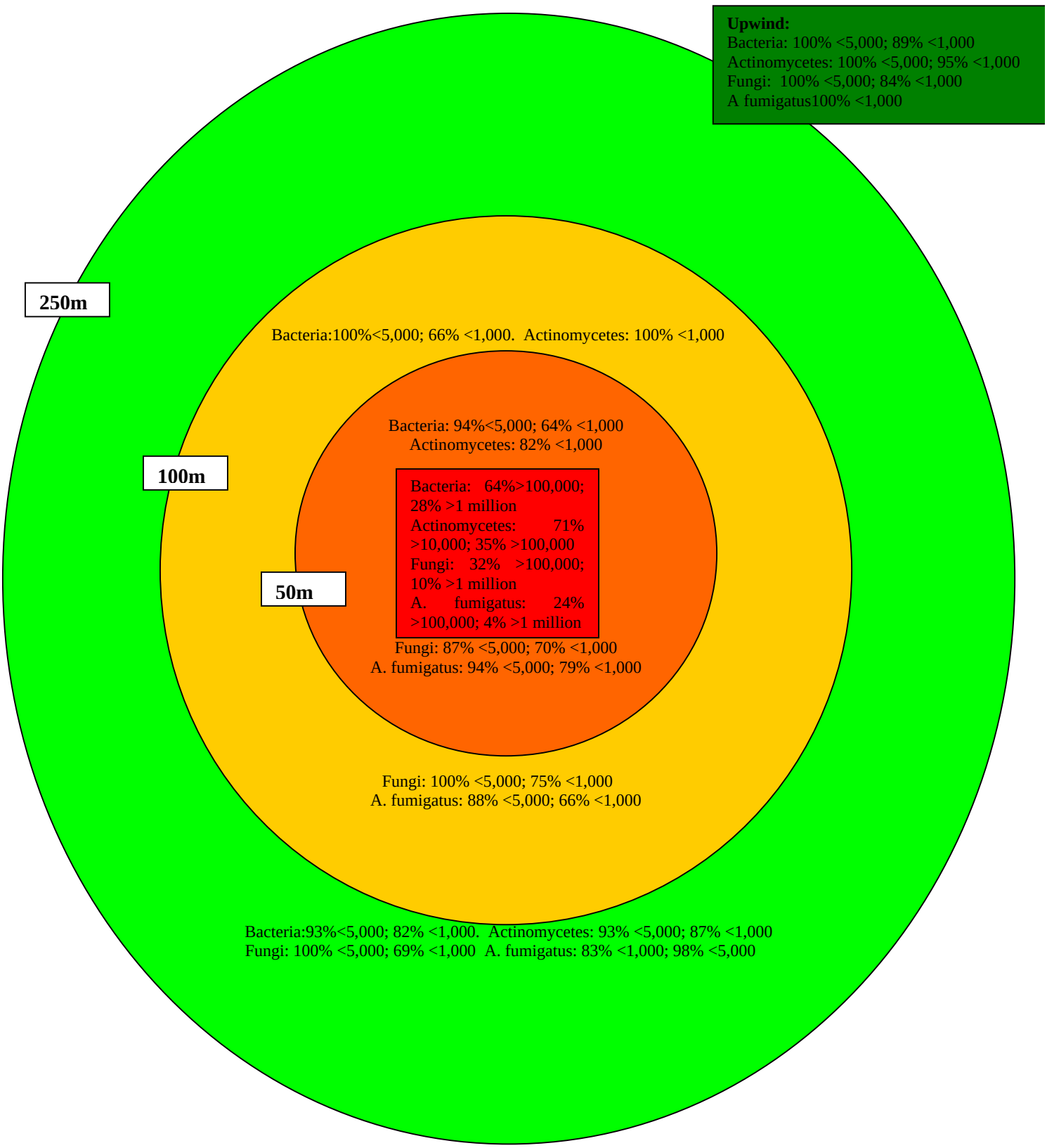
SITE	<1000	1,000-5,000	5,000 – 10,000	10,000 – 50,000	50,000 – 100,000	100,000 – 500,000	500,000 – 1,000,000	>1,000,000	Total
SITE B Winter	16 (94.1)	0	1	0	0	0	0	0	**17**
SITE B Summer	4 (17.4)	6	3	2	1	5	1	1	**23**
SITE C Winter	6 (66.7)	1	2	0	0	0	0	0	**9**
SITE C Summer	10 (62.5)	3	0	0	0	2	1	0	**16**
SITE D Winter	18 (90.0)	1	0	0	0	1	0	0	**20**
SITE D Winter	11 (78.6)	3	0	0	0	0	0	0	**14**
SITE D Summer	4 (36.4)	4	0	0	1	2	0	0	**11**

In both seasons and for the majority of bioaerosol counts the values were <1,000 cfu/m^3, but with a tendency for a greater proportion of the total number of samples at any site to be <1,000 cfu/m^3 in winter. In summer, some differences become more apparent at higher concentrations for each bioaerosol component, for example more samples were in the 100,000 – 500,000 cfu/m^3 exposure band during summer at each site.

3.3 SUMMARISED DATA FOR POTENTIAL EXPOSURE TO BIOAEROSOLS IN AND AROUND COMPOSTING FACILITIES – 'RISK ZONES'

The data in Section 3.2 has been stratified by concentration for the main bioaerosol components measured, for individual sites or by work activities.

In this Section the data have been summarised for all sites to provide an overview of the likelihood of exposure to bioaerosols and at what concentration, at different locations on a composting facility. These data, from Tables 14 to 17, are expressed as a schematic diagram of a composting site and its surrounding areas, colour coded red to green according to the likelihood of high exposure to bioaerosols, in Figure 6. It is assumed that the sites selected for inclusion in this study are representative of typical UK sites. The aim therefore is to provide a 'risk zone' model which can be used by operators to apply controls proportionate to the likelihood of workers' exposure to bioaerosol.



NEXT TO COMPOST HANDLING MACHINERY
UP TO 50 METRES FROM COMPOST HANDLING
BETWEEN 50 AND 100 METRES FROM COMPOST HANDLING
BETWEEN 100 AND 250 METRES FROM COMPOST HANDLING
UPWIND OF COMPOSTING OPERATIONS

Figure 6. Schematic diagram of composting facilities and associated bioaerosol exposure

To summarise from the above data taken from this study:

If you are working next to composting handling machinery and **not** protected within a vehicle cab:

- There is a 64% chance of being exposed to more than 100,000 cfu/m^3 bacteria and a 28% chance of being exposed to more than 1 million cfu/m^3 bacteria;
- There is a 71% chance of being exposed to more than 10,000 cfu/m^3 actinomycete spores and a 35% chance of being exposed to more than 100,000 cfu/m^3 actinomycete spores;
- There is a 32% chance of being exposed to more than 100,000 cfu/m^3 fungal spores and a 10% chance of being exposed to more than 1 million cfu/m^3 fungal spores;
- There is a 24% chance of being exposed to more than 100,000 cfu/m^3 *Aspergillus fumigatus* spores and a 4% chance of being exposed to more than 1 million cfu/m^3 *Aspergillus fumigatus* spores.

However, if you are working with composting handling machinery and **are** protected by a vehicle cab (data from Tables 14-17 in this report):

- There is a 28% chance of being exposed to more than 100,000 cfu/m^3 bacteria and a 5% chance of being exposed to more than 1 million cfu/m^3 bacteria;
- There is a 58% chance of being exposed to more than 10,000 cfu/m^3 actinomycete spores and a 14% chance of being exposed to more than 100,000 cfu/m^3 actinomycete spores;
- There is a 30% chance of being exposed to more than 10,000 cfu/m^3 fungal spores, a 6% chance of being exposed to more than 100,000 cfu/m^3 fungal spores but no samples yielded more than 1 million cfu/m^3 fungal spores;
- There is a 24% chance of being exposed to more than 10,000 cfu/m^3 *Aspergillus fumigatus* spores, a 13% chance of being exposed to more than 100,000 cfu/m^3 *Aspergillus fumigatus* spores but no samples yielded more than 1 million cfu/m^3 *Aspergillus fumigatus* spores.

If you are working further away from composting handling machinery, and up to 50 metres from composting:

- There is a 94% chance that exposure to airborne bacteria will be less than 5,000 cfu/m^3 and a 64% chance that exposure to airborne bacteria will be less than 1,000 cfu/m^3;
- There is an 82% chance that exposure to airborne actinomycete spores will be less than 1,000 cfu/m^3;
- There is an 87% chance that exposure to airborne fungal spores will be less than 5,000 cfu/m^3 and a 70% chance that exposure to airborne fungal spores will be less 1,000 cfu/m^3;
- There is a 94% chance that exposure to airborne *Aspergillus fumigatus* spores will be less than 5,000 cfu/m^3 and a 79% chance that exposure to airborne *Aspergillus fumigatus* spores will be less 1,000 cfu/m^3.

If you are working between 50 and 100 metres from composting:

- There is a 100% chance that exposure to airborne bacteria will be less than 5,000 cfu/m^3 and a 66% chance that exposure to airborne bacteria will be less than 1,000 cfu/m^3;
- There is a 100% chance that exposure to airborne actinomycete spores will be less than 5,000 cfu/m^3 and a 95% chance that exposure to airborne actinomycete spores will be less than 1,000 cfu/m^3;

- There is an 100% chance that exposure to airborne fungal spores will be less than 5,000 cfu/m^3 and a 75% chance that exposure to airborne fungal spores will be less 1,000 cfu/m^3;
- There is an 88% chance that exposure to airborne *Aspergillus fumigatus* spores will be less than 5,000 cfu/m^3 and a 66% chance that exposure to airborne *Aspergillus fumigatus* spores will be less 1,000 cfu/m^3.

If you are working between 100 and 250 metres from composting:

- There is a 93% chance that exposure to airborne bacteria will be less than 5,000 cfu/m^3 and an 82% chance that exposure to airborne bacteria will be less than 1,000 cfu/m^3;
- There is a 93% chance that exposure to airborne actinomycete spores will be less than 5,000 cfu/m^3 and an 87% chance that exposure to airborne actinomycete spores will be less than 1,000 cfu/m^3;
- There is a 100% chance that exposure to airborne fungal spores will be less than 5,000 cfu/m^3 and a 69% chance that exposure to airborne fungal spores will be less 1,000 cfu/m^3;
- There is a 98% chance that exposure to airborne *Aspergillus fumigatus* spores will be less than 5,000 cfu/m^3 and an 83% chance that exposure to airborne *Aspergillus fumigatus* spores will be less than 1,000 cfu/m^3.

By comparison, upwind of composting operations:

- There is a 100% chance that exposure to airborne bacteria will be less than 5,000 cfu/m^3 and an 89% chance that exposure to airborne bacteria will be less than 1,000 cfu/m^3;
- There is a 100% chance that exposure to airborne actinomycete spores will be less than 5,000 cfu/m^3 and a 95% chance that exposure to airborne actinomycete spores will be less than 1,000 cfu/m^3;
- There is a 100% chance that exposure to airborne fungal spores will be less than 5,000 cfu/m^3 and an 84% chance that exposure to airborne fungal spores will be less 1,000 cfu/m^3;
- There is a 100% chance that exposure to airborne *Aspergillus fumigatus* spores will be less than 1,000 cfu/m^3.

3.4 IDENTIFICATION OF PREDOMINANT MICRO-ORGANISMS

Predominant microbial species were isolated and identified. Common environmental fungi such as *Penicillium*, *Cladosporium* and *Aspergillus* species, including *A fumigatus*, and bacteria such as *Bacillus*, *Micrococcus* and *Pseudomonas* species, were predominant isolates from all sites. In addition to these, DNA was extracted from representative colonies of fungi and bacteria from each site and identified using molecular-based methods as described in Materials and Methods (Section 2.4). Bacteria and fungi identified by DNA sequence analysis to genus level (95% confidence level) or species level (97% confidence level) are summarised in Table 25, together with the site from which they were isolated. This indicates the site from which the isolate was taken, but does not infer that the isolate was unique to the site.

Table 25. Predominant micro-organisms isolated from compost sites

Bacteria	**Fungi**
Acinetobacter sp.	*Absidia corymbifera*
Arthrobacter sp.	*Basidiomycete* yeast sp.
Cellulosimicrobium cellulans	*Chaetomium globosum*
Corynebacterium callunae	*Emericella nidulans*
Geobacillus thermonitrificans	*Galactomyces geotrichum*
Kocuria rosea	*Paecilomyces sp.*
Norcardiopsis sp	*Phoma sp*
Pseudoxanthomonas sp.	*Talaromyces sp.*
Rhodococcus rhodochrous	
Serratia rubidaea	
Saccharomonospora sp	
Saccharopolyspora sp	
Staphylococcus sp.	
Streptomyces sp.	
Thermobifida fusca	

As may be expected, bacterial isolates included thermophilic actinomycetes *Saccharomonospora sp, Saccharopolyspora sp* and *Thermobifida fusca.*

3.5 COMPARISON OF BIOAEROSOL PARTICLE SIZE DATA

Using six stage Andersen impactors, bioaerosol samples are collected in six size fractions according to the aerodynamic diameter of a particle supporting colony forming bacteria or fungi. Particle size ranges collected on the six stages of the Andersen sampler are as follows:

Stage 1 and 2 = >7 micron (nasal deposition)

Stage 3 and 4 = 3 – 7 micron (tracheal and bronchial deposition)

Stage 5 and 6 = <3 micron (alveolar deposition)

Bioaerosol size fraction data from samples taken at different locations upwind and downwind of composting operations were calculated for four site visits. Tables 26 and 27 compare fungal and bacterial particle sizes respectively for all four sites.

Table 26. Size fraction distribution (% of total) of fungi deposited in Andersen samplers

Site	Sample location	Andersen Sampler Stage					
		1	2	3	4	5	6
A	50m upwind	27	7	20	47	0	0
	50m downwind	1	1	7	79	12	0.1
	100m downwind	0.1	2	8	81	7.5	0.1
B	50m upwind	8.8	0	17.6	41	32	0
	50m downwind	0	2.5	10.5	82	4	0
	120m downwind	1.7	3.5	28	61	5	0.1
C	50m upwind	30	9	13	21	9	17
	10m downwind	3	3	12	72	9	0.3
	50m downwind	6	14	78	1.4	0	0
	150m downwind	4	1.8	26	65	2	0
	250m downwind	15	18	20	45	0	0
D	50m upwind	10	50	20	0	10	10
	10m downwind	13	34	8	31	11	2
	50m downwind	35	11	20	34	0	0
	150m downwind	31	23	18	27	0	0
	250m downwind	31	27	8	30	4	0

Table 27. Size fraction distribution (% of total) of bacteria deposited in Andersen samplers

Site	Sample location	Andersen Sampler Stage					
		1	2	3	4	5	6
A	50m upwind	20	13	9	13	31	13
	50m downwind	3	10	19	49	14	13
	100m downwind	9	5	4	13	38	30
B	50m upwind	44	13	6.9	10	11	15
	50m downwind	15	7.5	8.1	21.5	29.3	18
	120m downwind	4	5	8	27	37	19
C	50m upwind	30	25	8	7	17	11
	10m downwind	7	3	5	12	61	11
	50m downwind	4	2	24	46	22	2
	150m downwind	9	4	12	56	15	4
	250m downwind	18	7	6	18	47	4
D	50m upwind	45	20	10	4	7	15
	10m downwind	30	19	21	11	12	7
	50m downwind	36	21	11	14	9	9
	150m downwind	41	24	7	8	11	9
	250m downwind	33	31	13	7	11	3

Examining overall trends for fungal size distribution and bacterial size distribution across all four sites, Tables 26 and 27 respectively showed that size distributions at Site D differed from the other three in having higher proportions of fungal and bacterial counts at larger particle size ranges.

At Site A, where compost turning was being done, fungal counts upwind showed a tendency toward larger particle size, while for both downwind measurements there was a peak at stage 4 which corresponds to individual spore size. For bacteria, counts upwind showed an even distribution. Downwind measurements showed a peak at stage 4 at 50m downwind but at stages 5 and 6 at 100m downwind, which suggested association of bacterial cells with smaller dust particles at greater distance.

At Site B, where green waste shredding was being done, fungal counts for upwind and for both downwind measurements showed a peak at stage 4. For bacteria, counts upwind peaked at stage 1 then showed an even distribution for other stages. Downwind measurements showed peaks at stages 4 and 5 both at 50m and 120m downwind but also a presence at stage 6 suggesting an association of bacterial cells with smaller dust particles.

At Site C, where compost turning was being done, fungal counts upwind showed an even size distribution, while for all downwind measurements there were large peaks at stages 3 or 4. For bacteria, counts upwind peaked at stages 1 and 2 then showed an even distribution for other stages. Downwind measurements showed a large peak at stage 5 at 10m and 250m downwind, while for 50m and 150m peak numbers were at stage 4.

At Site D, where compost turning was being done, fungal counts upwind showed a large peak at stage 2 then an even size distribution. Downwind measurements at 10m peaked at stages 2 and 4, but for other measurements downwind distribution was even across stages 1 to 4. For bacteria, both for counts upwind and downwind peak numbers were found on stage 1 then progressively fewer on stages 2 to 6, suggesting larger particles were airborne even at greater distance.

Examining overall trends for fungal size distribution and bacterial size distribution across all four sites showed that size distributions at the Site D differed from the other three in having higher proportions of fungal and bacterial counts at larger particle size ranges.

4 DISCUSSION

4.1 EVALUATION OF BIOAEROSOL SAMPLING AND ANALYSIS METHODS USED

Three bioaerosol sampling methods were employed in this study; Andersen microbial impactors, Partisol filtration samplers and IOM personal filtration samplers. Andersen samplers and Partisol samplers can be used only for fixed point sampling and were used mainly to measure bioaerosols at some distance from compost handling activities, while IOM samplers were used to measure bioaerosol concentrations in the breathing zones of workers and at fixed locations close to compost handling activities, i.e., mostly on the outside of the cabs of vehicles working with compost materials. Andersen samplers are the method of choice in current guidelines published by the Composting Association (1999). Partisol PM_{10} filtration samplers are often used in ambient air pollution monitoring and would be compatible with requirements for waste composting sites, as described in Environment Agency guidance M17 (2004). Both are specialised equipment and require some specialist knowledge for their operation, but Andersen sampling is much more labour-intensive. IOM samplers are used for routine workplace dust exposure monitoring to HSE guidelines (HSE, 2000), adapted here for bioaerosol sampling. They are simple and practical to use and are capable of obtaining data more relevant to worker health evaluation.

Where bioaerosols were taken side by side with Andersen and Partisol samplers, although difficult to make direct comparisons because of different sampling times, general observations can be made. For airborne bacteria, the number of instances where Andersen samplers yielded greater numbers (n=27) were similar to instances when Partisol samplers yielded greater (n=25). For *Aspergillus fumigatus*, there was more difference, the number of instances where Andersen samplers yielded greater numbers (n=28) being more than instances when Partisol samplers had greater yield (n=18). The margin of difference was rarely more than one order of magnitude, and given other variable parameters, either method could be considered as being justified for use in obtaining bioaerosol data. In previous studies, while Andersen samplers yielded significantly higher bioaerosol counts than filters when collecting predominantly cellular bacteria in swine houses (Predicala *et al*, 2002), agar impaction and filtration sampling methods were found to be comparable for sampling *Aspergillus fumigatus* and other thermotolerant fungi (Engelhart *et al*, 2007).

From a practical viewpoint the Andersen impactor, collecting directly onto agar plates, is prone to microbial overload and this makes the sampler difficult to use with regards to sampling times. In this study, sampling times were 10-15 minutes duration where possible, but this had to be reduced to as little as three minutes in areas of high contamination, to avoid overload of the agar plates. Even at 15 minutes duration, it was only possible to obtain a ‘snapshot’ of bioaerosol emissions for activities that could continue for a 10-hour shift. Because Partisol samplers collect onto filters, they could be run for long periods without manual intervention, especially with sequential sampling using an automatic filter changer, to give a more realistic appraisal of aerosol production over an entire shift. Filtration-based methods are less prone to overload and can sample bioaerosols closer to the point of activity, thus obtaining a nearer approximation of a source term, and IOM samplers provide worker exposure data.

Culture based analysis of compost bioaerosol samples is the main method of measurement and likely to continue to be so in the near future, although other research studies are aimed at development of molecular based detection (a current study being undertaken by NPL for Defra; see details at
http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Comple

ted=0&ProjectID=15138#Description). From a practical point of view, for routine compost bioaerosol monitoring the Composting Association guidelines advocate only total bacteria and *Aspergillus fumigatus* monitoring, although within this study it was relevant to measure a wider range of bioaerosol components, especially as culture-based analyses from filtration samples (Partisol and IOM) allowed for a wider range of isolation media to be used from a single sample. Samples taken near compost handling activities in particular yielded large numbers of thermophilic actinomycetes. As these are fundamental to the composting process, arguably they are a better marker for composting activity than general bacterial counts, which could also be derived from other dust-borne sources. In addition, their role in allergic lung disease (Van den Bogart *et al.*, 1993; Bunger *et al.*, 2007) means that they are a valid health-based marker. However, difficulties in culturing (both generating yield and overcoming competition from other bacteria) have led researchers to opt for the simpler culture of total bacteria as a surrogate, as set out in Composting Association guidance. Improved culture media based on compost extract agar (Taha *et al*, 2007) may in future provide a better option.

As well as culture-based analysis, some direct microscopic counting of fluorescent stained microbial cells was done (DEFT method). The results confirmed those from previous studies that culture-based techniques measure only a proportion of the total number of cells present, often one to two orders of magnitude less. The health consequence of respiratory exposure to compost bioaerosols is more likely to be allergy rather than infection, and could be triggered by non-culturable as well as culturable bioaerosols, therefore it may be more relevant to measure the total bioaerosol load. However, microscopic counting is labour intensive, therefore it is unlikely to be superseded in the short term. Molecular-based methods such as quantitative polymerase chain reaction (qPCR) to generic target DNA sequences, or particle counting data may be a useful surrogate if a relationship between counts and cell numbers can be derived.

Total dust levels were low compared with occupational exposure limits, reflecting the mainly outdoor activities. Similarly, endotoxin levels were low compared with other work activities where organic material is handled, such as grain or animal feed handling on farms (see Section 4.6). This was probably partly a consequence of the relatively smaller proportion of growth of Gram negative compared to Gram positive bacteria in compost. Growth conditions in composting material favour thermophilic bacteria such as Gram positive actinomycetes or heat tolerant bacteria such as Gram positive spore forming *Bacillus* species.

Bioaerosol sampling with 6-stage Andersen samplers allows for size fractionation of the collected sample. Results showed that few fungal colonies grew on agar plates from Stages 5 and 6, reflecting that fungal spores are generally greater than three microns, the cut off point for particle size for these stages. *Aspergillus fumigatus* has a smaller spore size of around two micron, so the results suggested that spores may not have been present individually. Bacterial colonies were present on plates from Stages 5 and 6, indicating that bacteria were present as individual cells or spores as well as associated with larger particles. There was some indication from bacterial counts that a larger proportion was present in smaller size fractions with greater distance from composting activity. This is as would be expected, because larger dust particles would settle out of the dust aerosol.

4.2 OBSERVATIONS ON BIOAEROSOL AND DUST EMISSION FROM COMPOSTING ACTIVITIES AT INDIVIDUAL SITES

This study has generated information on the dispersal of bioaerosols from work activities on composting sites. Turning windrows of actively composting material for aeration purposes is

most likely to produce the greatest bioaerosol emission. This activity is usually performed on a weekly basis.

The production and dispersal of the bioaerosol during turning is influenced by compost maturity, moisture levels, and energy input from the turning machinery. For example, on Site B, a custom-built turning machine was used to turn the compost (Appendix; Photograph 1). This consisted of a helical screw to cut into the side of the windrow, then the compost was fed onto a conveyor which projected the compost from a height of approximately three metres to form a new well-mixed windrow. Site C also used a customised machine for turning (Appendix; Photograph 2). This machine straddled the windrow and turned the compost using a rotary drum with flails on it. The machine moved slowly along the windrow. Unlike the method above, the compost was semi-contained underneath the machine by a plastic curtain. Although the energy input was high and potentially able to create dust, the compost gained little height to disperse the dust widely. Sites D and A used mechanical shovels to turn the windrows (Appendix; Photograph 3). This was a less energetic method, but because it involved lifting shovel loads of compost to the fully extended height of the machine (approx. 5m) and tipping the compost with a jerking action, any dust generated could be spread widely.

4.3 COMPOST SITE BIOAEROSOL EMISSION AND DISPERSION

4.3.1 Overview

During the sampling visits, there was a continuous working pressure to maintain a flow of material through the composting procedure. Because of this, it was not feasible to expect the site to perform single tasks during air sampling, which limited the opportunity to derive task-specific emission data. However, where possible downwind sampling positions were selected to minimise the effects of other activities.

It would be predicted that aerosols dispersed from compost turning and shredding would decrease in concentration with distance from the activity. This has mostly been confirmed by the results from this study. Our results suggest a major decrease in aerosol from the immediate vicinity of the activity, as measured by samplers placed on the outside of vehicle cabs, to sampling points even as short a distance away as 10m from activities, with a similarly large decline from 10m to 50m distance from activity. Although the bioaerosol concentration was reduced, the pattern of decline in numbers was less consistent from 50m to a 250m distance from compost handling activities. This may have been the result of unpredictable influences such as wind current, turbulence and/or particle size. One site in particular, Site A, is on a steep slope, so that the compost handling activity was elevated compared to the location of downwind samples on the days of bioaerosol sampling. These conditions may have allowed airborne particles, which would normally have settled out, to remain airborne for longer. Having compost activity at a height greater than the surrounding area has been shown to have a significant effect on bioaerosol dispersion, with higher than expected bioaerosol concentrations measured in surrounding areas (Herr *et al.*, 2003 and Herr, data presented at Environment Agency workshop, February 2006). This should be taken into consideration during site selection. An additional factor that could have affected bioaerosol concentrations at Site A was that compost screening activity was taking place at the facility at the same time as our bioaerosol sampling. This was unavoidable, and our assessment at the time was that this should not have interfered by contributing to the overall bioaerosol levels in the vicinity. However, the results from the first visit to this site showed high background counts compared to bioaerosol counts downwind of compost handling activity, suggesting an additional bioaerosol source.

Results obtained from many of the sites included air samples taken as close as possible to the compost handling activity by using IOM filtration samplers mounted on vehicles involved in the compost handling. Siting samplers in this location provides an estimate of the potential exposure to bioaerosols that workers would encounter if not protected by vehicle cabs or personal protection. In addition, bioaerosol emission data from sampling in this location could be used for modelling downwind dispersion, as it is a practical way to obtain bioaerosol data from as close as possible to the compost handling activities. For example, the level of total inhalable dust measured by this method in the immediate vicinity of a shovel loader at Site B visit 2 was 37.35 mg/m^3 of air compared to 8.90 mg/m^3 of air inside the cab. This level was reduced to less than 1 mg/m^3 at the 10 and 50m downwind sample points, as measured by the Partisol samplers. To some extent this is not comparing like for like, because the Partisol sampler collects PM_{10} particles compared to the IOM which collects the inhalable fraction which could include particles larger that 10 micron. However, the operation of the Partisol sampler at a higher flow rate meant there was a greater chance of collecting measurable quantities of dust, yet levels were still at the threshold of detection. A similar reduction in endotoxin concentration was also found: 262 EU/m^3 of air was measured in the immediate vicinity of compost turning, while less than 1 EU/m^3 of air was detectable at 10m downwind.

Bioaerosol concentrations measured in samples from the same site reflected the results of the dust measurements, with considerable reduction in bioaerosol concentrations downwind compared to those measured on the outside of vehicle cabs. For example, at Site B visit 2 bacterial concentrations in excess of 4 million (4.27×10^6) cfu/m^3 of air were sampled at the vehicle cab compared to 58,000 (5.8×10^4) cfu/m^3 of air sampled at 10m downwind and 6,000 cfu/m^3 at 150m downwind. Fungal concentrations were in excess of 1 million (1.04×10^6) cfu/m^3 of air at the vehicle cab, compared to 44,000 (4.4×10^4) cfu/m^3 of air sampled at 10m downwind and 6,270 cfu/m^3 at 150m downwind. Similarly, at Site D visit 2 bacterial concentrations in excess of 105,000 (1.05×10^5) cfu/m^3 of air were sampled at the vehicle cab compared to 3,080 (3.08×10^3) cfu/m^3 of air sampled at 10m downwind and 106 cfu/m^3 at 250m downwind. Fungal concentrations were in excess of 60,000 (5.00×10^4) cfu/m^3 of air outside a shredding machine, compared to 414 cfu/m^3 of air sampled at 10m downwind and 18 cfu/m^3 at 250m downwind.

From an occupational exposure viewpoint, concentrations of bacteria and fungi measured at the source of the bioaerosol emission on vehicle cabs, often in excess of 1 million cfu/m^3 of air sampled, were comparable with highly contaminated occupational settings known to be associated with allergic respiratory disease, such as the handling of grain in enclosed buildings on farms (Swan *et al.*, 2003). However, this is an area of little manual activity other than driving the machines, and in most cases the machines had cabs with filtered air, thus providing protection of workers from exposure. However, on one of the machines the cab door was missing, eliminating any protection afforded by the air filtering system, and emphasising the need for attention to control measures to reduce workers' exposure.

Placing the results into context from an environmental exposure viewpoint is less simple because of limited data on the level of chronic bioaerosol exposure that may trigger allergic response. In the absence of such data, the most common approach is to use established benchmarks to compare bioaerosol concentrations within the proximity of, and influenced by, composting operations. These include upwind background measurements, as taken in this study, where it is assumed that no other significant bioaerosol source is present. Another approach is to compare bioaerosol levels downwind of composting activities with 'typical' ambient bioaerosol levels, constantly present and to which the human population is continually exposed.

On many compost facilities, it is difficult to achieve the complete absence of other bioaerosol sources because they are sited among other operations handling organic material, such as landfill sites, and this may affect background counts. Also, the other activities associated with waste reception and handling prior to composting will add to the overall background bioaerosol burden. Within this context, the upwind bioaerosol data obtained provided a point of comparison against which to monitor the decline in bioaerosol concentrations downwind and with distance from compost bioaerosol generation.

Across the sites visited at different times of the year, airborne bacterial concentrations 50m upwind of site operations ranged from below the level of detection to 1,702 cfu/m^3 and fungi from 51 to 2,418 cfu/m^3, with the large majority of samples yielding fewer than 1,000 cfu/m^3 air of either bacteria or fungi. By comparison, 'typical' bacterial and fungal concentrations from previous studies ranged from none detected to 7,200 (7.20 x 10^3) and 42 to 1,600 (1.60 x 10^3) cfu/m^3 respectively (Jones and Cookson, 1983). Data on 'typical' ambient bioaerosol levels constantly present are also discussed in detail in Swan *et al* (2003). While most samples at the maximum downwind monitoring distance of 250m from operations yielded fewer than 1,000 cfu/m^3 of either bacteria or fungi, the largest concentration of any sample at this distance was at Site B, visit 2 in summer , when total bacterial counts were 18,501 cfu/m^3 and fungal counts were 7,647 cfu/m^3. Bacterial counts at 250m distance from composting exceeded 1,000 cfu/m^3 on only one other sampling visit, 1,710 cfu/m^3 at Site F visit 2 during winter sampling, and fungal counts also exceeded 1,000 cfu/m^3 on only one other sampling visit, 5,546 cfu/m^3 at Site D during summer sampling. This showed that on occasion it is possible for bioaerosol concentrations at site boundaries to be in excess of 'typical' background levels under certain conditions. However, the general picture was that there was little evidence that the composting operations made a major contribution to the overall bioaerosol burden by a distance of 250m from activities. Therefore there was no evidence from the samples collected that the presence of composting operations represented a significant risk to sensitive receptors at the current Environment Agency 250m guidance limit.

4.3.2 Application of bioaerosol sampling to dispersion modelling

A range of sampling devices and analysis techniques were used during the project. An aim was to examine the use of newer sampling techniques that could be used to sample for longer durations close to composting activities. The data derived showed that there can be differences between observations using different sampling approaches and that changes in concentration with distance may not always show simple reductions. Previous observations have shown the possibility of considerable variation during activities (Taha *et al*, 2006).

The durations over which exposure must be assessed will help to inform the approach to sampling. The observed variation over these durations will also need to be examined for the possible effect on exposure. Since activities, with higher emissions, only occupy part of the time both the average level and concentration variation observed during an activity (Taha *et al*, 2006) would have less influence on exposure levels if the duration of interest for exposure was greater than the length of activities. Similarly the use of conservative estimates for emissions during activities, or uncertainty in estimated source strengths, would have less influence if the duration over which exposures were examined was long compared to the duration of activities.

4.3.3 Seasonal effects

At some of the sites included in this study there was the opportunity to undertake bioaerosol sampling in contrasting seasons, i.e., autumn/winter vs. spring/summer. For most bioaerosol counts the values at these sites were <1,000 cfu/m^3, but in winter there tended to be a greater proportion of the total number of samples at any site that yielded <1,000 cfu/m^3. In summer, some differences become more apparent at higher concentration bands for each bioaerosol component. For example, more samples were in the 100,000 – 500,000 cfu/m^3 exposure band for total bacteria and total fungi during summer at each site. This is as may be expected. Fundamentally, site activities may not differ with season, although it is anticipated that more green waste will be handled in summer and that microbial activity could be greater in the unprocessed green waste in warmer weather. Cooler wetter conditions in winter may reduce bioaerosol generation, while windier conditions would aid dispersion and dilution, but lower ambient temperature, higher humidity and less ultraviolet light could improve survival of micro-organisms. Conversely, the drier conditions in summer are more likely to lead to greater dust and bioaerosol generation, and it is expected that these effects will predominate. Therefore, although it is not expected that overall exposure mitigation measures should be different between seasons, there may be the need for more frequent maintenance, e.g., replacement or cleaning of cab filters, during drier, dustier conditions.

4.4 PERSONAL AND TASK-SPECIFIC MONITORING OF EXPOSURE – WORKERS IN VEHICLE CABS

Most of the monitoring of personal exposure to bioaerosols that was done was associated with driving vehicles during compost handling. A total of 35 measurements were taken from the 14 site visits. In 28% of these samples, potential exposure to bacteria exceeded 100,000 (10^5) cfu/m^3 air sampled. In 30% of samples potential exposure to fungi exceeded 10,000 (10^4) cfu/m^3 air sampled, with 6% exceeding 10^5 cfu/m^3, and in 24% of samples potential exposure to *Aspergillus fumigatus* exceeded 10^4 cfu/m^3. Potential exposure to thermophilic actinomycetes exceeded 10^4 cfu/m^3 in 58% of samples and 10^5 cfu/m^3 in 14% of samples.

As a means of comparison, where possible, samplers were also placed on the outside of vehicle cabs. This provided a reference point for the bioaerosol concentrations to which workers could be exposed if **not** mitigated by the presence of the vehicle cab. No data were collected regarding any air conditioning or cab filters in use.

As would be expected, in most cases the workers' potential exposure was less than the bioaerosol levels measured outside cabs, often considerably less, although the proportion differed widely. Adequate protection by vehicle cabs therefore could be important in reducing exposure, but should not be relied upon without more information about the efficacy of the cab air filtration system.

Previous studies in agricultural vehicle cabs have demonstrated that, even where filters are in place and well maintained, any protective effect against bioaerosol exposure can be negated very quickly by opening a window or door (Thorpe *et al*, 1997). This emphasises the importance of having operational procedures to ensure that vehicles are moved outside of the high exposure zone before operators disembark.

4.5 COMPARISON OF BIOAEROSOL DATA FROM ALL SITES AND STRATIFICATION OF BIOAEROSOL DATA

The assumption is made that the sites in this study, and the conditions during which samples were taken, were representative of UK sites and activities. The sites were chosen in consultation with Environment Agency staff who have a good overview of the industry.

4.5.1 Exposure banding

In order to provide an accessible overview of the large number of results from this study, they have been presented in 'exposure bands'. These bands are aimed at subdividing the bioaerosol concentrations, and do not correspond to trigger levels for health effects. However, the lower band (less than 1,000 cfu/m^3 air) corresponds to typical ambient bioaerosol levels where no significant bioaerosol source is present, and the highest band (greater than 1 million cfu/m^3 air) represents typical bioaerosol levels found in highly contaminated workplace environments where respiratory immunological response has been observed in exposed workers (Swan *et al*, 2003).

This breakdown of the data showed that, as would be expected, highest bioaerosol concentrations were associated with close proximity to compost handling, with a rapid decline in bioaerosol concentrations with distance from source. It was important to collect samples at distance from compost handling to determine how far workers would need to be from the bioaerosol source before bioaerosol levels were reduced to background. As a result of the number of samples that were taken at distance from source, 52.7% of the bacterial bioaerosol samples, 48% of total fungi and 71% of *Aspergillus fumigatus* samples yielded fewer than 1,000 cfu/m^3, and around two thirds of bacterial and fungal samples and 86% of *Aspergillus fumigatus* samples yielded less than 5,000 cfu/m^3.

For individual sites, for the reasons above most samples taken yielded fewer than 1,000 cfu/m^3 air. However at most sites, some samples yielded tens of thousands of bacteria and fungi in close proximity to waste handling.

It may be anticipated that sites where in-vessel composting systems were used would generate less bioaerosol. However, the results from this study did not indicate that this was the case. Whilst the actively composting material is enclosed when in the vessel systems and does not require turning for aeration, some bioaerosol generating activities still take place, e.g., turning and screening or other handling of composted material during the maturation stages after its removal from the vessels. Consequently, samples taken at 10m distance from such activities were just as likely to yield high concentrations of airborne bacteria and fungi at an in-vessel plant as at an open windrow site. Differences in bioaerosol generation therefore were more attributable to other site characteristics, or seasonal influences. For example, comparing similar activities (screening and clamp emptying) at two in-vessel sites, samples taken 10m downwind on two occasions at one site yielded no more than 10,000 cfu/m^3 bacteria or fungi, while samples at another site yielded in excess of 50,000 cfu bacteria and 10,000 – 50,000 cfu fungi /m^3 air. This emphasises the importance of assessing bioaerosol generation and workers' potential exposure according on-site activities and tasks rather than the general mode of operation of the site.

4.5.2 Derivation and use of 'Risk Zone' data

Bioaerosol data from all sites have been summarised in Section 3.3 as a 'risk zone' model. This model, together with the calculated data, aims to provide for operators a method by which they can assess the likelihood of unprotected workers on site being exposed to large concentrations of bioaerosol. At more peripheral areas, and upwind of sites, the same treatment of the data summarises the very much reduced likelihood of exposure to large concentrations of bioaerosol.

Therefore, using the 'risk zone' model, operators can select the level of protection proportionate to the risk. For example, if a worker is required to be in the 'red' zone closest to compost handling activities, they may be working in a vehicle. In that case the cab may afford some protection but (see also above) this could be variable and additional protection such as RPE may be appropriate. Suitable RPE would also be appropriate to consider if workers were not within vehicles. It may be worth composting sites considering the establishment of other operational procedures, such as moving vehicles out of 'red' zones before opening cab doors or windows or before personnel leave cabs.

Further away from the immediate vicinity of composting activity, in the 'amber' zones, the likelihood of high exposure to bioaerosol is reduced, and there may be less need for personal protection. However, there may be a greater likelihood that workers will be outside of vehicles, e.g., undertaking manual duties, therefore not being afforded any other means of mitigation of exposure.

At the 'green' zone at the periphery of the site, the results from this study have demonstrated that the overall likelihood of exposure to bioaerosols is only a few percentage points greater than background levels measured upwind of composting activity. This is important information not only for operators undertaking on-site risk assessments for workers, but also provides useful data for assessing the overall risk to sensitive receptors beyond the site boundary.

4.6 COMPARISON OF COMPOST BIOAEROSOL EMISSIONS WITH OTHER STUDIES AND OTHER INDUSTRIES

To benchmark the data from this study it is useful to compare it with those from other published compost bioaerosol site studies and to bioaerosol emission data from other industries.

The following tables (Tables 28 to 30) are taken from a previous HSL review (Swan *et al*, 2003).

Table 28 (Table 4 in Swan *et al*, 2003). Fungal and bacterial concentrations in ambient air

Location	Airborne fungi (cfu/m^3)	Airborne bacteria (cfu/m^3)	Reference
UK suburban	273 (0-7200)	79 (42-1600)	Jones & Cookson, 1983
UK urban/industrial	1,200	500	Crook & Lacey, 1988
UK in homes	1096 (28-35,000)		Hunter & Lea, 1994
Outdoor ambient, Paris	92 (3-675)		Mouilleseaux *et al* 1994
France	2,999- 9841 max.		Chaumont *et al*, 1990
Netherlands	941		Verhoeff *et al*, 1992
Netherlands	0 - 15,643		Beaumont *et al*, 1985
Austria rural	185	327	Kock *et al* 1998
Scandinavia rural		99 (2 - 3,400)	Bovallius *et al* 1978
Scandinavia urban		850 (100 - 4,000)	Bovallius *et al* 1978
Finland	750		Nevalainen *et al*, 1994
US urban	930 (0 - >8,200)		Shelton *et al*, 2002
US rural	600	2,000	Folmsbee & Strevett, 1999
US urban	700	1,500	Folmsbee & Strevett, 1999
US rural	8,651 (80-94,000)	3,204 (160-17,600)	Hryhorczuk *et al*, 1996

Table 29 (Table 5 in Swan *et al*, 2003). Airborne bacteria and fungi cfu/m^3 and endotoxin (ng/m^3) in various workplaces - agriculture (from Crook, 1995, Eduard, 1997 and Crook and Swan, 2001)

Work activity	Bacteria	Fungi	Endotoxin (where measured)	Predominant organisms
Grain stores on farms	10^5	10^4	10^3	Fungi including *Aspergillus*
Handling mouldy hay, grain on farms	10^8	10^8		*Aspergillus fumigatus*, actinomycetes
Grain harvesting	10^7 - 10^8	10^5 - 10^7		Fungi including *Aspergillus*, Gram positive bacteria
Animal feed mills	-	10^3	10^1 -10^2	Fungi including *Aspergillus*
Cattle sheds	10^3 - 10^5	10^4 - 10^5	10^3 - 10^4	Fungi including *Aspergillus*
Horse stables	10^5	10^3 - 10^4	10^1 - 10^3	Fungi including *Aspergillus*
Pig houses	10^4 - 10^6	10^4 - 10^5	10^2 -10^4	Gram positive and negative bacteria
Poultry houses	10^5	10^3	10^2	Fungi including *Aspergillus*
Handling mushroom compost	10^7	10^5		Actinomycetes
Picking mushrooms	10^3	10^5		Fungi (*Trichoderma*)
Wood bark composting	10^4 - 10^5	10^6 - 10^7		Fungi (*Paecilomyces*)

Table 30 (Table 6 in Swan *et al*, 2003). Airborne bacteria and fungi cfu/m^3 and endotoxin (ng/m^3) in various workplaces - food processing and industry (from Crook, 1995, Eduard, 1997 and Crook and Swan, 2001)

Work activity	Bacteria	Fungi	Endotoxin (where measured)	Predominant organisms
Handling domestic waste (doorstep collection)	10^3 - 10^4	10^4 - 10^5	0-20	Gram negative bacteria, *Aspergillus*, *Penicillium*
Domestic waste transfer station	10^5	10^6		Gram negative bacteria, *Aspergillus*, *Penicillium*
Domestic waste incineration	10^7	10^7		Gram negative bacteria, *Aspergillus*, *Penicillium*
Domestic waste materials recycling	10^5	10^5	10^3	Gram negative bacteria, *Aspergillus*, *Penicillium*
Domestic waste landfill sites	10^6	10^5		Gram negative bacteria, *Aspergillus*, *Penicillium*
Citrus warehouse	-	10^5		Fungi (*Penicillium*)
Sugar beet factory	10^5	10^3		Gram negative bacteria
Potato processing	10^5	-	10^2	Gram negative bacteria
Tea factory	10^2	10^3		*Aspergillus*
Textile mills	10^5	10^5	10^1 -10^3	Gram negative bacteria
Paper mills	10^4 - 10^6	10^2	0-20	Gram negative bacteria
Fibreboard and chipboard factories	-	10^4	10^1 -10^2	*Aspergillus fumigatus*, *Penicillium*
Humidifiers in factories	10^5	-		Gram negative bacteria
Metalworking in engineering works	10^6	-	10^2	Gram negative bacteria
Industrial process water	10^3	-	10^4	Gram negative bacteria
Fermenters in biotechnology	10^2 - 10^4		10^2	Process organism (Gram negative bacteria)

The results from this study, for samples taken in close proximity to compost handling, showed 28% of samples having greater than 10^6 cfu bacteria/m^3 air and 10% of samples having greater than 10^6 cfu fungi/m^3 air. By comparison with the above, this would place potential exposure as comparable to work with domestic waste in materials recycling or at a waste transfer station, but less than exposure indoors at an incineration plant; to work with grain or with pigs or poultry on farms but less than handling mushroom compost in indoor facilities, and considerably less than working with mouldy hay or grain.

Table 31 summarises bioaerosol concentrations from previously published studies at waste composting facilities, placed roughly in order by measured concentrations. For comparison, bioaerosol measurements from this study (colour highlighted) are placed in context.

Table 31. Previously published data on bioaerosols (cfu/m^3) associated with composting

Site/activity	Bacteria	Actino-mycetes	Fungi	Aspergillus fumigatus	Reference
Green and source separated household waste – in-vessel unloading (household derived waste)	$>10^7$	$>10^4$	$>10^4$		Wheeler *et al*, 2001
Green and source separated household waste – green waste	$>10^6$	$>10^5$	$>10^5$		Wheeler *et al*, 2001
Green and source separated household waste – mixed waste	$>10^5$	$>10^5$	$>10^4$		Wheeler *et al*, 2001
Mushroom compost – mixing indoors		10^7-10^9	10^3-10^5		Crook and Lacey, 1991; van den Bogart et al 1993
Green waste composting turning windrows		10^6-10^7		10^6-10^7	Taha et al, 2006
Outside vehicle cabs – compost windrow turning	**10^5-10^6**	**10^4-10^5**	**10^5-10^6**	**10^5-10^6**	**This study**
Windrow turning		10^6			Lacey, 1997
Forced aerated windrows under cover	10^5-10^7				Albrecht et al, 2007
Green waste composting	10^5	10^5	10^5		Herr et al, 2003
Windrow and in-vessel composting source separated household waste	10^3-10^5	10^3	10^3-10^5		Tovalen et al, 1998
Household waste sorting & composting – in vessel and indoor windrows	10^5	10^3	10^4	10^4	Lavoie and Alie, 1997
Green waste shredding		$<5x10^4$			Lacey, 1997
Household waste recycling & composting	10^4-10^5		10^3		Marchand et al, 1995

Site/activity	Bacteria	Actino-mycetes	Fungi	Aspergillus fumigatus	Reference
Household waste sorting & composting – indoor windrows, outdoor maturing	10^4	10^4	10^4	10^3	Lavoie and Alie, 1997
Mushroom compost – outdoor windrows		10^3-10^5			Crook and Lacey, 1991
Mushroom compost – mixing indoors		10^5			Kleyn et al, 1981
Green waste composting	10^5			10^4	Sanchez-Monedero et al, 2005
Enclosed composting facility	10^5		10^5		Reinthaler et al, 1997
Green and household waste				10^5	Fischer et al, 1998
Green waste compost facility	10^4		10^4		Hryhorczuk et al, 1996; Curtis et al, 1999
Indoor windrows green waste	10^4		10^3		Heida et al, 1995
Outdoor composting facility	10^3 - 10^4	10^3	10^2 - 10^4		Folmsbee and Strevett, 1999
Within 50m of compost handling	**10^3 - 10^4**	**10^3**	**10^3 - 10^4**	**10^3 - 10^4**	**This study**
Windrows wood chips & sewage compost		10^4			Millner et al, 1980
Green waste composting	10^4				Fracchia et al, 2006
Screening prior to waste composting	10^4				Byeon et al, 2008
Windrows wood chips & sewage compost	10^3-10^4		10^2-10^3	10^2	Chiang et al, 2003
Green waste composting	10^3-10^4				Nikaeen et al, 2008
In-vessel, post compost sorting	10^4			10^2	Danneberg et al, 1997

Site/activity	Bacteria	Actino-mycetes	Fungi	Aspergillus fumigatus	Reference
Open composting plant		10^3			Haas *et al*, 1999
Enclosed biosolids composting				10^3	Epstein et al, 2001
Sewage sludge composting				10^3	Kothary et al, 1984
Enclosed composting plant				10^2	Schilling et al, 1999

Facilities described above were outdoors and windrow based unless otherwise described.

5 CONCLUSIONS

5.1 EXISTING KNOWLEDGE ABOUT BIOAEROSOLS FROM WASTE COMPOSTING

A previous review by HSL and the Composting Association (Swan *et al*, 2003) provided an overview of the hazards associated with bioaerosols from composting and compared the information available at that time with other industries known to be associated with allergic respiratory ill health. The review also included information on the potential use of computational dispersion modelling to estimate bioaerosol concentrations downwind of composting facilities. Gaps in knowledge were identified, which led to the following recommendations:

1. That further exposure measurement studies on composting facilities should include personal exposure measurement, coupled with work task analysis, to establish task-related exposure assessment. This should include investigation of the use of in-vessel systems, including all the associated pre- and post- in-vessel tasks, and for all compost sites include ad-hoc activities such as equipment maintenance and cleaning. More detail of workplace controls used, such as engineering controls or personal protection, should be recorded.
2. That respiratory health screening and biological monitoring (immunoassay against representative biological components of compost, as well as measurement of serological biomarkers of early response to immunotoxic agents) should be implemented at existing and especially at new compost sites to establish baseline data of workers respiratory health and immune status and to allow a longitudinal assessment to be made of worker response to bioaerosol exposure. That similar long term health monitoring of workers at neighbouring sites, or of residents near to new composting facilities may be appropriate, although the logistics and responsibilities for doing so is less clear. In either case, it would be most useful to link such health monitoring with exposure assessment.
3. That molecular based detection techniques should be applied to the measurement of compost bioaerosols, both to establish the full picture of occupational exposure to allergenic and immunotoxic bioaerosols and as a means of profiling bioaerosols dispersed from compost sites.
4. It is recommended that, if resources allow, continuous monitoring may be appropriate at selected composting sites to establish a more complete picture of bioaerosol levels, especially at the periphery of sites.
5. That further work should be performed to establish source terms for use in dispersion models. One possible approach would be to use a laboratory method, such as the ‘dustiness drum’, to estimate bioaerosol concentration and size distribution associated with mechanical handling of known quantities of compost material at different stages of composting. The measured bioaerosol concentrations would give an indication of the possible range of release concentrations.

5.2 WHAT THIS STUDY ADDS TO KNOWLEDGE ABOUT BIOAEROSOLS FROM WASTE COMPOSTING

Of the above recommendations, the work undertaken in this study has addressed points 1, 3, 4 and 5. Point 2, regarding respiratory health screening, fell outside the remit of this study but is likely to be addressed as part of a review currently being undertaken by IOM for Defra

(http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=15140#Description). Molecular based detection methods (point 3) and dustiness drum tests (part of point 5) were done in the Environment Agency funded component of this study and have been described in detail in the Environment Agency report (Crook *et al*, 2008). How this study has addressed the other points is described below.

Bioaerosols were sampled at sites representative of commercial scale waste composting in the UK. The samples taken were linked to specific activities likely to generate compost bioaerosols, such as turning and screening, and samples were collected from as close as possible to the source of emission. It was not possible to associate bioaerosol sampling with site activities such as equipment maintenance and cleaning. The dispersion of bioaerosols from compost handling activities was estimated by collecting bioaerosol samples at several points downwind increasing in distance from the emission site up to 250m. Upwind background samples were used as a benchmark.

The results of this study have provided information on the dispersal of bioaerosols from work activities on composting sites, as well as information on the potential for bioaerosol generation from compost. The sampling took place during both winter and summer periods to provide an insight into the differences in bioaerosol generation that may exist.

The results confirm that, close to the source of composting processes, large concentrations of bacteria, actinomycetes and fungi, and to a lesser extent endotoxin and dust, may be aerosolised. Bacteria and fungi frequently in excess of 100,000 (10^5) cfu/m^3 of air and sometimes in excess of 1 million (10^6) cfu/m^3 air were measured immediately adjacent to the release area (windrow turning). Although the pattern of concentrations varied at some of the sites, from the data gathered in this study it could be observed that there was a general trend of decreasing bioaerosol with distance from the source. This is most prominent at 50m distance from the source compared to the immediate area of release (samples taken outside vehicle cabs), and at 10m distance. By 50m and 100m distances downwind of the process, bioaerosol concentrations were substantially reduced by comparison to those levels measurements at source.

Bioaerosol sampling methods were compared. The Andersen sampler, which collects airborne particles directly onto agar plates, is the method most commonly used at present to collect bioaerosols on compost sites, as recommended by industry guidance. Although providing useful data, its practical use has limitations, including a short sampling time before being overloaded. Two methods that collect onto filters were tested. Although collected bioaerosol yields may differ slightly, between the methods used, the use of filter samplers provide the ability to sample for longer periods and in closer proximity to composting activities. Also, the Partisol filtration sampler method is that currently used in air pollution monitoring, collecting the PM_{10} particle size range used in human respiratory health evaluations, and therefore could provide comparable bioaerosol data. Filtration sampling may be a practical advantage and the use of such methods may warrant further investigation.

It is recommended that further work be carried out to establish simple, practical methods for bioaerosol sampling at compost sites. A report by HSL for the Environment Agency, submitted in 2007, provided a summary of recently developed methods potentially suitable for bioaerosol sampling on waste sites. Bioaerosol sampling methods for compost sites are also being investigated in a current Defra funded project, details available at

http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=15138#Description.

For ease of interpretation, the bioaerosol emission data were subdivided into exposure bands for the four main bioaerosol components for individual sites and for site activities. A ‘risk zone’

approach was also applied to the overall emission data for each of the four main bioaerosol components, to summarise the likelihood of exposure to bioaerosols at different distances from composting activities. In summary:

- Bioaerosol concentrations at 50m upwind of site operations were within a range considered to be 'typical' background levels, with the large majority (84%+) of samples yielding less than 1,000 cfu/m^3 air of bacteria, actinomycetes, fungi and *Aspergillus fumigatus*.

- Close to compost handling activities, if workers are not protected from exposure, they may be exposed to concentrations of airborne bacteria and fungi that frequently exceed 100,000 (10^5) cfu/m^3 and occasionally (28% of bacterial samples and 10% of fungal samples) exceed 1 million cfu/m^3 air sampled.

- Downwind of compost handling activities, although at some sites the bioaerosol levels at times were higher than upwind even at 100 to 250m distance, still the majority of samples yielded fewer than 1,000 cfu/m^3 air. At least 93% of bacteria and 98% of *Aspergillus fumigatus* bioaerosol concentrations were less than 5,000 cfu/m^3 air, and could be considered to be within the range of 'typical' background levels.

- There was little evidence therefore that the composting operations studied made a major contribution to the overall bioaerosol burden by a distance of 250m from activities.

Bioaerosol emissions from commercial waste composting activities will continue to be a health concern for workers on site and to near neighbours. This study has provided evidence of the potential for compost site workers to be exposed to large concentrations of bioaerosols, and some previous epidemiological studies have examined the effect of such levels of exposure to compost bioaerosols and shown the potential for allergic respiratory ill health.

The data from this study has demonstrated that compost bioaerosol emissions rapidly decline with distance from source and that at site boundaries are within what could be considered as 'typical' background levels. Only limited information exists on the effects of long term exposure to bioaerosols at or slightly above typical environmental levels, and the threshold dose that may trigger respiratory response. Continued research in this area is necessary to resolve such questions.

6 APPENDIX 1: BIOAEROSOL DATA FOR INDIVIDUAL STUDY SITES

6.1 SITE A VISIT 1:

Operation	Sampling location	Sample / Filter no.	Dust mg/m^3	Vol Air sampled m^3	EU/m^3	DEFT COUNT (per m^3 of air)	Bacteria 25^{o}C CFU/m^3	Bacteria 37^{o}C CFU/m^3	Thermo-philic bacteria 55^{o}C CFU/m^3	Fungi Malt 25^{o}C CFU/m^3	Fungi DG18 25^{o}C CFU/m^3	Asp Fumigatus 40^{o}C CFU/m^3
No operation	50m upwind	Partisol 3	0.02	0.654	<LOD	4,581,040	NR	NR	<LOD	229	152	<LOD
	50m Downwind	Partisol 2	0.14	0.65	<LOD	9,218,461	NR	NR	<LOD	76	ND	<LOD
	125m Downwind	Partisol 1	0.03	0.616	<LOD	14,590,909	NR	NR	<LOD	324	81	<LOD
Shredding green waste	50m upwind	Partisol 6	0.05	2.064	<LOD	4,354,651	NR	NR	<LOD	96	242	24
	50m Downwind	Partisol 5	0.04	2.212	<LOD	5,417,721	NR	NR	<LOD	158	113	45
	125m Downwind	Partisol 4	0.03	2.1	<LOD	9,986,666	NR	NR	<LOD	1,785	2,095	2,119
Shredding	CONTROL	Partisol	-	0	<LOD	NR	NR	NR	<LOD	<LOD	<LOD	<LOD

<LOD = below limit of detection. NR = no result - = assay not done

6.2 SITE A VISIT 2

Operation	Sampling Location	Sample / Filter no.	Dust mg/m3	Vol Air sampled m^3	EU/m3	DEFT COUNT (per m3 of air)	Bacteria 25°C CFU/m^3	Bacteria 37°C CFU/m^3	Thermo-Philic Bacteria 55°C CFU/m^3	Fungi Malt 25°C CFU/m^3	Fungi DG18 25°C CFU/m^3	Asp Fumigatus 40°C CFU/m^3
Turning	50m Upwind	Partisol 4	0.01	1.13	<LOD	7,953	88	88	-	88	176	-
	50m Downwind	Partisol 2	0.02	1.619	<LOD	27,757	1,636	4,169	494	1,636	2,100	2,069
	100m Downwind	Partisol 3	0.01	1.553	<LOD	9,645	321	1,513	354	321	1,802	2,189
No operation	50m upwind	Partisol 1	0.01	0.838	<LOD	3,575	59	238	-	59	596	-
	50m Downwind	Partisol 5	0.03	1.441	<LOD	2,079	138	69	34	138	138	69
	100m Downwind	Partisol 6	0.96	0.987	<LOD	<LOD	-	101	50	-	-	-
Driver Turning	IOM	8	-	0.602	7.44	<LOD	5,897	6,810	5,147	5,897	2,990	3,495
Driver screening	IOM	9	-	0.572	32.34	15,713	24,912	2,447	8,916	24,912	10,489	1,049
Rest room	IOM	10	-	0.586	1.14	30,675	426	682	511	426	-	-
Turning	50m upwind	Andersen 12	-	0.283	-	-	NR	293	-	-	-	4
	50m Downwind	Andersen 13	-	0.283	-	-	NR	2,406	-	-	-	4,205
	100m Downwind	Andersen 14	-	0.283	-	-	NR	2,164	-	-	-	3,734

Operation	Sampling Location	Sample / Filter no.	Dust mg/m3	Vol Air sampled m^3	EU/m3	DEFT COUNT (per m3 of air)	Bacteria 25°C CFU/m^3	Bacteria 37°C CFU/m^3	Thermo-Philic Bacteria 55°C CFU/m^3	Fungi Malt 25°C CFU/m^3	Fungi DG18 25°C CFU/m^3	Asp Fumigatus 40°C CFU/m^3
Turning	Control	Andersen 15	-	-	-	-	NR	NR	-	-	-	-
Driver Turning	IOM	1b	2.88	0.26	NR	NR	NR	NR	NR	NR	NR	3,495
Driver screening	IOM	2b	1.25	0.44	NR	NR	NR	NR	NR	NR	NR	1049
Rest room	IOM	3b	0.84	0.415	NR	NR	NR	NR	NR	NR	NR	NR
Litter picking	IOM	4b	0.78	0.18	NR	NR	NR	NR	NR	NR	NR	NR

<LOD = below limit of detection. NR = no result - = assay not done

6.3 SITE E VISIT 1

Operation	Sampling Location	Sample / Filter no.	Dust mg/m3	Vol Air sampled m^3	EU/m3	DEFT COUNT (per m3 of air)	Bacteria 25°C CFU/m^3	Bacteria 37°C CFU/m^3	Thermo-Philic Bacteria 55°C CFU/m^3	Fungi Malt 25°C CFU/m^3	Fungi DG18 25°C CFU/m^3	CFU/m^3 Malt 40°C	Aspergillus fumigatus CFU/m^3
Turning shredding windrow moving	50m Upwind	Partisol 1	0.03	4.3	0		46	207	104	138	127	-	0
	10m Downwind	Partisol 2	0.02	2.5	0.24		20	140	260	240	200	60	40
	10m Downwind total turning	Partisol 3	0.01	5.6	0		475	335	379	70	97	9	0
	50m Downwind	Partisol 4	0.02	5.6	0		317	220	88	220	132	-	0
	250m Downwind	Partisol 5	0.02	5.7	0		245	359	379	131	122	9	0
Personal	General duties outside	IOM 1	0.56	0.75	1.6		2726	2726	5053	931	1862	-	66
	Loading shovel driver	IOM 2	0.58	0.43	0		4895	583	3730	2214	1748	-	233
Static	Front of loading shovel	IOM 3	0.72	0.67	0		8084	4341	8159	9132	9057	-	3593

Operation	Sampling Location	Sample / Filter no.	Dust mg/m3	Vol Air sampled m^3	EU/m3	DEFT COUNT (per m3 of air)	Bacteria 25°C CFU/m^3	Bacteria 37°C CFU/m^3	Thermo-Philic Bacteria 55°C CFU/m^3	Fungi Malt 25°C CFU/m^3	Fungi DG18 25°C CFU/m^3	CFU/m^3 Malt 40°C	Aspergillus fumigatus CFU/m^3
Static	Driver of telehandler for shredder	IOM 4	0.77	0.72	32.3		11142	7103	10446	2159	2298	-	418
	Front of telehandler	IOM 5	2.17	0.71	40.9		25708	5028	12252	8853	8569	-	5949
	Front of turning machine	IOM 6	0.17	0.29	0		1678	2852	17785	4027	168	2685	2349
Turning shredding windrow moving	Upwind 50m	Andersen 1						226				14	12
	Downwind 10m	Andersen 2						450				28	25
	Downwind 50m	Andersen 3						497				15	10
	Downwind 250m	Andersen 4						214				42	34

6.4 SITE E VISIT 2 (MBT PLANT)

Operation	Sampling Location	Sample / Filter no.	Dust mg/m3	EU/m3	Bacteria 25°C CFU/m^3	Bacteria 37°C CFU/m^3	Thermo-Philic Bacteria 55°C CFU/m^3	CFU/m^3 Malt 25°C	Aspergillus fumigatus CFU/m^3
No operation	20m Upwind	Partisol 1	0	<LOD	130	<LOD	<LOD	423	<LOD
	10m Downwind	Partisol 2	0.03	<LOD	172	<LOD	<LOD	215	<LOD
	50m Downwind	Partisol 3	0.01	<LOD	164	<LOD	<LOD	411	<LOD
	100m Downwind	Partisol 4	0.02	<LOD	2256	<LOD	<LOD	214	<LOD
Turning	50m Upwind	Partisol 1	0	<LOD	22	<LOD	66	132	<LOD
	10m Downwind	Partisol 2	0.04	<LOD	450	200	100	<LOD	<LOD
	50m Downwind	Partisol 3	0.02	<LOD	364	27	771	133	26
	100m Downwind	Partisol 4	0.01	<LOD	95	<LOD	95	71	24
	150m downwind	Partisol 5	0	<LOD	70	27	<LOD	<LOD	<LOD
Screening	50m Upwind	Partisol 1	0.07	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
	50m Downwind	Partisol 2	0	<LOD	100	<LOD	<LOD	50	<LOD
	100m Downwind	Partisol 3	0	<LOD	850	<LOD	243	182	<LOD
	150m Downwind	Partisol 4	0	<LOD	185	<LOD	<LOD	62	<LOD
	200m Downwind	Partisol 5	0.01	<LOD	633	<LOD	281	141	<LOD
Personal	Telehandler loading shredder	IOM 1	3.03	<LOD	73181	19120	49069	761	254
Static	outside shredder	IOM 2	0.60	<LOD	3667	3333	667	1667	<LOD
Personal	driver moving shredded to windrow	IOM 3	0.24	<LOD	3498	1792	7509	427	85
Static	Front of shovel of above	IOM 4	0.67	<LOD	12845	7845	9655	2241	<LOD
Static	Front of turner	IOM 6	<LOD	<LOD	7278	4905	6962	475	<LOD
No operation	20m Upwind	Andersen				ND			<LOD

Operation	Sampling Location	Sample / Filter no.	Dust mg/m3	EU/m3	Bacteria 25°C CFU/m^3	Bacteria 37°C CFU/m^3	Thermo-Philic Bacteria 55°C CFU/m^3	CFU/m^3 Malt 25°C	Aspergillus fumigatus CFU/m^3
No operation	10m Downwind	Andersen				ND			<LOD
	50m Downwind	Andersen				ND			<LOD
	100m Downwind	Andersen				ND			<LOD
Turning	50m Upwind	Andersen				205			<LOD
	10m Downwind	Andersen				2491			<LOD
	50m Downwind	Andersen				3942			<LOD
	100m Downwind	Andersen				331			40
	150m downwind	Andersen				256			249
Screening	50m Upwind	Andersen				<LOD			<LOD
	50m Downwind	Andersen				<LOD			<LOD
	100m Downwind	Andersen				<LOD			<LOD
	150m Downwind	Andersen				<LOD			<LOD
	200m Downwind	Andersen				<LOD			<LOD

6.5 SITE B VISIT 1

Operation	Sampling Location	Sample / Filter no.	Dust mg/m3	Vol Air sampled m^3	EU/m3	DEFT COUNT (per m3 of air)	Bacteria 25°C CFU/m^3	Bacteria 37°C CFU/m^3	Thermo-Philic Bacteria 55°C CFU/m^3	Fungi Malt 25°C CFU/m^3	Fungi DG18 25°C CFU/m^3	Asp Fumigatus 40°C CFU/m^3
Turning	50m Upwind	Partisol 1	0.03	2.67	0.57	5,610	<LOD	<LOD	18	93	74	<LOD
	50m Downwind	Partisol 2	0.06	2.17	1.06	5,522	69	92	276	230	276	<LOD
	120m Downwind	Partisol 3	0.04	1.58	1.81	15,169	158	31	189	348	348	<LOD
No operation	50m Upwind	Partisol 4	<LOD	0.65	2.83	138,276	<LOD	76	<LOD	76	76	<LOD
	120m Downwind	Partisol 5	<LOD	0.713	0.98	16,807	<LOD	<LOD	<LOD	<LOD	70	<LOD
	50m Downwind	Partisol 6	<LOD	0.601	1.16	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Shredding	50m Upwind	Partisol 7	0.03	3.274	0.24	9,150	45	30	15	15	91	<LOD
	50m Downwind	Partisol 8	0.06	2.253	0.35	-	44	22	22	466	355	167
	120m Downwind	Partisol 9	0.03	1.924	0.25	23,357	<LOD	77	25	155	467	<LOD
	Control	Partisol 10	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
	IOM	11	<LOD	0.556	35.61	96,992	1,528	6,294	2,967	2,607	4,946	<LOD
	IOM	12	<LOD	0.552	460.14	16,8253	543	<LOD	13,586	52,536	43,478	5,625
	IOM	13	<LOD	0.58	125.00	299,600	517	51,724	13,793	1,551	1,206	345
	Control	14	<LOD	-	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Shredding	120m Downwind	Andersen 15	-	0.43	-	-	-	100	-	-	-	644
	50m Downwind	Andersen 16	-	0.43	-	-	-	121	-	-	-	21
	50m Upwind	Andersen 17	-	0.43	-	-	-	23	-	-	-	6

Operation	Sampling Location	Sample / Filter no.	Dust mg/m3	Vol Air sampled m^3	EU/m3	DEFT COUNT (per m3 of air)	Bacteria 25°C CFU/m^3	Bacteria 37°C CFU/m^3	Thermo-Philic Bacteria 55°C CFU/m^3	Fungi Malt 25°C CFU/m^3	Fungi DG18 25°C CFU/m^3	Asp Fumigatus 40°C CFU/m^3
Shredding	Control	Andersen 18	-	0.43	-	-	-	<LOD	-	-	-	<LOD

6.6 SITE B VISIT 2

Operation	Sampling Location	Sample / Filter no.	Dust mg/m3	EU/m3	Bacteria 25°C CFU/m^3	Bacteria 37°C CFU/m^3	Thermo-Philic Bacteria 55°C CFU/m^3	CFU/m^3 Malt 25°C	Aspergillus fumigatus CFU/m^3
Shredding/screen and clamp empty	50m upwind	Partisol	0.03	0.2	772	193	19	1815	135
	10m shred downwind	Partisol	0.17	10.2	20432	58843	25499	44132	29421
	10m clamp 50m shred downwind	Partisol	0.07	2.2	12658	11076	12658	9638	8055
	150m shred 140m clamp downwind	Partisol	0.03	0.7	2064	6008	2730	6270	222048
	250m shred 240m clamp downwind	Partisol	0.02	1.7	8012	7465	3241	7647	2058
Not shredding and screen	50m upwind	Partisol	0.03	2.3	770	86	ND	2481	128
	10m downwind	Partisol	0.04	0.9	5890	3009	4481	5826	1024
	50m downwind	Partisol	0.06	2.0	163265	696279	5702	36615	43818
	150m downwind	Partisol	0.03	0.8	21658	53342	54627	9062	5463
	250m downwind	Partisol	0.01	3.5	10544	18501	12798	7361	1326
Shredding/screen and clamp empty	50m upwind	Andersen				100			15
	10m shred downwind	Andersen				121			8940
	10m clamp 50m shred downwind	Andersen				23			2147
	150m shred 140m clamp downwind	Andersen				2587			4841
	250m shred 240m clamp downwind	Andersen				787			328
Driver of mechanical shovel household waste reception	personal	IOM	8.9	1693	501859	3624535	286245	78996	111524

Operation	Sampling Location	Sample / Filter no.	Dust mg/m3	EU/m3	Bacteria 25°C CFU/m^3	Bacteria 37°C CFU/m^3	Thermo-Philic Bacteria 55°C CFU/m^3	CFU/m^3 Malt 25°C	Aspergillus fumigatus CFU/m^3
Outside cab of above	static	IOM	37.35	6641	4272388	3171642	626866	1044776	1436567
Driver of Tele-handler mechanical shovel, green waste shredding	Personal	IOM	1.93	126	729572	153696	149805	7977	4086
Outside cab of above	static	IOM	11.43	1321	3972868	474806	224806	115504	426357
Driver of mechanical shovel, loading clamps	personal	IOM	0.82	26	32227	11035	24609	36133	224161
Outside cab of above	static	IOM	1.74	55	10714	241313	24324	67568	125483
Driver of mechanical shovel, loading 2nd barrier to first	personal	IOM	0.68	115	117350	498008	27888	103586	59761
Outside cab of above	static	IOM	5.80	605	2792969	113281	1171875	1464844	625000

6.7 SITE C VISIT 1

Operation	Sampling location	Sample / Filter no.	Dust mg/m^3	Vol Air sampled m^3	EU/m^3	DEFT COUNT (per m^3 of air)	Bacteria 25^{o}C CFU/m^3	Bacteria 37^{o}C CFU/m^3	Thermo-philic bacteria 55^{o}C CFU/m^3	Fungi Malt 25^{o}C CFU/m^3	Fungi DG18 25^{o}C CFU/m^3	Asp Fumigatus 40^{o}C CFU/m^3
Static	Front of turning machine	IOM 1	25.66	0.346	262.4	139,669,017	420,520	591,040	3,757	13,872	15,173	-
	Front of loader	IOM 2	0.44	0.272	31.6	5,617,500	24,816	11,029	625,000	9,191	9,191	-
	Background Kitchen	IOM 3	0.38	0.26	<LOD	4,263,538	576	1,153	1,346	-	-	-
	Front of grabber loading screener	IOM 4	2.06	0.398	26.38	8,355,678	25,502	25,125	1,884	13,316	14,321	-
Personal	Grabber driver	IOM 5	0.47	0.45	3.33	3,861,511	12,666	19,555	114,444	2,777	3,000	-
	on turning machine	IOM 6	0.58	0.326	3.68	7,811,656	17,024	19,938	70,552	6,441	5,368	-
	shredder loader	IOM 7	1.18	0.178	<LOD	8,752,359	2,640	34,550	6,460	7,022	5,617	-
	tidying inside shredder bay	IOM 8	0.74	0.46	15.65	8,076,173	28,478	65,217	9,565	73,913	126,086	-
Control		IOM 9	-	-	<LOD	<LOD	<LOD	-	-	-	-	-
Turning	50m Upwind	Partisol 1	0.09	1.072	<LOD	111,791	NR	-	-	-	-	-
	10m Downwind	Partisol 2	0.13	1.1	<LOD	3,322,836	3,318	7,409	11,818	1,681	1,272	9,545

Operation	Sampling location	Sample / Filter no.	Dust mg/m^3	Vol Air sampled m^3	EU/m^3	DEFT COUNT (per m^3 of air)	Bacteria 25^{o}C CFU/m^3	Bacteria 37^{o}C CFU/m^3	Thermo-philic bacteria 55^{o}C CFU/m^3	Fungi Malt 25^{o}C CFU/m^3	Fungi DG18 25^{o}C CFU/m^3	Asp Fumigatus 40^{o}C CFU/m^3
	50m Downwind	Partisol 3	0.04	2.305	<LOD	935,843	780	1,757	1,648	216	954	542
Turning	150m Downwind	Partisol 4	0.01	2.741	<LOD	1,781,641	91	182	36	164	164	55
	250m Upwind	Partisol 5	0.02	2.686	<LOD	256,545	465	819	130	204	74	56
No operation	250m Upwind	Partisol 6	0.03	0.649	<LOD	415,469	-	385	154	231	308	-
	150m Downwind	Partisol 7	0.08	0.783	<LOD	880,051	-	446	63	-	-	-
	Nil	Partisol 8	-	-	<LOD	-	-	-	-	-	-	-
	10m Downwind	Partisol 9	0.02	2.34	<LOD	-	-	-	-	-	21	-
	50m Upwind	Partisol 10	0.07	1.09	<LOD	879,559	-	-	-	-	-	-
Turning	Control	Partisol 11	-	0	<LOD	<LOD	-	-	-	-	-	-
	50m Upwind	Andersen 4	-	0.425	-	-	-	91	-	-	-	19
	10m Downwind	Andersen 5	-	0.085	-	-	-	305	-	-	-	3,942
	50m Downwind	Andersen 6	-	0.142	-	-	-	859	-	-	-	8,951
	150m Downwind	Andersen 7	-	0.283	-	-	-	254	-	-	-	739
	250m Downwind	Andersen 8	-	0.283	-	-	-	298	-	-	-	250
	Control	Andersen	-	-	-	-	-	-	-	-	-	-

6.8 SITE-C VISIT 2

Operation	Sampling Location	Sample / Filter no.	Dust mg/m3	Vol Air sampled m^3	EU/m3	DEFT COUNT (per m3 of air)	Bacteria 25°C CFU/m^3	Bacteria 37°C CFU/m^3	Thermo-Philic Bacteria 55°C CFU/m^3	Fungi Malt 25°C CFU/m^3	Fungi DG18 25°C CFU/m^3	CFU/ m^3 Malt 40°C	Aspergillus fumigatus CFU/m^3
Screening + clamp empty	50m Upwind	Partisol 1	0.02	3.1	0.4	966	161	177	48	758	565		16
	10m Downwind	Partisol 2	0.03	3.1	0.3	15354	785	1923	2244	1875	1603		641
	50m Downwind	Partisol 3	0.05	3.1	0.4	977	1354	2430	5447	1566	1663		<LOD
	150m Downwind	Partisol 5	0.04	2.5	0	-	180	100	20	659	1119		<LOD
Not working	50m Upwind	Partisol 6	0.15	0.6	0	-	1000	583	250	833	1083		<LOD
	10m Downwind	Partisol 7	0.15	0.6	0	20556	600	858	686	1887	1630		<LOD
	50m Downwind	Partisol 9	0.22	0.4	0	-	1589	2567	-	1589	1589		<LOD
	150m Downwind	Partisol 10	0.24	0.4	0	-	2561	854	366	1341	1341		<LOD
Personal	Screening compost from windrow	IOM 1	1.06	0.4	14.9	380444	108466	138889	113757	3175	1190		264
Static	outside above cab	IOM 2	8.27	0.4	1144.3	-	1546391	1159794	377577	14820	13660		644

Operation	Sampling Location	Sample / Filter no.	Dust mg/m3	Vol Air sampled m^3	EU/m3	DEFT COUNT (per m3 of air)	Bacteria 25°C CFU/m^3	Bacteria 37°C CFU/m^3	Thermo-Philic Bacteria 55°C CFU/m^3	Fungi Malt 25°C CFU/m^3	Fungi DG18 25°C CFU/m^3	CFU/ m^3 Malt 40°C	Aspergillus fumigatus CFU/m^3
Personal	Unloading 2nd barrier to windrow	IOM 3	0.46	0.4	1.5	191496	7474	18041	22165	1418	1675		1030
Static	Outside above cab	IOM 4	10.76	0.4	576.1	91249	1408629	2322335	25000	11294	1459390		<LOD
Personal	Transport screened waste to landfill	IOM 5	1.26	0.4	23.1	447047	61518	119110	745000	3403	2618		497382
Static	Outside above cab	IOM 6	7.89	0.4	237.7	46813	937500	507813	4000	6771	8073		1041
Static Control	In kitchen	IOM 7	0.52	0.4	0	107000	5769	3434	5450	6044	3709		4532
static	Household bay not working		0.77	0.4	12.5	-	17751	7544	16124	71006	517751		295858
Screening + clamp empty	Upwind 50m	Andersen 1		0.2				715					<LOD
	Downwind 10m	Andersen 2		0.14				4755					7
	Downwind 50m	Andersen 4		0.06				4456					219
Screening + clamp empty	Downwind 150m	Andersen 5		0.06				8175					35

6.9 SITE D VISIT 1

Operation	Sampling location	Sample / Filter no.	Dust mg/m^3	Endotoxin EU/m^3	Bacteria 25^oC CFU/m^3	Bacteria 37^oC CFU/m^3	Thermophilic bacteria 55^oC CFU/m^3	Mesophilic Fungi 25^oC	A.fumigatus 40^oC
Turning	50m upwind	Partisol	<LOD	<LOD	105	553	316	158	<LOD
	10m downwind	Partisol	0.04	<LOD	315	1638	252	2079	693
	50m downwind	Partisol	0.02	<LOD	<LOD	122	<LOD	153	<LOD
	150m downwind	Partisol	<LOD	<LOD	<LOD	57	<LOD	57	<LOD
	250m downwind	Partisol	0.02	<LOD	<LOD	16	17	17	<LOD
Nil	50m upwind	Partisol	<LOD	<LOD	122	4791	491	246	<LOD
	10m downwind	Partisol	<LOD	<LOD	630	789	<LOD	315	<LOD
	50m downwind	Partisol	<LOD	<LOD	<LOD	138	<LOD	69	<LOD
	150m downwind	Partisol	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
	250m downwind	Partisol	<LOD	<LOD	195	<LOD	<LOD	<LOD	<LOD
Turning	50m upwind	Andersen				479			28
	10m downwind	Andersen				1394			164
	50m downwind	Andersen				1091			17
	150m downwind	Andersen				314			7

Operation	Sampling location	Sample / Filter no.	Dust mg/m^3	Endotoxin EU/m^3	Bacteria 25^oC CFU/m^3	Bacteria 37^oC CFU/m^3	Thermophilic bacteria 55^oC CFU/m^3	Mesophilic Fungi 25^oC	A.fumigatus 40^oC
Turning	250m downwind	Andersen				348			7
Driver turning	Personal	IOM	3.18	15	$1.78x10^5$	$1.76x10^5$	$4.38x10^3$	$1.74x10^3$	201
Driver on 360 shredding wood	Personal	IOM	1.30	68	$3.84x10^4$	$1.58x10^4$	$1.15x10^3$	943	202
Static on above	Static	IOM	0.65	NT	$3.15x10^4$	$4.10x10^4$	$3.70x10^3$	$8.60x10^3$	$1.48x10^3$
Driver turning and mixing	Personal	IOM	0.43	<LOD	$3.89x10^3$	$3.67x10^3$	$2.21x10^3$	$2.70x10^3$	762
Static on above	Static	IOM	19.22	426	$1.63x10^6$	$7.49x10^5$	$1.33x10^6$	$1.25x10^5$	$1.63x10^5$

6.10 SITE D VISIT 2

Operation	Sampling location	Sample / Filter no.	Dust mg/m^3	Vol Air sampled m^3	EU/m^3	DEFT COUNT (per m^3 of air)	Bacteria 25^{o}C CFU/m^3	Bacteria 37^{o}C CFU/m^3	Thermo-philic bacteria 55^{o}C CFU/m^3	Fungi Malt 25^{o}C CFU/m^3	Fungi DG18 25^{o}C CFU/m^3	Asp Fumigatus 40^{o}C CFU/m^3
Turning	50m Upwind	Partisol 1	0.0	4.554	<LOD	-	176	165	110	44	66	11
Turning	10m Downwind	Partisol 2	0.2	5.194	4.9	-	289	3,080	1,155	298	414	67
Turning	50m Downwind	Partisol 3	0.2	5.672	0.8	-	599	326	785	53	88	18
Turning	150m Downwind	Partisol 4	0.1	5.7	0.5	-	816	395	368	70	123	-
Turning	250m Downwind	Partisol 5	0.0	5.668	0.2	-	203	106	26	18	18	-
Personal	driver turning	IOM 1	1.4	0.54	2.4	-	9,630	4,444	3,611	56	93	-
Static	outside above cab	IOM 2	6.7	0.538	53.2	-	105,948	100,372	50,186	9,944	9,758	186
Personal	driver 360 shredding wood	IOM 3	2.3	0.522	<LOD	-	7,759	6,897	6,130	1,916	10,249	2,490
Static	360 shredding	IOM 4	11.1	0.516	34.3	-	31,977	27,132	10,271	7,849	62,984	1,744
Personal	driver turning and mixing	IOM 5	0.6	0.526	<LOD	-	1,141	2,376	570	475	951	570
Static	turning shovel	IOM 6	16.2	0.52	153.6	-	70,962	35,000	37,692	28,654	43,654	2,212
Control		IOM 7	-		-	-	-	-	-	-	-	-
Turning	Upwind 50m	Andersen 1	-	0.425	-	-	-	452	-	-	-	2
Turning	Downwind 10	Andersen 2	-	0.085	-	-	-	12,638	-	-	-	577
Turning	Downwind 50	Andersen 3	-	0.142	-	-	-	2,198	-	-	-	57
Turning	Downwind 150	Andersen 4	-	0.283	-	-	-	636	-	-	-	15
Turning	Downwind 250	Andersen 5	-	0.283	-	-	-	148	-	-	-	18
	control	Andersen 6	-	-	-	-	-	<LOD	-	-	-	<LOD

6.11 SITE D VISIT 3

Operation	Sampling Location	Sample / Filter no.	Dust mg/m3	Vol Air sampled m^3	EU/m3	DEFT COUNT (per m3 of air)	Bacteria 25°C CFU/m^3	Bacteria 37°C CFU/m^3	Thermo-Philic Bacteria 55°C CFU/m^3	Fungi Malt 25°C CFU/m^3	Fungi DG18 25°C CFU/m^3	CFU/m^3 Malt 40°C	Aspergillus fumigatus CFU/m^3
Turning	50m Upwind	Partisol 1	0.1	4.26	0.4	419159	1702	1526	610	2418	1373	47	12
	10m Downwind	Partisol 2	0.5		4.6	105541	17045	12500		21591	4886	534	5000
	50m Downwind	Partisol 3	0.5		10.3	45869	2399	4338		6634	8676	5103	4593
	150m Downwind	Partisol 4	0.3		3.0	12692	767	807		5043	5649	293	232
	250m Downwind	Partisol 5	0.1		1.8	2332	486	321		5546	3503	58	58
Personal	driver greenwaste grabber	IOM	0.5		9.6	37217	15839	127329	14286	44255	52795	6755	62888
Static	outside above cab	IOM	6.5		521.4	22975	167945	575153	334356	19172	237730	2530674	214723
Personal	Driver mechanical shovel, green waste	IOM	0.6		23.2	72019	6330	8253	8333	3606	5128	6490	1522
Static	Outside above cab	IOM	15.5		34.9	28533	666667	587302	88889	206349	230159	1508	1508
Personal	driver digger turning compost	IOM	0.3		3.3	10156	5763	5678	6102	1271	2712	1610	<LOD

Operation	Sampling Location	Sample / Filter no.	Dust mg/m3	Vol Air sampled m^3	EU/m3	DEFT COUNT (per m3 of air)	Bacteria 25°C CFU/m^3	Bacteria 37°C CFU/m^3	Thermo-Philic Bacteria 55°C CFU/m^3	Fungi Malt 25°C CFU/m^3	Fungi DG18 25°C CFU/m^3	CFU/m^3 Malt 40°C	Aspergillus fumigatus CFU/m^3
Static	Outside above cab	IOM	5.0		22.0	nr	477816	426621	311433	383959	255973	281570	254237
Control		IOM 7											
Turning	Upwind 50m	Andersen 1					452						
	Downwind 10	Andersen 2					12638						
	Downwind 50	Andersen 3					2198						
	Downwind 150	Andersen 4					636						
	Downwind 250	Andersen 5					148						
	control	Andersen 6											

6.12 SITE F VISIT 1

Operation	Sampling location	Sample / Filter no.	Dust mg/m^3	Endotoxin EU/m^3	Bacteria 25^{o}C CFU/m^3	Bacteria 37^{o}C CFU/m^3	Thermophilic bacteria 55^{o}C CFU/m^3	Mesophilic Fungi 25^{o}C	A.fumigatus 40^{o}C
Turning and shredding	50m upwind	Partisol	0.03	<LOD	41	27	162	378	95
	10m downwind	Partisol	0.11	2.1	99778	74279	18293	144124	199557
	50m downwind	Partisol	0.07	<LOD	233	567	<LOD	1933	4100
	120m downwind	Partisol	0.06	<LOD	45	67	<LOD	580	4512
	250m downwind	Partisol	0.02	<LOD	22	<LOD	<LOD	302	1118
No operation	50m upwind	Partisol	0.03	<LOD	1866	466	187	466	373
	10 downwind	Partisol	<LOD	<LOD	<LOD	117	<LOD	233	117
	50m downwind	Partisol	0.02	<LOD	<LOD	<LOD	<LOD	700	<LOD

Operation	Sampling location	Sample / Filter no.	Dust mg/m^3	Endotoxin EU/m^3	Bacteria 25^{o}C CFU/m^3	Bacteria 37^{o}C CFU/m^3	Thermophilic bacteria 55^{o}C CFU/m^3	Mesophilic Fungi 25^{o}C	A.fumigatus 40^{o}C
No operation	120m downwind	Partisol	<LOD	<LOD	198	198	<LOD	198	<LOD
	250m downwind	Partisol	0.1	<LOD	130	<LOD	<LOD	<LOD	<LOD
Turning and shredding	50m upwind	Andersen				<LOD			27
	10m downwind	Andersen				<LOD			4250
	50m downwind	Andersen				<LOD			5
	120m downwind	Andersen				<LOD			<LOD
	250m downwind	Andersen				<LOD			<LOD
No operation	50m upwind	Andersen				<LOD			
Driver turning	Personal	IOM	1.49	<LOD	37190	52342	39945	11157	1722
Outside of mechanical shovel whilst turning	Static	IOM	1.09	0.9	28533	50272	10394	3193	747
Driver of shovel loading shredder	Personal	IOM	1.75	8.5	98611	56250	55556	375000	465278

Operation	Sampling location	Sample / Filter no.	Dust mg/m^3	Endotoxin EU/m^3	Bacteria 25^{o}C CFU/m^3	Bacteria 37^{o}C CFU/m^3	Thermophilic bacteria 55^{o}C CFU/m^3	Mesophilic Fungi 25^{o}C	A.fumigatus 40^{o}C
Outside of mechanical shovel whilst shredding	Static	IOM	0.94	10.3	269337	283149	43508	324586	131215

6.13 SITE F VISIT 2

Operation	Sampling Location	Sample / Filter no.	Dust mg/m3	EU/m3	Bacteria 25°C CFU/m^3	Bacteria 37°C CFU/m^3	Thermo-Philic Bacteria 55°C CFU/m^3	CFU/m^3 Malt 25°C	Aspergillus fumigatus CFU/m^3
Turning	10m upwind	Partisol	0.02	<LOD	357	<LOD	<LOD	51	<LOD
	10m downwind	Partisol	0.11	<LOD	$4.31x10^3$	$5.43x10^3$	$5.46x10^3$	117	29
	50m downwind	Partisol	0.08	<LOD	$1.94x10^3$	$5.28x10^3$	<LOD	278	<LOD
	120m downwind	Partisol	0.02	<LOD	213	568	142	35	<LOD
	250m downwind	Partisol	0.03	<LOD	211	$1.71x10^3$	184	53	<LOD
No operation	10m upwind	Partisol	0.02	<LOD	<LOD	<LOD	<LOD	40	<LOD
	10 downwind	Partisol	0.04	<LOD	<LOD	<LOD	40	40	40
	50m downwind	Partisol	0.02	<LOD	640	<LOD	116	116	<LOD
	120m downwind	Partisol	0	<LOD	106	35	<LOD	71	<LOD
	250m downwind	Partisol	0.05	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
Turning	10m upwind	Andersen				<LOD			2
	10m downwind	Andersen				<LOD			18
	50m downwind	Andersen				<LOD			<LOD
	120m downwind	Andersen				<LOD			7
	250m downwind	Andersen				<LOD			4
Driver turning	Personal	IOM	1.1	<LOD	$1.42x10^5$	$2.15x10^5$	$6.65x10^4$	$1.58x10^3$	$3.16x10^4$
Outside of mechanical shovel whilst turning	Static	IOM	23.4	<LOD	$4.73x10^6$	$8.64x10^6$	$1.43x10^5$	971	$2.67x10^4$
Driver of shovel tidying around windrows	Personal	IOM	0.8	3.9	$7.89x10^4$	$1.93x10^5$	$2.61x10^4$	$1.34x10^4$	<LOD

Operation	Sampling Location	Sample / Filter no.	Dust mg/m3	EU/m3	Bacteria 25°C CFU/m^3	Bacteria 37°C CFU/m^3	Thermo-Philic Bacteria 55°C CFU/m^3	CFU/m^3 Malt 25°C	Aspergillus fumigatus CFU/m^3
On the ledge at the back of the turning space	Static	IOM	6.4	26.2	$1.18x10^6$	$3.04x10^6$	$6.46x10^4$	$9.81x10^3$	<LOD
Driver turning (short)	Personal	IOM	<LOD	<LOD	$1.00x10^5$	$1.94x10^6$	$6.46x10^4$	$6.25x10^3$	<LOD
Front on turner	Static	IOM	<LOD	<LOD	$8.38x10^4$	$2.31x10^5$	$1.64x10^5$	3750	<LOD

7 APPENDIX 2: PHOTOGRAPHS OF SITE EQUIPMENT

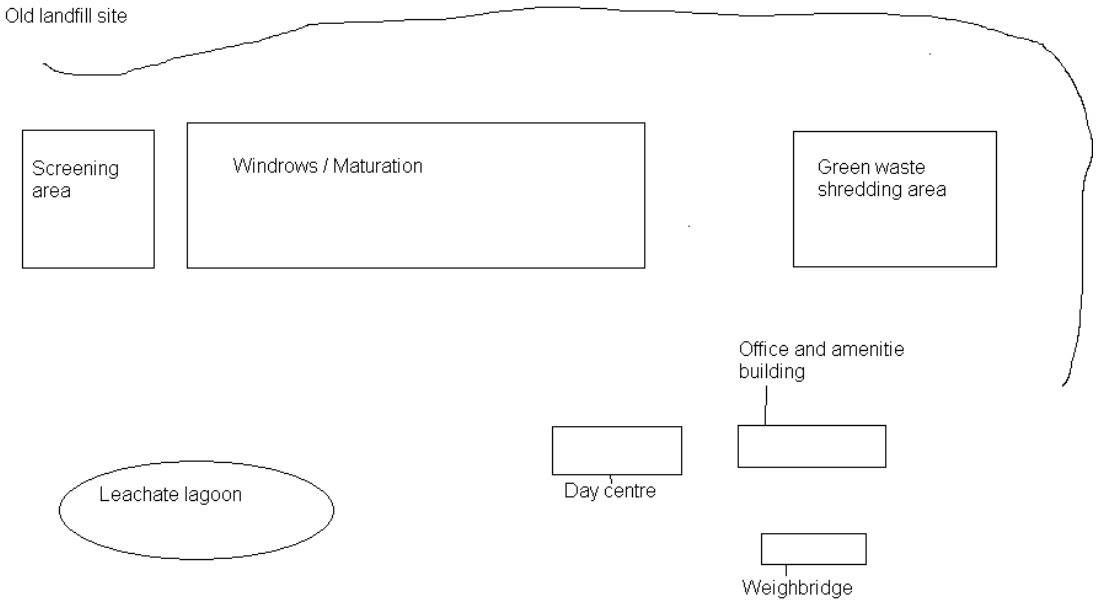
7.1 PHOTOGRAPH 1. TURNING MACHINE AT SITE B

7.2 PHOTOGRAPH 2. TURNING MACHINE AT SITE C

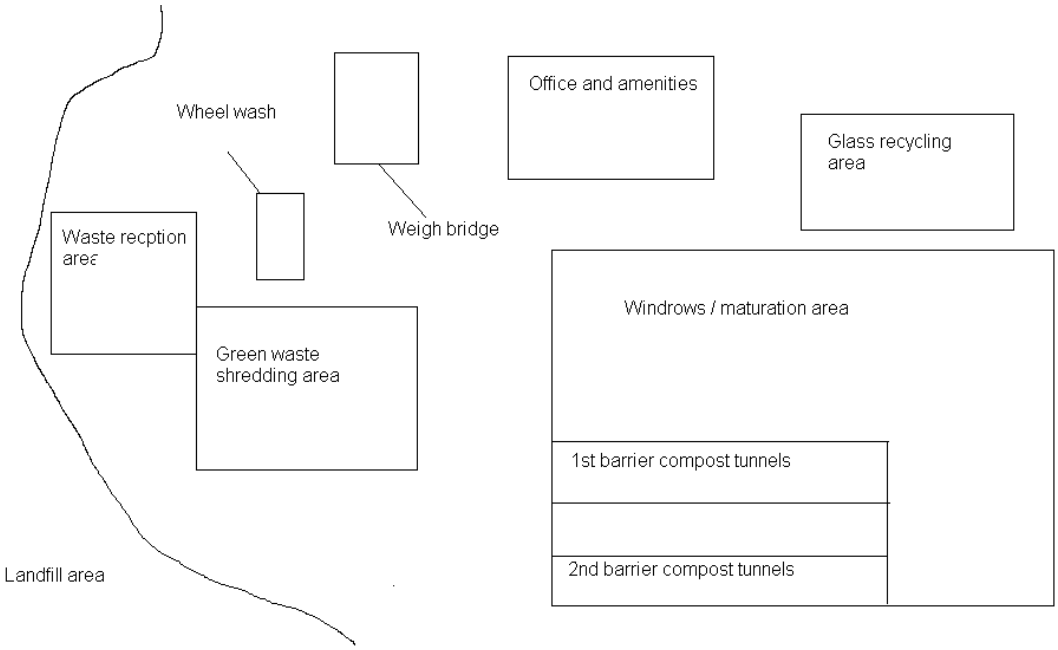
7.3 PHOTOGRAPH 3. TURNING AT SITE D (ALSO METHOD FOR SITE A)

8 APPENDIX 3: SITE PLANS

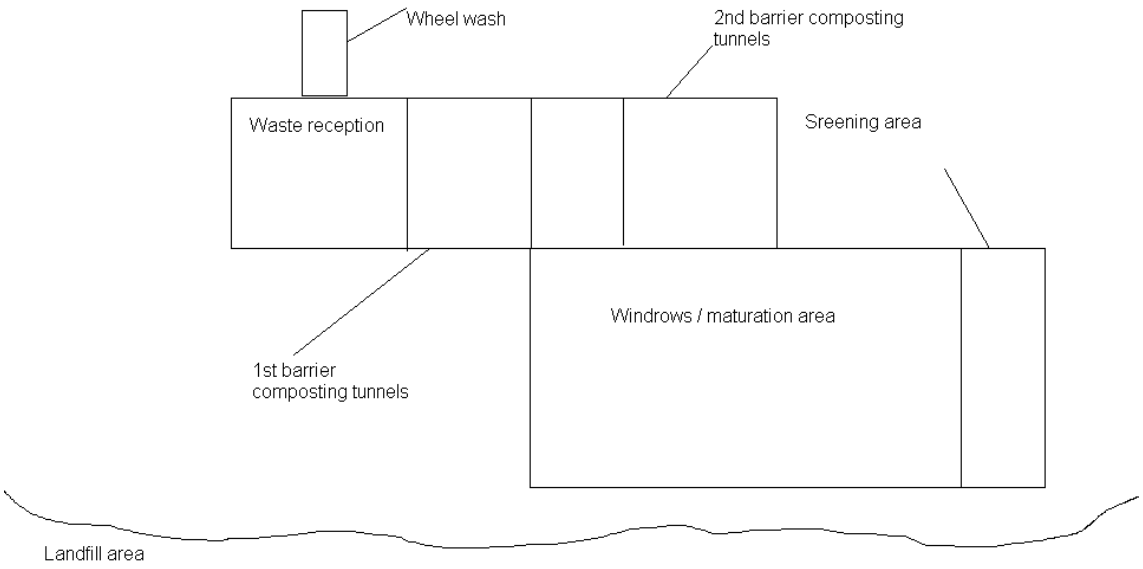
8.1 SITE PLAN (SITE A)



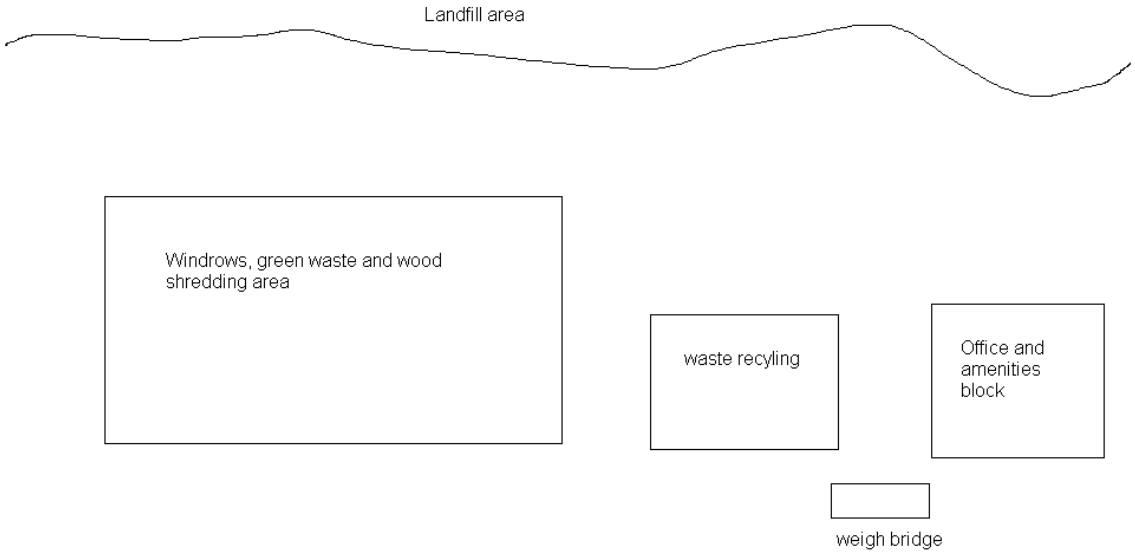
8.2 SITE PLAN (SITE B)



8.3 SITE PLAN (SITE C,)



8.4 SITE PLAN (SITE D)



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HSE

Health and Safety Executive

Bioaerosol emissions from waste composting and the potential for workers' exposure

Composting organic waste is an important component of the waste management process in the UK and the strategy to reduce waste to landfill, and as a result there has been an increase in the number of commercial composting operations. Microbiological activity is fundamental to the composting process, therefore any handling of composting material is likely to make airborne significant quantities of those micro-organisms (referred to as bioaerosols). Workers mechanically handling compost on these sites may therefore be at risk of considerable exposure to bioaerosols depending on their work task, their proximity to the bioaerosol source and the control measures put in place. In addition, because the work is largely done out of doors, there is the potential for bioaerosols generated to disperse some distance from the point source. Consequently, there is concern that people living or working in the vicinity of waste composting sites (sensitive receptors) may also be exposed to these bioaerosols.

Bioaerosols were sampled at sites representative of commercial scale waste composting in the UK. The samples taken were linked to specific activities likely to generate compost bioaerosols, such as turning and screening, and samples were collected from as close as possible to the source of emission. The dispersion of bioaerosols from compost handling activities was estimated by collecting bioaerosol samples at several points downwind increasing in distance from the emission site up to 250m. Upwind background samples were used as a benchmark. The sampling took place during both winter and summer periods to provide an insight into the differences in bioaerosol generation that may exist.

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