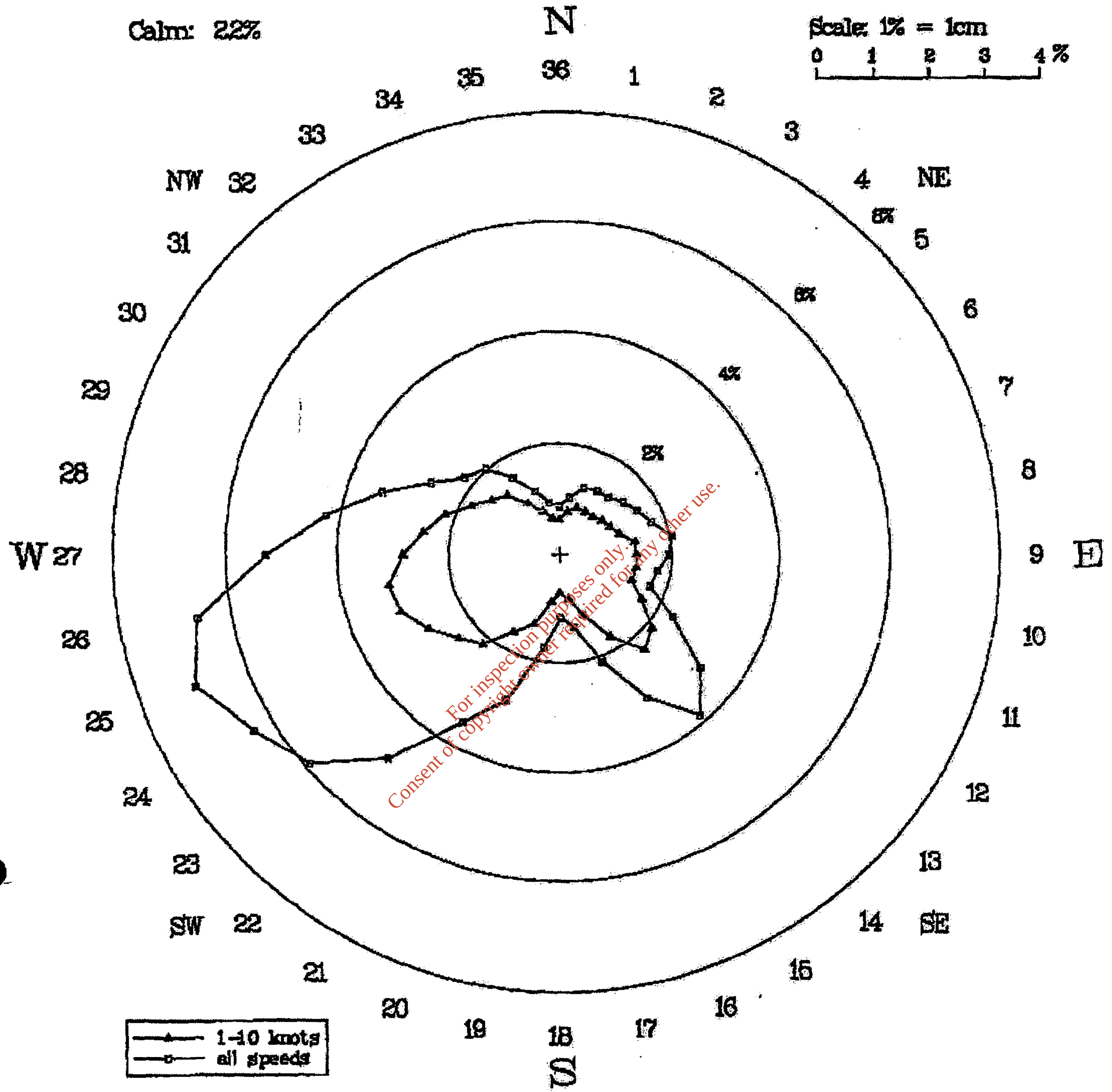
APPENDIX 1

30 Year Dublin Wind Rose

6919712001

Percentage Frequency of Occurrence of Wind Directions



Percentage Frequency of Occurrence of Wind Speeds

+ less than 0.1

0	1-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	41-47	over 48	knots
2.2	10.2	18.0	27.4	28.4	9.7	3.5	0.6	+	+	0.0	%

mean wind speed: 10.0 knots standard deviation: 5.9 knots

anemometer height: 12m

Met Eireann, Glasnevin Hill, Dublin 9.

APPENDIX 2

Photograph

O' Callaghan Moran & Associates.
Granary House, Rutland Street,
Cork Ireland.
Tel. (021) 4321521 Fax. (021) 4321522
email : ocm@indigo.ie

CLIENT	Kings Tree Services Ltd
TITLE	Residential Properties
Details	© Ordnance Survey Ireland. Government of Ireland.
FIGURE NUMBER	Appendix 2
Scale	Not To Scale
Revision	A

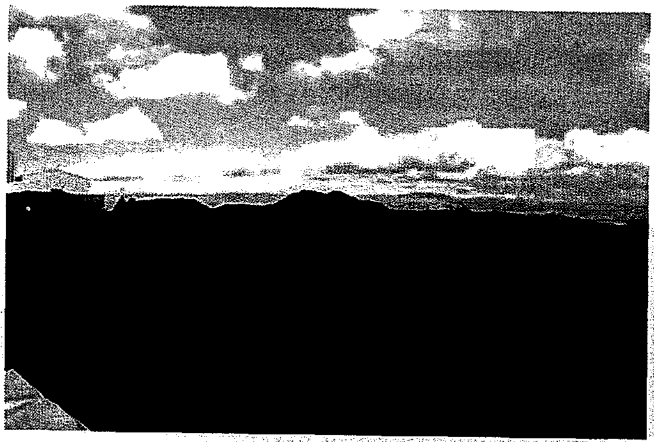
APPENDIX 3

Bioaerosols and Composting: A Literature Evaluation, Cre 2004

COMPOSTING ASSOCIATION
of IRELAND TEO

Bioaerosols and Composting

A Literature Evaluation



August 2004

Bioaerosols and Composting

A Literature Evaluation

This report was part funded by the EPA

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cré
COMPOSTING ASSOCIATION of IRELAND

Table of Contents

Recommended Reading

1. The Composting Association. Standardised Protocol for the Sampling and Enumeration of Airborne Micro-organisms at Composting Facilities. 1999.

2. Gilbert J.E. 1998. Health and Safety at Composting Sites. A Guidance Note for Site Managers. The Composting Association (UK) Pp 1-32.

3. Jensen, P. A., Schafer, M. P., 1998 Sampling and Characterization of Bioaerosols. NIOSH Manual of Analytical Methods. 82-112.

List of Tables

Chapter 1

Introduction

Composting is a microbiological process and during mechanical agitation of composting material, biological agents are aerosolised (i.e. become airborne), giving rise to the term 'bioaerosol'. Most of the composting done in Europe is done by open air windrow system, for instance in the UK and Denmark around 90% of composting is done by open air windrow. (Slater et al., 2001)

Bioaerosols are an issue in composting because of their potential negative impact on public or worker health. Occupational health and safety concerns and public health issues are varied. They include exposure to aerosols, primarily worker inhalation and also the potential for bioaerosols to migrate to areas beyond a facility perimeter and affect the nearby inhabitants. The predicted increase in large scale composting across Ireland over the next five years will result in increasing pressures being placed on the industry to identify new sites for composting facilities.

Bioaerosols of concern during composting consist of a range of micro-organisms (*Actinomycetes*, bacteria, fungi) and organic constituents of microbial and plant origin (Millner et al., 1994, Millner 1995). Focus to date has been on *Aspergillus fumigatus* (AF), fungus and bacteria. Fine dust is also very important as it is respirable and can affect the lung function of workers.

The responses to bioaerosols are host and dose dependent; that is some individuals may respond to a dose that does not affect others (Millner et al., 1994, Millner 1995).

Most reported cases of aspergillosis (the condition caused by *Aspergillus fumigatus*) have occurred in immuno-compromised individuals. Instances of aspergillosis in healthy individuals are rare, even when involved in occupations associated with exposures to high concentrations of airborne *Aspergillus fumigatus* (Millner et al., 1994, Millner 1995).

Other responses to bioaerosols can range from mild cases of inflammation and allergy to serious tissue or systemic infection by secondary pathogens (Millner et al., 1994, Millner 1995). Inflammation responses can include Mucous Membrane Irritation (MMI), Organic Dust Toxic Syndrome (ODTS) or Hypersensitive Pneumonitis (HP). Allergenic responses may stimulate inflammatory responses as well as a broad range of typical allergenic responses (e.g. mild itching, watery eyes/nose or asthma) (Millner et al., 1994, Millner 1995).

Endotoxins are the part of the outer layer of the cell wall of gram-negative bacteria. The primary concern with endotoxins is for workers. It was reported that there is little evidence to suggest that exposure to airborne endotoxins cause toxic conditions. (Millner et al., 1994, Millner 1995).

It is also important to note that bioaerosols are not exclusive to composting facilities. Bioaerosols may be found in non-occupational environments (e.g. home lawns, wooded areas, attics) and occupational environs (e.g. farms, mushroom production, timber processing and cotton processing) (Millner et al., 1994, Millner 1995).

Millner et al., 1994, Millner (1995), Poulsen et. al., (1995) and Ault and Schott, (1993) provide reviews on bioaerosols and composting.

In Ireland, the Environmental Protection Agency considers bioaerosol emissions as one of the potential negative impacts of composting facilities. It has recently requested some waste license applicants to submit a Bioaerosol Monitoring Plan as part of the information to be supplied with the application.

The objective of this study is to provide a comprehensive reference document for bioaerosol emission management in composting facilities in Ireland. This is based on exhaustive evaluation of international literature on bioaerosol concentrations from composting facilities, in Europe and elsewhere. An assessment is made of the potential health risks associated with bioaerosols at composting facilities. Sampling methodologies are presented. Recommendations are made on how to minimise bioaerosol generation through compost facility siting/design and site operation.

The scope of this paper does not extend to compost site odour.

Chapter 2

Bioaerosol Concentrations

2.1 Dust

The International Standardization Organization (ISO 4225-ISO, 1995), define dust as: 'small solid particles, conventionally taken as those particles below 75 µm in diameter, which settle out under their own weight but which may remain suspended for some time'. The Council Directive 1999/30/EC have defined PM_{10} as: 'particulate matter which passes though a size selective inlet with a 50% efficiency cut-off at 10µm aerodynamic diameter. There is very little information available on PM_{10} levels at composting sites in Europe.

Dust produced during composting is technically not a bioaerosol, but, it may carry microbial constituents. The dust at a composting facility can include bacteria, fungi, dry plant particles or insects, depending on the feedstock.

Dust at composting facilities can be produced during transportation, mixing, sieving, processing and storing of feedstock or finished product. The majority of dust generation at a composting facility is due to insufficient moisture in the composting material. Table 1 presents an overview of dust concentrations from a variety of activities at a number of composting facilities.

Dust concentrations have been reported between 0.1 to 12.0 mg/m^3 (Table 1) at composting sites reviewed, but are generally less than 2 mg/m^3. Dust concentrations may vary with various composting activities (e.g. grinding, turning, screening etc.). It has been shown that there is significant reduction in dust concentrations when there is sufficient moisture in the composting system. (Epstein et al., 2001).

At a large scale industrial and domestic waste plant in Germany, fine dust concentrations of greater than 6mg /m^3 were recorded for short periods when the waste was being delivered to the plant (Streib et al., 1996).

In a composting site in Colorado, it was reported that when the moisture level of the compost was increased the dust concentration dropped dramatically (Epstein et al., 2001). The concentrations of dust were highest during pile construction but surprisingly the concentrations were low during pile screening. However, results from Sweden have shown high concentrations of dust recorded in the pile screening area. (Millner 1995).

In a study conducted by one of the authors of the report, (van der Werf et al.,1996) dust concentrations were low 10 metres upwind and downwind of composting activities.

The National Authority for Occupational Safety and Health (Ireland) have set a 8 hour exposure limit of 10 mg/m^3 for non specific total inhalable dust and 4 mg/m^3 for total respirable dust. A 6 mg/m^3 over short periods fine dust concentration threshold has been suggested in Germany (Streib et al., 1996).

Table 1: Dust Concentrations Recorded at Various Composting Sites

Location	Type of Composting Facility	Recorded Concentrations(mg/m^3)	Comments	Reference
Sweden	Solid Waste Composting Facility (indoor and outdoor sites).	1×10^{-1} -1.2×10^{1} airborne dust in screening area.	Median value 10.6 mg/m^{3}in screening area. Not stated if enclosed facility or otherwise.	Millner (1995)
Netherlands	Source separated organic waste, food and yard waste. Indoor Composting Plant. Aerated Tunnels.	0.4-3.1 personal dust exposures.	Further details of site not specified.	Douwes et al., (1997)
Germany	285 tonne p.a. domestic waste. 1800.000 tonne p.a. domestic/industrial. Unsorted.	>6×10^{0} fine dust for short periods Generally much lower.	Threshold Concentrations 6 mg / m^3. Highest concentrations found in waste delivery.	Streib et al., (1996)
Colorado, USA.	Aerated Static Pile, Biosolid composting, Enclosed Building. 2800 tonne p.a.	Total Dust 5×10^{-1} -2.47×10^{2} Respirable dust <2.5×10^{-1} – 1.47×10^{0} Feedstock Mixing: < 1.8×10^{-1} - 1.22×10^{0} respirable dust Pile Construction: 1.47×10^{0} -1.26×10^{0} – respirable dust Pile Breakdown: <2.3×10^{-1} -0.75×10^{-1} respirable dust Pile Screening: <2.4×10^{-1} -<0.3×10^{-1} respirable dust	Depends on process, season, and composting activity. There is a 90% reduction in concentrations if certain measures are undertaken i.e. increase moisture. Highest during pile construction.	Epstein et al., (2001)
Ontario, Canada	Outdoor Windrow Leaf and Yard Composting 1600 tonne p.a.	0.11×10^{-1} -1.15×10^{0} total dust	Measured over a two day period snap shot, 10m upwind and downwind.	van der Werf 1996; van der Werf and van Opstal (1996)
Illinois USA	Yard Waste (outdoor) 14624 m^3 landscape waste (grass clippings, leaves, tree branches).	3.9×10^{-1} -1.8×10^{0} total dust	10 sampling days at various sites in and around composting facilities.	Hryhorczuk et al., (2001)

2.2 *Aspergillus fumigatus*

Aspergillus fumigatus is a highly ubiquitous fungus. It has been associated with soil, crop plants, bird droppings, chicken roosts, cattle dung, horse dung, hay, fodder, corn, straw, grass and compost. It is also found on refrigeration and bathroom walls and building vent systems where moulds have had a chance to grow (Millner et al., 1994).

Table 2 depicts *Aspergillus fumigatus* data from various composting facilities.

Aspergillus fumigatus concentrations were in the range of 10^2 to 10^3 CFU/m^3 with several concentrations of 10^4 recorded in German literature (Böhm et al., 2002). Highest concentrations were recorded whenever the piles were disturbed (i.e. during pile construction or screening). In one case in Denmark the concentrations were almost below detection and similar to background concentrations (Neilson et. al., 1997). Concentrations dropped considerably at a distance of 150 m downwind and 75 m upwind (Nielson et al., 1997).

In a study carried out for the UK Environmental Agency by Casella et al., 2001 it was found that spore (fungi especially *Aspergillus fumigatus)* concentrations decreased by 80% to 90% from 20m to 40 m from the source.

The optimisation of bioaerosol (including dust and *Aspergillus fumigatus*) dispersal can be achieved through increasing the height of release or through increasing the turbulence and thereby increasing the spread of the plume. Turbulence around the plant can be increased by providing structures that impede the airflow. These can be walls or fences, or can be more natural structures such as earth mounds (bunds) or tree screens. (Wheeler et al., 2001). Britter et al., (1998) has assessed the effect of these structures on turbulence and has found that they have increased dispersion characteristics. The impacts of these structures for increasing turbulence will have to be measured as they are likely to be site specific.

In a study carried out in New York, off-site concentrations ranged from 5.6 x 10^2 CFU/m^3 with a maximum of 6.4 x 10^3 CFU/m^3 (Recer et. al., 2001). In a companion study undertaken by Browne et al., (2001) in order to provide data about daily changes in symptom occurrence, a variety of health symptoms were recorded by participants in a diary. Data was analysed in relation to spore concentrations observed during the study period. Other data collected included temperature, ozone level, nitrogen oxide level, sulphur dioxide concentrations and ragweed pollen grains. Ozone, ragweed and temperature were significantly associated with allergy and asthma incidence ($p<0.05$). For both daily mean and maximum *Aspergillus fumigatus* concentrations there was no positive association with allergy and asthma symptom incidence. The results of the study suggested that if increased concentrations of *Aspergillus fumigatus* spores generated during operations at the composting facility are leading to increases in allergy and asthma symptoms these increases were too small to detect, given the limitations of the study (Browne et al., 2001).

Fischer et al., 1998 investigated the effect of turning frequency on the concentrations of *Aspergillus fumigatus* during windrow composting of garden and kitchen waste. *Aspergillus fumigatus* concentrations in the centre of the windrows were reduced after two weeks of composting from >10^3 dry weight of compost to 10^2. Surface concentrations of *Aspergillus fumigatus* remained high in the least frequently turned windrows. The more frequently the compost pile was turned the faster the temperature increased to a level which can eliminate *Aspergillus fumigatus*. Fischer et al., 1998 concluded that health risks to compost plant workers could be lowered by frequent turning of the windrows, reducing the *Aspergillus fumigatus* concentrations on the surface on the compost. This study also showed that 10 metres downwind from the turning process *Aspergillus fumigatus* levels had decreased by 2 to 3 magnitudes.

Data depicting *Aspergillus fumigatus* concentrations in other industries are included in Table 3. Concentrations found in composting sites are in the lower range of concentrations found in other industries and agricultural activities.

Aspergillus fumigatus concentrations of 5 x 10^3 to 2 x 10^6 CFU/m^3 were found in hay silos during hay turning and in stables (Lacey et., al 1992, Millner et., al 1994).

Table 2: Bioaerosol *Aspergillus fumigatus* Concentrations recorded at various composting sites

Location	Type of Composting Facility	Recorded Concentrations(CFU/m³)[a]	Comments	Reference
Germany	Site 1: Landfill Site enclosed composting facility, 4000 tonne p.a., open air curing for 12 weeks Site 2: 300 tonne p.a. biowaste and greenwaste, open windrow.	Site 1: 1.2×10^2 Site 2: 8.6×10^1		Reinthaler et al., (1998/1999)
Germany	Literature search of levels.	Delivery: 2.6×10^4 Sorting: 3.9×10^4 Turning: 4.6×10^4 Post Treatment: 1.5×10^4 Background: 3.1×10^3		Böhm et al., (2002)
Germany	Enclosed system.	Near Rotating Sieve: 2.03×10^3 75 m up-wind: $<0.00 \times 10^0$ 150 m down-wind: 2.00×10^2 Exhaust from biofilter: $6. \times 10^2$ Control Site: 7.77×10^1	Composting green waste and biowaste-details of size of site not recorded.	Danneberg et al.,(1997)
Denmark	Source Separated Household Waste.	Very low concentrations-equivalent to background concentrations.		Nielson et al., (1997)
Italy	3 municipal waste composting sites.	1: 4.9×10^3 2: 2×10^2 3: 7.8×10^3 (Maximum concentrations).		Varese et al., (2002)
UK	Site 1: 5000 tonne p.a. botanic and kitchen waste. Site 2: 12,000 p.a. tonnes of greenwaste	Site 1:Turning: 9×10^3 Site 2: Spreading: 1.4×10^2		Gilbert et al., (2002)

[a] Details of sampling site (i.e. upwind or downwind) stated where available.

Table 2 (continued): Bioaerosol *Aspergillus fumigatus* Concentrations recorded at various composting sites

Location	Type of Composting Facility	Recorded Concentrations (CFU/m^3)		Comments	Reference
Colorado, USA	Aerated Static Pile, Biosolid Composting. Enclosed Building. 2800 tonne p.a.	Mixing	1.1 x 10^3	Measured in summer. 90% reduction with certain measures. Very low concentrations were measured in winter.	Epstein et al., (2001)
		Pile construction	<74 – 77 x 10^2		
		Pile Breakdown	1.4 x 10^2 to > 4.4 x 10^2		
		Pile Screening	< 47 to > 4.4 x 10^2		
		No Activity	3 - 7		
Ontario, Canada	Outdoor Windrow Leaf and Yard Composting 1600 tonne p.a.	0.4 x 10^3- 7.8 x 10^3		Measured over a two day period snap shot. 10m upwind and downwind	van der Werf (1996); van der Werf and van Opstal (1996)
Long Island, New York	Residential neighbourhood, near yard waste composting site	5.6 x 10^2 (mean) 6 x 10^3 (max)		Processing 25,000 tonnes p.a. 1 year study period. Samples taken 2 upwind, 1 downwind.	Recer et. al., (2001)
Norman, Oklahoma, USA	Outdoor Municipal Waste Composting Facility	9.72 x 10^2 (mean)			Folmsbee and Strevett (1999)
Maryland	Enclosed Compost Facility	Mean: 22 1.44 x 10^2 max		Details of facility not stated	Millner et al., (1994)/ Millner (1995)
Portland	Not Stated	2x 10^1 at 6 metres		Details of facility not stated	Millner et al., (1994)/ Millner (1995)
New Jersey	Yard Waste	5 x 10^3 during high activity		Details of facility not stated	Millner et al., (1994)/ Millner (1995)
Connecticut	Yard Waste	2.6 x 10^3		Details of facility not stated	Millner et al., (1994)/ Millner (1995)
New York	Yard Waste	6 x 10^2		Details of facility not stated	Millner et al., (1994)/ Millner (1995)

Table 3: Bioaerosol *Aspergillus fumigatus* Concentrations for other Industries/Activities (Adapted from Ault and Schott 1993)

Activity	Recorded Concentrations (CFU/m^3)	
Mulched Lawn	6.9 x 10^2	
Compost Site (Quiescent)	0-2.4 x 10^1	
Hay barn	5.5 x 10^3	
Poultry House (in spring)	2.1 x 10^3	
Mushroom House (stationary beds)	3.3 x 10^2 (90% non mould spores)	
Timber Processing	1 x 10^2-1 x 10^4	
Debarking	1.27 x 10^4 heartwood	Includes all fungi *Penicillium* and *A. fumigatus* predominate
	5.3 x 10^4 sapwood	
	6.5 x 10^4bark	
Composted Wood Chips	1.4 x 10^6 (Includes all fungi)	

2.3 Total Fungi

Table 4 depicts total fungi from various composting facilities.

Total fungi concentrations ranged from 10^2 for an idle pile in Germany to 10^5 at the biofilter, at the same plant (Kampfer 2002). Concentrations were also higher closer to the point of activity than further downwind from the site. Activity in the composting site resulted in elevated fungi counts, in one case the concentrations were elevated ten fold during shredding, (Jager et al., 1994).

Hass et al., (1999) reported that there were seasonal differences in fungi concentrations. It was found that fungi concentrations were higher during the summer than the winter. This is probably due to the fall in ambient temperatures in winter as colder temperatures may curb the growth of micro-organisms. In another case, in Germany. Böhm et. al., (2002) the highest concentrations of fungi were recorded during delivery of wastes. Marchand et al., (1995) reported fungi concentrations were highest during waste storage and sorting activities through to the discharge of compost from a tunnel composting system. Hryhorczuk et al., (2001) found that fungi concentrations were higher off site than on site although this was attributed to the site's location in a wooded area.

Fungi concentrations in other industries are depicted in Table 5. Concentrations of various activities including agricultural, sawmill, range from $10^2 - 10^9$ CFU/m^3 Stetzenbach., (1997).
Bioaerosol fungi concentrations at composting facilities are similar to concentrations found in other industries and environments.

Table 4: Total Bioaerosol Fungi Concentrations recorded at various composting sites

Location	Type of Composting Facility	Recorded Concentrations(CFU/m^3)	Comments	Reference
Germany	300 tonne p.a. open windrow 4,000 tonne p.a. enclosed system	Highest near bio-filter. 3.9 x 10^3 – 3.3 x 10^3 Post Composting 1.4 x 10^3 – 1.5 x 10^3 Control Sites 5.9 x 10^2 – 5.4 x 10^2	Mould concentrations higher during the summer than the winter	Hass et al., (1999)
Germany	285 tonne p.a. domestic waste 1800,000 tonne p.a. domestic/industrial	8.4 x 10^5 in composting area	Measured during winter	Streib et al., (1996)
Germany	1: Domestic Waste Sludge (drum piles) 2: Biowaste and garden waste, Indoor Hall Composting, no forced aeration	1: at start 9.4 x 10^3 at 3 months 1.9 x 10^4 background concentrations: 1.4 x 10^2 2: at start: 7.5 x 10^3 outdoor concentrations: 3.4 x 10^3	Shredding increases fungi concentrations ten fold (waste volume processed not specified)	Jager et al.,(1994)
Germany	Literature Search	Delivery: 4 x 10^4 Sorting: 2.3 x 10^4 Turning: 4.3 x 10^4 Post Treatment: 1.7 x 10^4 Background: 3.8 x 10^3 – 6 x 10^4	Literature Review	Böhm et al., (2002)
Germany	8,000 tonne p.a. Pile composting, covered by membrane Open storage (in sheds) Domestic waste 70% and plant waste 30%	Turning: 3 x 10^4 Shredding: 8 x 10^2 Idle Pile: 9 x 10^2 x 1.5 10^3		Kampfer (2002)
	40,000 tonne p.a. Domestic waste	Biofilter: 5.4 x 10^5		

Table 4 (continued): Total Bioaerosol Fungi Concentrations recorded at various composting sites

Location	Type of Composting Facility	Recorded Concentrations (CFU/m^3)		Comments	Reference
Germany	Closed System	Near Rotating Sieve	2.48 x 10^3	Total fungi at 22°C and 30 °C. Composting green waste and Biowaste. Further details of site not recorded	Danneberg et al., (1997)
		75 m up-wind	1 x 10^2		
		150 m down-wind	3.9 x 10^2		
		Exhaust from biofilter	9.4 x 10^2		
		Control Site	8 x 10^2		
Canada	Enclosed System Mixed Waste	7 x 10^2 - 7.2 x 10^3			Marchand et. al., (1995)
Illinois, USA	Yard Waste (outdoor). 14624 m^3 landscape waste (grass clippings, leaves, tree branches)	Off site	8.651 x 10^3	Site located in wooded area.	Hryhorczuk et al., (2001)
		On site	3.068 x 10^3		

Table 5: Bioaerosol Fungi Concentrations for other Industries/Activities

Adapted from Stetzenbach, L. 1997

Activity / Industry	Fungi (CFU/m^3)
Animal Facilities	10^2 – 10^8
Composting	10^2 – 10^7
Agricultural Harvesting and Storage	10^3 – 10^9
Sawmill	10^4 – 10^8
Manufacturing Technology	10^2 – 10^6
Water Treatment (Activated Sludge)	10 – 10^3

2.4 Bioaerosol Endotoxin

Endotoxins are constituents of gram-negative bacteria. Table 6 depicts endotoxin data from various composting facilities.

There was a lot of variation in the recorded endotoxin levels, from <1 to 640 ng/m^3. In Denmark when bioaerosols were artificially generated, concentrations[b] of 14,000 ng/m^3 were found. Concentrations of this magnitude do not reflect any other concentrations recorded in other sites mentioned during normal composting activity. In the other sites, maximum concentrations were found at pile construction and screening, that is whenever the piles are disturbed. Concentrations are higher in summer than in winter (Epstein et al., 2001).

Epstein et al., (2001) reported that endotoxin concentrations dropped considerably when certain measures were taken (e.g. if the compost is moistened). The concentrations of endotoxins also dropped considerably some distance from the plant, for example concentrations dropped by 80 times at 150 metres downwind, indicating minimal health problems for the general public if their homes are at least 150 metres away. There was a good correlation between total respirable dust and endotoxin concentrations, indicating any measures taken to reduce dust would effectively reduce endotoxin concentrations (Epstein et al., 2001).

General threshold levels are given by the International Committee of Occupational Health but these are only guidelines and no data is available on dose-response relationships. These are depicted below.

Potential Health Effect	ng/m^3
Mucous Membrane Irritation	20-50
Acute Bronchial Constriction	100-200
Organic Dust Toxic Syndrome	100-2000

As reported by Epstein et al., 2002

Rylander suggested that up to 100 ng/m^3 should be considered as safe until additional information is available (Rylander 1993). The Dutch Expert Committee on Occupational Standards of the National Health Council (Heedrik, et. al., 1997) proposes a value of 4.5ng/m^3 over an 8 hour exposure period.

Endotoxin concentrations from other industries/activities are depicted in Table 7. The data reported in Table 6 typically falls within the low to mid range of data depicted in Table 7.

[b] This figure is not particularly relevant as (i):it is artificially generated and (ii): concentrations of this magnitude have not been recorded in other sites reviewed in Table 6.

Table 6: Bioaerosol Endotoxin Concentrations recorded at various composting sites

Location	Type of Composting Facility[c]	Recorded Concentrations (ng/m^3)		Comments	Reference
Sweden	Solid Waste Composting Facility	$1 - 4.2 \times 10^1$. (Indoor and outdoor sites)		Stated safe concentrations of: 100 ng/m^3	Millner (1995)
Netherlands	Source separated organic waste, food and Yard Waste. Indoor Composting Plant. Aerated Tunnels.	3.6×10^{-1} - 2.12×10^0 initially. After certain measures (i.e. general site management) were taken concentrations dropped to a maximum of 7.8×10^1.		Links were made to enhanced inflammatory reactions of upper airways. Further details of site not reported.	Douwes et al., (2002)
UK	12 Material Recovery Plants Surveyed Processing Industrial, Household, Commercial Waste.	$3.2 \times 10^{-1} - 5.8 \times 10^1$		>7 ng/m^3 recorded at seven sites.	Gladding et al., (1999)
Denmark	Source Separated Household Waste.	Maximum concentrations were recorded as: 1.4×10^4		Bioaerosols artificially generated in rotating drum.	Nielson et al., (1997)
Germany	Enclosed System.	Near Rotating Sieve	2.07×10^1	Composting green waste and biowaste- further details of site not recorded.	Danneberg et al., (1997)
		75 m upwind	1.6×10^{-1}		
		150 m downwind	2.36×10^{-1}		
		Exhaust from biofilter	8×10^{-3}		
		Control Site	7×10^{-2}		
Colorado, USA	Aerated Static Pile, Biosolid Composting. Enclosed Building. 2800 tonne p.a.	Feedstock Mixing	5×10^{-1} – 7.7×10^1	Depends on process, season. There is a 90% reduction in concentrations if certain measures are undertaken i.e. increase moisture.	Epstein et al., (2001)
		Pile Construction	5×10^{-1} – 2.51×10^2		
		Pile Breakdown	2.2×10^1 - 6.4×10^2		
		Pile Screening	1.68×10^2 – 4.88×10^2		
		Compost Building	7×10^1 – 2.29×10^2		

[c] Details of compost site shown if available

Table 6: (Continued) Bioaerosol Endotoxin concentrations recorded at various composting sites

Location	Type of Composting Facility	Recorded Concentrations (CFU/m^3)	Comments	Reference
Ontario, Canada	Outdoor Windrow Leaf and Yard Composting 1600 tonne p.a.	<$1.9 \times 10^0 - 4.7 \times 10^1$	Measured over a two day period snap shot, 10m upwind and downwind.	van der Werf 1996; van der Werf and van Opstal 1996
Illinois USA	Yard Waste (outdoor) 14624 m^3 landscape waste (grass clippings, leaves, tree branches)	1.2×10^{-1} -6.1×10^0	10 sampling days at various sites in and around composting facilities.	Hryhorczuk et al., 2001

Table 7: Bioaerosol Endotoxin Concentrations in other industries

Adapted from California Department of Health Services Environmental Health Investigations Branch Oakland, California 1999 (Mc Neel et al., 1999)

Industry	Endotoxin Concentration ng/m^3
Livestock Industry	$5. \times 10^1$ -$1. \times 10^2$
Animal Feed Production	1.61×10^4
Glasshouse	6×10^0 -7.79×10^2
Household waste composting plant	2.1×10^1
Garden-waste composting plant	8×10^{-2}
Fur Animal Bedding	6.2×10^1 - 1.950×10^3

2.5 Total Bioaerosol Bacteria

Bacteria are prevalent in the composting process. Table 8 depicts total bacteria from various composting facilities.

The total bacterial concentrations varied from 10^2 to 10^5 CFU/m^3 with most levels around 10^2 CFU/m^3. In one case when bioaerosols were artificially generated using a rotating drum, the levels were recorded at 10^7 CFU/m^3. Turning and shredding resulted in higher airborne bacterial concentrations in general, as with other bioaerosols.

In one case, the bacterial concentrations in the air increased as the composting proceeded (higher levels after three months) (Jager et al., 1994). Concentrations dropped considerably at some distance from the plant (75 metres upwind 4.3 x 10^2 CFU/m^3 and 150 metres downwind 2.83 x 10^3 CFU/m^3) and the drop was, as expected, more pronounced upwind than downwind. It was also found that biofilters decreased concentrations considerably (3.3 x 10^1 CFU/m^3) (Danneberg et al., 1997).

In the case of a plant in Germany (biowaste, hall composting, 3-4 meter high non-aerated piles), the concentrations were so high that the author recommended special protection for plant personnel working directly beneath the shredding process. (Jager et al., 1994). In contrast with another plant in Germany where windrow composting was being undertaken, the concentrations in and near the plant were the same as naturally occurring concentrations. (Reinthaler et al., 1998/1999). However, the impact of nearby farms in affecting the neighbourhood air cannot be excluded.

Bacterial concentrations from other industries/activities are depicted in Table 9. Total bacteria concentrations reported in Table 8 are within the range of those reported in Table 9.

Table 8: Total Bioaerosol Bacteria Concentrations recorded at various composting sites

Location	Type of Composting Facility	Recorded Concentrations (CFU/m^3)		Comments	Reference
Germany	Site 1: Landfill Site Composting Facility, closed 4000 tonne p.a., open air curing for 12 weeks Site 2: 300 tonne p.a. Biowaste and greenwaste, open windrow.	Site 1: 4.5×10^3 Site 2: 1.6×10^2			Reinthaler et al., (1998/1999)
Germany	1: Domestic Waste Sludge Drum Piles (plant D) 1m high, aerated.	1: $1.2 \times 10^4 - 8.3 \times 10^4$		Highest concentrations during shredding. 10 fold above without shredding (tonnage processed not specified)	Jager et al., (1994)
	2: Biowaste and Garden Waste (Plant E) Indoor Hall Composting, no forced aeration 3-4 m high	2: 2.1×10^4 during shredding 1.3×10^3 outdoor concentrations			
Germany	Literature search of levels	Delivery	1.6×10^4		Böhm et al., (2002)
		Sorting	1.4×10^4		
		Turning	2.8×10^4		
		Post Treatment	5.4×10^4		
		Background	1.3×10^4		
Germany	8, 000 tonne p.a. Pile composting, covered by membrane Open Storage (in sheds) Domestic Waste 70% and Plant waste 30%	Turning	3.5×10^5		Kampfer (2002)
		Shredding	4.3×10^3		
		Idle Pile	1×10^3		
	40,000 tonne p.a. Domestic waste	Biofilter	8.9×10^6		
		Raw air	8.8×10^5		

Table 8: (Continued) Total Bioaerosol Bacteria Concentrations recorded at various composting sites

Location	Type of Composting Facility	Recorded Concentrations (CFU/m^3)		Comments	Reference
Germany	Enclosed System	Near Rotating Sieve	7.67×10^4	Greenwaste and Biowaste. Details of quantities not specified.	Danneberg et al., (1997)
		75 m up-wind	4.33×10^2		
		150 m down-wind	2.83×10^3		
		Exhaust from biofilter	3.30×10^1		
		Control Site	3.11×10^2		
Denmark	Source Separated Household Waste	1.7×10^7	Bioaerosols generated experimentally via rotating drum		Nielson et al., (1997)
UK	Site 1: 5000 tonne p.a. botanic and kitchen waste	Shredding	1.17×10^4 to 2.1×10^4	Site 1: Concentrations vary depending sampling date.	Gilbert et al., (2002)
		Turning	6×10^2 to 9×10^2		
	Site 2: 12,000 tonne p.a. tonnes of greenwaste.	Turning	6×10^2 to 2×10^4	Site 2. high background concentrations (Background concentrations: 1.6×10^3).	
Canada	Enclosed System Mixed Waste.	8.7×10^3 - 5.3×10^5		Particularly high during turning and sorting. Further details of site not recorded.	Marchand et al., (1995)
Illinois, USA	Yard Waste (outdoor). 15000 m3 landscape waste (grass clippings, leaves, tree branches)	4.8×10^2- 7.8×10^4		10 sampling days at various sites in and around composting facilities.	Hryhorczuk et al., (2001)

Table 9: Bacteria Bioaerosol Concentrations for other Industries/Activities

Adapted from Stetzenbach, L. 1997

Activity / Industry	Bacteria Concentrations(CFU/m^3)
Animal Facilities	$10^3 – 10^5$
Composting	$10^3 – 10^6$
Agricultural Harvesting and Storage	$10^2 – 10^3$
Sawmill	$10 - 10^3$
Manufacturing Technology	$10^2 – 10^6$
Water Treatment (Activated Sludge)	$10^2 – 10^6$

2.6 Conclusions on Concentration Data

The data presented are indicative (i.e. general comparison) rather than absolute. Given slightly different methodologies used for data collection and other variables, the data reported by different authors can only be compared on this basis.

The quantitative differences observed by different authors are caused by different types of facilities, sampling locations and especially by air sampling instruments with their various advantages and disadvantages. The concentrations can vary greatly with different measuring systems used (Griffiths and De Cosemo 1994, Reinthaler et., al 1998/99). See also Chapter 5 Sampling.

The bioaerosol concentration data reviewed generally fell into the ranges of other industries/activities.

Various authors have also found high microbial loads in the air of sorting facilities and have shown that these high loads depend on input material, facility, specific factors such as transporting technology and frequency of cleaning procedures (Danneberg et., al 1998, Deininger 1998, Jager et., al 1995, Missel 1997).

In general, it is reasonable to assume that workers may be exposed to potentially higher bioaerosol concentrations at closed composting facilities, where the ability of ambient air to dilute bioaerosol concentrations is reduced, as compared to an outdoor windrow facility. The installation of appropriate air handling equipment may abate this potential greater impact at an enclosed facility. Given appropriate air handling and other abatement systems, the potential for off-site migration of bioaerosols may be less from an enclosed facility than an open windrow facility.

To obtain indicative data in Ireland, air sampling using standardised methods could be used at new or existing composting facilities.

Given the very dynamic nature of air sampling, extremely targeted experiments would have to be carried out simultaneously with different composting units, and different feedstocks, to obtain more reliable data regarding the effects of the compost process or feedstocks on various parameters. Sampling methods would have to be standardised as well as analytical methods, as these also have an effect on recorded levels (see Chapter 5 Bioaerosol Sampling).

Chapter 3

Background Bioaerosol Concentrations

Table 10 depicts data outlining the distance, from various composting activities, at which background bioaerosol concentrations are attained. These distances vary considerably (61 - 2,614 metres), although generally background concentrations are achieved within a few hundred metres.

The impact of a composting operation on background concentrations of bioaerosols can be variable and is a function of wind direction/speed, weather, concentration of various bioaerosols at source and type of composting activity at site. (Reinthaler et, al. 1998/1999)

In the case of bio-solid (sewage sludge) composting background concentrations are reached at 2,614 metres and 806 metres. In most cases background concentrations are reached at a distance of less than 200 - 300 metres. In three cases, the background concentrations are reached at a distance of 500 metres.

According to Reinthaler et., al (1998/1999), Austrian law, in relation to potential hazard to neighbouring residents, requires a distance of 300 meters for large scale composting facilities (> 4,000 tonne per annum). In Germany, various regulations in different German states require between 200 meters and 500 metres (Ruf 1994), but these legal regulations target odour, which according to Reinthaler may often be a more significant problem than bacteria or fungi in the ambient air.

Bioaerosol concentrations and dispersion of bioaerosols depend on a number of site specific factors, these include feedstock, method of composting, configuration of composting site, method used for and frequency of pile turning, prevailing atmospheric conditions, moisture of composting piles, landscaping i.e. trees, bunds, fences, background concentrations. Background concentrations can depend on proximity to agricultural activity, wooded area, landfill, or other industry which produces bioaerosols. Therefore it can be seen that bioaerosol concentrations in a composting site are site specific.

Milner et al. 1994 after reviewing published data has concluded that 'the data have indicated that at distances of 76-152 m from the compost facility perimeters the airborne concentrations of *Aspergillus fumigatus* were at or below background concentrations.

Gilbert and Ward 1999 have found that *Aspergillus fumigatus* and mesophilic bacteria were found to reach background concentrations within 200m have suggested a set back distance on this basis, providing that routine sampling should be carried out at a facility if a 'sensitive receptor' lies within 200 metres of the site boundary .

A distance of 250 metres was recommended by the U.K Environment Agency, this distance provides an additional 'safety factor' over the 200 metres suggested by Gilbert and Ward 1999 and is considerably greater than the distance recommended by Millner et al., 1994. The U.K Environment Agency has also stated that this distance can be reviewed on a case by case basis. The UK Environmental Agency have chosen the 250 metres distance in spite of the fact that background levels of bioaerosols are reached within 200 metres of the source and that spore concentrations decreased by 80%-90% at a distance of 20-40metres from source. (Casella et al., 2001) Dust concentrations reached 'safe levels' levels at a distance of less than 100 metres. (Wheeler et al., 2001)

In view of these conflicting recommendations, in the absence of any clear cut data and the absence of a dose response relationship it is recommended that there be a guideline set-back distance or buffer zone of 200 metres from the site boundary composting facilities to the nearest dwelling, to facilitate abatement of bioaerosols from a composting facility. This buffer distance is arbitrary and the minimum distance where bioaerosols reach background levels can vary a great deal, due to the factors discussed above. The 200 metre distance would be particularly applicable to 'benign' feedstocks, e.g. greenwaste composting. Also where there are trees or bunds, this buffer distance could be slightly relaxed. This set back distance could also be relaxed if the composting carried out on an enclosed site utilising biofilters with appropriate site management practices.

It should also be noted that as far as the authors are aware, no other European country have a national regulation on set back distance to a sensitive receptor.

Table 10: Buffer distances where measured concentrations reach background concentrations

Reference/Site Details (Volume processed not detailed in reviewed papers)		**Parameter Measured**	**Distance to where conc. reach Background conc.(metres)**
McNeel et al., 1999	Greenwaste	*Aspergillus fumigatus*	152 - 502
	Biosolids		149 - 806
Reinthaler et al., 1998/1999	Waste Sorting Open Windrow	Bacteria and *Aspergillus fumigatus*	At 200 concentrations are significantly reduced
Heller et al., 2000	Partly Indoor	Fungi and *Aspergillus fumigatus*	200
	Indoor		500
Millner et al., 1995	General Recommendation	*Aspergillus fumigatus*	61- 152
Oregon Department of Environmental Quality 2001 (Tetratach 2001)		*Aspergillus fumigatus*	1: 76-304 2: at 182 no effect on public health
Danneberg et al., 1997	Herhof System	Endotoxin	150
		Total microbial concentrations	No increase > 500
California Integrated Waste Management Board, (Ault et al., 1993)	Sewage Sludge-enclosed system.	*Aspergillus fumigatus*	610 upwind 304-2614 downwind

Chapter 4

4.1 Bioaerosols and Health Risks

The health risks posed by bioaerosols come under the jurisdiction of the Health and Safety Authority. A study carried out by 25 scientists and engineers in the U.S.A., drawn largely from regulatory and research agencies came to the following conclusions after examining the full spectrum of potential bioaerosol agents of composting and their health impacts (Millner 1995).

- The general population is not at risk to systemic or tissue infections from composts associated bioaerosol emissions
- Immuno-compromised individuals are at increased risk of infection by various opportunistic antigens such as *Aspergillus fumigatus*, occurrence is not only in composts but also in other self heated organic materials present in the natural environment.
- Asthmatics and other "allergic" individuals are at increased risk to responses to bioaerosols from a variety of environmental sources and organic dust sources, including composts.
- Some types of bioaerosols can cause occupational allergy and diseases. Some types of bioaerosols are present in the air at facilities that compost organic materials. Available epidemiological evidence does not support the suggestion of allergic, asthmatic, acute or chronic respiratory diseases in the general public around the sites evaluated. The conclusion was drawn that "composting facilities do not pose any unique endangerment to the health and welfare of the general public". The basis for this conclusion is the fact that workers were regarded as most exposed part of the community, and where worker health was studied, for periods up to ten years on a composting sites, no significant adverse health impact were found.
- Occupational exposure to bioaerosols on composting sites may be significant, depending on the circumstances on the site, operational characteristics, and worker proximity. Compost site workers are clearly more exposed to compost bioaerosols than the surrounding population. However, as already stated, worker populations at such facilities thus far have not shown any significant difference in overall body or respiratory fitness as compared to non exposed persons.
- Dose and effect responses for concentrations of dust, microorganisms, and toxins for people working in plants could not be determined.
- Because of continuing public concern and because of the wide range of potential respiratory responses to organic dust, additional study would be helpful to further verify this apparent lack of adverse health impacts from composting facilities. Two kinds of studies (epidemiological and annoyance studies) would be helpful for defining potential impact of bioaerosols from any source, composting or otherwise. Annoyance studies are much easier to conduct; they can and have yielded useful information at much less cost.

Conclusions between dose, effects in regard to frequency of exposure, worker symptoms and dust, microorganism and toxin concentrations could not be determined.

Only few published studies exist where the health of residents near to composting facilities has been investigated, but where this has been done there is no evidence of significant ill health compared to unexposed controls. (Swan et al., 2003). The precise risk of bioaerosols is impossible to quantify due to the lack of defined dose-response relationships. (Wheeler et al., 2001)

Investigations in Scandinavia (Nersting 1993) showed that exposure to airborne microorganisms (type not specified) higher than 10^5 CFU/m^3 was the cause of different serious health problems of workers in a plant. Technical change at the plant reducing the exposure concentrations of the microbial air pollution, lead to a decrease in the health problems.

The health risks depend not only on the conditions of the environment, but also on the individual conditions, especially the disposition and susceptibility of a person. (Emmerling 1995). This is the reason for the difficulties in establishing threshold levels for airborne microorganisms in an occupational setting. Castellan et al., found a level of approx 10 ng/m^3 as the maximum (endotoxin) exposure limit without significant response.

No legal occupational exposure limits are available for exposure to microorganisms and their decomposition products. As the relationship between exposure to biological agents in organic waste and health effects is not clear, it is not possible yet to draw qualitative conclusions on the health risks due to biological agents. The amount of data is limited, and in some cases the quality of the studies is poor. Furthermore, as stated by the experts, differences in methodology do not allow comparison of the results between studies (van Yperen et al., 1997).

Rylander (1983) has stated that spore concentration for sensitization must be at least 10^8 CFU/m^3. Other authors have identified the relevant concentration of fungal spores to be between 10^6-10^{10} CFU/m^3 (Lacey et al., 1972). Malmros (1993) has suggested, the limits and recommended levels for employment in composting plants are 10,000 CFU/m^3 for total bacteria. The author adds, however, that these figures require further research.

As there was no data to show health risks due to exposure to biological agents during recovery of organic waste in groups with an increased risk, no conclusion can be drawn (van Yperen et al., 1997).

Similarly, Reinthaler (1998/1999) could not demonstrate a correlation between micro-organism concentrations and adverse effects for human health at the work place and sorting facility.

Some studies suggest that there may be a link between occupational exposure to compost workers and non-immuno-specific or allergic inflammation. However they conclude that the findings need to be confirmed in a larger study (Dowves et al., 2000).

There are currently no occupational exposure standards for bioaerosols either in the UK or throughout Europe (Gladding et al., 1999). Telephone calls made to the Austrian EPA and scientists working on composting in Italy and Norway confirmed that no standards on bioaerosol concentrations are available. (Personal communication, Prasad 2002).

It should also be kept in mind that to date despite 3,400 yard waste composting facilities, over 300 bio-solid composting facilities and numerous other food, animal manure and municipal solid waste composting facilities in the U.S., to date there is no (clear cut) evidence that either the public or workers have been affected by bioaerosol concentrations. (Epstein 2002).

Chapter 5

Bioaerosol Sampling

5.1 Determining Bioaerosol Sampling Requirements

5.1.1 Baseline Bioaerosol Monitoring

It is recommended that some baseline bioaerosol research is undertaken as it pertains to composting, since no data from Ireland is available. It is important that bioaerosol concentrations be measured at composting and non-composting locations. Data collection should focus at least on *Aspergillus fumigatus*, dust and possibly total bacteria. It needs to be recognised that bioaerosols are constantly present in the ambient atmosphere as a consequence of dust and soil and the natural breakdown of vegetation. (Swan et al., 2003)

Sampling should be considered prior to constructing and/or during the compost facility commissioning phase to ensure that bioaerosol concentrations fall within expected ranges.

5.1.2 Active Facility Bioaerosol Monitoring

As in other jurisdictions, it is recommended that bioaerosol monitoring should only be carried out if there is a definite requirement. (Gilbert et al., 1999) It may be prudent to collect bioaerosol samples periodically. The Standardised Protocol for the Sampling and Enumeration of Airborne Microorganisms at Composting Facilities - The Composting Association (1999) recommend 'that sampling should only be carried out at sites that meet certain criteria'. These are 'the proximity to the site of neighbouring homes, businesses or other installations; whether any complaints about emissions from the site have been received, or if local factors indicate that sampling would be prudent'.

Oregon Department of Environmental Quality (Tetra-tech 2001) similarly suggest that bioaerosol monitoring 'is not usually done routinely but is done if there is concern for worker health'.

Sampling should also be considered if workers are exhibiting adverse effects that may be attributable to bioaerosols.

First of all, any visible signs of mould growth should be addressed; growth on walls, floors, ceilings, in air conditioning system etc. If workers or surrounding inhabitants are still exhibiting adverse reactions, air monitoring may need to be considered. Interpretation of results needs to be carefully undertaken as false positives may lead to unnecessary concern.

One must play special attention to the sampling method used due to the heterogeneous microbial composition of air at composting plants. The sampling method has to generate reproducible results and also the method must be able to collect a wide range of microbial concentrations and different groups of organisms which require special environmental consideration for their survival.

5.1.2.1 Bioaerosol Monitoring Considerations

If air monitoring is being considered there are a number of factors to be taken into account.

- **Why Sample:** Before a sampling method is chosen it is important to define the reason for monitoring i.e. are workers/surrounding neighbourhoods exposed to higher concentrations than background concentrations/non-exposed workers or communities, or are they exhibiting any adverse reactions to possible bioaerosol concentrations?

- **What to sample for:** The specific parameters to be monitored need to be defined i.e. specific organisms, dust. These may need to be monitored during specific stages in the composting process i.e. feedstock delivery, shredding, turning etc.

- **When and where to sample:** The samples taken should be representative of the bioaerosol concentrations over area and time. Ideally, a study should be undertaken over a 12 month period to take into consideration seasonal and weather variation. Selection of monitoring sites will also need to be agreed on, i.e. areas of activity, sites of worker exposure, prevailing winds and surrounding populations. Sampling locations are chosen depending on the parameters to be monitored and the reason for monitoring. Background samples need to be measured at the same time - there is extreme variation in bioaerosol concentrations over a short period of time. Background concentrations may vary considerably and depend on nearby activity i.e. farming, passing traffic etc.

- **Cost:** Sampling, analysis and interpretation of data involve a team of highly trained individuals. Due to the high number of samples to be taken, intensive hands-on attention is needed. These factors can contribute to the high costs of the studies. Costs of between €5,000 - €100,000 or more are required to study a compost site for one parameter (*Aspergillus fumigatus*). The smaller figure would only provide for intermittent sampling at a couple of locations for a couple of months and is not very good evidence for a regulatory body. (Haines1995). It seems appropriate that the Irish Government, which aims to implement at least 300,000 tpa composting capacity in the country because of its international obligations, should contribute significantly to the funding of bio-aerosol monitoring at Irish sites once they are operational.

- **Research:** Research on the effect of compost bioaerosol on human health will need a multi-disciplinary approach and may require a pan European dimension.

5.2 Sampling Methods

When it is decided what parameters are to be monitored, a sampling method can be chosen. There are a few basic methods that can be considered:

- Collection of microorganisms onto a membrane filter or impinger, filter pore size will need to be discussed, depending on the size of microorganisms to be monitored.
- Collection of microorganisms directly onto growth media, i.e. using an Anderson Sampler, this is the most common method of evaluation.
- Collection of microorganisms into an adhesive surface for microscopic examination.
- Collection of airborne material into a coated glass slide for measuring optical density.
- Organic dust is measured by collecting dust and measuring total and respirable dust.

(adapted from McNeel et al., 1999)

The Composting Association (UK) has produced a document detailing sampling and enumeration of airborne microorganisms. (Standardised Protocol for the Sampling and Enumeration of Airborne Microorganisms at Composting Facilities, 1999). This is a very comprehensive document, detailing when and where to carry out sampling for detection of *Aspergillus fumigatus* and mesophilic airborne bacteria. The scope of the protocol, enumeration of colonies, as well as methods of sampling and equipment used are given. There are other factors that need to be taken into consideration, that are also covered in this protocol; these include meaningful and accurate data recording, interpretation and reporting.

Comparison of various samplers is discussed by Jensen et al., (2002). The concentrations of bioaerosols recorded will vary depending on the sampler used. (Jensen et al., 1998) Wheeler et al., (2001) found poor correlations between a filter and Anderson sampler for the measurement of fungi and bacteria.

The NIOSH Manual of Analytical Methods provides general guidelines when choosing the appropriate sampler for the bioaerosol of interest. Temperature and relative humidity may need to be noted as these can have an effect on the numbers of bioaerosols collected. Full monitoring guidelines can be found in the NIOSH Manual of Analytical Methods, Sampling and Characterization of Bioaerosols (Jensen et al., 1998).

Chapter 6

Addressing bioaerosols at Irish composting facilities

As has been noted throughout this document, the potential health effects of bioaerosols on workers and the general public tends towards there being no negative impacts. However, this is not conclusive. Like any other potential risk, steps can be taken to reduce the risks posed by bioaerosols.

6.1 Bioaerosol Control Plan

Bioaerosols represent a worker health and safety issue, as well as potential off-site receptor health and safety issue, although the emphasis should be strongly placed on compost facility workers.

It is recommended that a bioaerosol control plan be developed during the waste licensing/permitting process for composting facilities. It should include considerations for facility siting, and design, site operation.

A bioaerosol control plan, which would become an integral part of site procedures, could consist of the following parts:

6.1.1 Facility Siting and Design

In general, the siting requirements to address bioaerosols can be included within the context of requirements to address other potential compost facility nuisances such as dust, noise and odour. However, the proximity to potentially sensitive sub-populations needs to be considered. Those most sensitive to bioaerosols are immuno-compromised or immuno-deficient individuals. In particular, additional care should be taken when siting a facility in proximity to hospitals or health care centres.

There are in some cases buffer zones delineated between a compost facility and a potential receptor but these zones have been put into place to mitigate nuisance odours and for aesthetic reasons. (See Chapter 3)

A facility should be designed to minimize the impact of bioaerosols on worker health and safety and off-site receptor health and safety. (See section 6.1.2.)

Enclosed facilities should have adequate ventilation and air exchanges. This type of design consideration is similar to those used to ensure that odorous process air is removed from the facility.

As pointed out in Chapter 3, it is recommended that there be a guideline set back distance or buffer zone of 200m from the boundary of a composting facilities to the sensitive receptor, to facilitate abatement of all potential nuisances emanating from a composting facility, including bioaerosols. This set back distance could be further reduced, depending on the efficiency of biofilters, whether the site is enclosed, efficient site management and the use of landscaping e.g. trees or bunds, fences.

Bunds, trees or fences will enhance turbulence and hence dispersion and reduce the exposure concentrations of bioaerosols the public and workers.

6.1.2 Site Operation

A plan should be formulated which addresses steps taken to minimise bioaerosol generation and how to protect workers at the site. The plan should also consider the potential for off-site migration of bioaerosols. This plan should consist of the following generic recommendations:

6.1.2.1 Operational controls

This relates to compost facility operations.

a. It is important to maintain a proper composting environment. Regular and thorough mixing of compost piles will aid proper composting and minimise the presence of *Aspergillus fumigatus*.
b. Optimal moisture content for windrows is 50-60%. Dust concentrations can be greatly reduced if moisture levels are maintained at optimal concentrations.
c. Maintain a clean site to reduce dust generation. Have a means of wetting down dry and dusty surfaces.
d. All facility operators and compost workers should be trained in methods of dust and bioaerosol control.
e. Schedule worker rotations to ensure that exposure to potentially high bioaerosol generating activities is minimized.
f. Construction of windrows to be as high as possible, but not so as to reduce the efficacy of the composting process. This increases the height of release of bioaerosols enhances dispersion. Windrows can also be used to create an effective barrier and to increase turbulence.
g. Very frequent turning (i.e. daily to 2-3 times a week) to decrease the concentrations of *Aspergillus fumigatus* in the windrows.

6.1.2.2 Engineering controls

a. Consider installing a High Efficiency Particulate Abatement (HEPA) filtration unit in wheeled loader or JCB cabs. These filters are designed to provide flow-through ventilation, from the ceiling, past the operators breathing zone, and exiting through the floor of the cab
b. Ensure that the door seals and structure of wheeled loader or JCB cabs are sufficiently airtight.
c. The cab interior is subjected to a thorough and regular surface cleaning.

6.1.2.3 Protective equipment

a. Mechanical Agitation or Manual Handling: Workers mechanically agitating the active compost or curing compost in an unfiltered wheeled loader or JCB should consider using dust-mist class (NIOSH Class N-95) mask.
b. Normal work clothes and/or coveralls are suitable for site activities.
c. Workers should wear work gloves.

(Additional details can be found in "Health and Safety at Composting Sites: A Guidance Note for Site Managers", The Composting Association 1999)

6.1.2.4 Worker hygiene

a. Hands should be washed prior to drinking, eating or smoking.
b. There should be no eating, drinking or smoking while working.
c. Consider providing and laundering worker overalls.
d. For very large facilities consider installing a changing room with showers.

6.1.2.5 Medical consideration

a. Potential workers for the compost site should be screened to identify predisposed (to the potential effects of bioaerosols) individuals.
b. Workers should receive medical reviews on a biannual basis or when clinically indicated.
c. Workers should ensure that immunizations (i.e. tetanus) are up-to-date

6.1.2.6 Sampling

Sampling is typically undertaken when there is a definite requirement.

Chapter 7

Conclusions and Recommendations

Composting is a microbiological process. When a composting mass is disturbed via activities such as shredding, turning, forced aeration and screening, microorganisms as well as microbial fragments are aerosolised. Dust, although technically not a bioaerosol may have microorganisms or microbial fragments adhered to its surface and therefore should be included in the consideration of bioaerosols. Indeed, the control of conditions that result in dust generation can play a significant role in minimizing bioaerosol generation.

This literature review indicates that the potential health risk associated with composting to workers and especially the general public are minimal and can be managed if certain procedures, as described in this report, are developed.

It is also recommended that research on bioaerosols from composting should be conducted to develop baselines in Ireland as no such information is presently available. Bioaerosols can be generated by other non-waste treatment activities.

In order to develop a firm guideline regarding the set back distance guideline, research needs to be carried out on a pan-European level by a multi-disciplinary team to define to a dose response relationship between bioaerosol exposure and public health (including industry workers) at composting sites. The Irish EPA and the Irish Health and Safety Authority amongst others should be actively involved.

Then, as a result of this study, a rational guideline can be given on a set back distance from source to a sensitive receptor on a rational basis.

Table 11 summarises recommendations made throughout this document.

Table 11: Summary of Recommendations of the Authors

Future Research	There is an urgent need for milti-disciplinary research which includes health professionals should be carried out and may require a pan European dimension.
Baseline Bioaerosol Sampling	It is recommended that some baseline bioaerosol research be undertaken as it pertains to composting. It is important that bioaerosol concentrations be measured at composting and non-composting locations. Data collection should focus at least on *Aspergillus fumigatus*, dust and possibly total bacteria.
Facility Siting	It is recommended that there be a guideline set-back distance or buffer zone of 200m from composting facilities to a sensitive receptor for the abatement of all potential nuisances emanating from a composting facility, including bioaerosols.
Bioaerosol Sampling	As in other jurisdictions it is recommended that bioaerosol monitoring is only carried out when there is a definite requirement.
Development of Educational Material	It is recommended that educational material be developed for site managers, workers and general public regarding bioaerosols.

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