SPECIAL RESEARCH REPORT

BIOAEROSOLS ASSOCIATED WITH COMPOSTING FACILITIES

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Contents

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BIOAEROSOLS

An Overview

Composting has been a long accepted and practiced means of processing organic materials into useful products that are being beneficially recycled in the environment. Because of an increased number of questions about possible adverse health effects that persons might experience from living near a composting facility, the Composting Council, the U.S. Environmental Protection Agency (EPA), the U.S. Department of Agriculture (USDA) and the National Institute for Occupational Safety and Health (NIOSH) assembled, in January 1993, a group of international experts on bioaerosols, risk assessment and composting. These experts were drawn largely from regulatory (EPA and the Department of Health of the State of New York) and research (USDA, NIOSH) agencies. The composting industry, consultants, academia, and environmental groups were also represented.

During that intensive two and one-half day January meeting, the twenty five scientists and engineers reviewed, discussed, analyzed and debated the concerns, facts, and current status of the question: *"Do bioaerosols associated with the operation of biosolids or solid waste composting facilities endanger the health and welfare of the general public and the environment?"*

The workshop participants attempted to examine the full spectrum of potential bioaerosol agents and impacts, including actinomycetes, bacteria, fungi, arthropods, protozoa, and organic constituents of microbial and plant origin and not just those that might arise from the fungus *Aspergillus fumigatus*. To the best of our knowledge this is one of the first attempts at viewing the comparative health impacts of such a broad spectrum of bioaerosols from different sources of decomposing organic materials, (e.g., grass clippings, wood chips, food and household wastes, agricultural wastes, and biosolids) in the environment. As such, the report on this effort helps establish a scientifically reasoned basis for evaluation of health impacts from bioaerosols associated with the processing and handling of biologically degraded materials at composting facilities compared with other sources, and helps set the stage for future advances in knowledge about this important subject.

During the twenty one month period of time following the workshop, participants and other reviewers scrutinized a number of iterative versions of the report resulting in the following state-of-the-knowledge document entitled *Bioaerosols Associated with Composting Facilities*. Relevant data that became available during this period — such as that from the yard waste composting site study in Islip, New York — were incorporated into the report which has been edited and guided by Dr. Patricia Millner of USDA.

This state-of-the-knowledge report cites examples of individual case findings of allergic responses as well as more serious diseases that have resulted from occupational exposure to some types of bioaerosols in a wide variety of organic dusts. In spite of the fact that some types of bioaerosols can cause occupational allergies and diseases, and that some of the same types of bioaerosols are present in the air at facilities that compost organic materials, the expert participants did not find epidemiological evidence to support the suggestions of allergic, asthmatic, or acute or chronic respiratory diseases in the general public at or around the several open air and one enclosed composting sites evaluated.

Thus, in response to the question initially posed to the expert participants at the workshop, the answer that emerged was: "*Composting facilities* ***do not*** *pose any unique endangerment to the health and welfare of the general public.*" The major basis for this conclusion was the fact that workers were regarded as the most exposed part of the community and where worker health was studied, for periods of up to ten years on a composting site, no significant adverse health impacts were found. In addition, the measured concentrations of targeted bioaerosols in residential zones around composting facilities showed that the airborne concentrations of bioaerosols were not significantly different from background, (i.e., as if the composting facility were not there). A likely reason that the bioaerosol levels were not significantly different from ambient is because the naturally decomposing self-heating organic matter on which these subsequently aerosolized microbes thrive are widely distributed throughout the environment.

Considering the wide range of potential respiratory responses to organic dusts, it was also the consensus of the participants that additional research be conducted to more clearly define the nature and health impacts of bioaerosols from composting facilities compared with all other environmental sources. Specifically, they recommended that assessments be made of "annoyances" and irritants at and around compost sites and that these be coupled with determinations of ambient concentrations of targeted bioaerosols from sites upwind and downwind of composting facilities and other sources that occur naturally in the environment. Furthermore, the participants recommended operational steps that could be taken at composting sites to reduce the generation and dispersal of, and consequently potential for exposure to, bioaerosols.

Reviewers: The complete text of the report, Bioaerosols Associated With Composting Facilities, has been reviewed by the following: E. Petsonsk, M.D., NIOSH, Morgantown, WV; G. Kullman, NIOSH, Morgantown, West Virginia; J.E. Parker, M.D., NIOSH, Morgantown, WV; R. Sjoblad, USEPA, Rosslyn, Virginia; J. Kough, USEPA, Rosslyn, Virginia; D. Bassett, USEPA, Washington, DC; J. Alpert, E & A Environmental Consultants, Canton, MA; J. Sherwin, NOVON/ Warner-Lambert, Morris Plains, NJ; J. Cook, National Audubon Society, Islip, NY; and C. Murray, WSSC, Silver Spring, MD. All the reviewers' comments have been included in the text.

Workshop Participants: The workshop participants included the following: J. Alpert, E & A Environmental Consultants, Canton, MA; D. Bassett, USEPA, Washington, DC; C. Cannon, Composting Council, Alexandria, VA; J. Cook, National Audubon Society, Islip, NY; J. Cookson, INET, Potomac, MD; E. Epstein, E & A Environmental Consultants, Canton, MA; J. Haines, New York State Museum, Albany, NY; E. Horne, New York State Department of Health, Albany, NY; J. Kough, USEPA, Rosslyn, VA; M. Kramer, Environmental Health Associates, Baltimore, MD; D. Lewis, NIOSH, Morgantown, WV; B. Lighthart, USEPA, Corvallis, OR; M. Maritato, ChemRisk, Portland, ME; P. Millner, USDA, ARS, Beltsville, MD; R. Monk, Composting Council, Alexandria, VA; C. Murray, WSSC, Silver Spring, MD; B. Ooi, Organic Recycling, Inc., Valley Cottage, NY; S. Olenchock, NIOSH, Morgantown, VW; R. Rylander, University of Gothenburg, Gothenburg, Sweden; J. Sherwin, NOVON/Warner-Lambert, Morris-Plains, NJ; R. Sjoblad, USEPA, Rosslyn, VA; W. Sorenson, NIOSH, Morgantown, WV; L. Stainer, NIOSH, Morgantown, WV; and J. Walker, USEPA, Washington, DC.

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Bioaerosols Associated With Composting Facilities

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Composting is one of the major treatment processes used to transform wastes into agriculturally useful products. The potential health risks associated with exposure to biological aerosols (hereafter referred to as bioaerosols) generated from the processing and handling of composted organic materials are a major concern in jurisdictions evaluating existing compost installations or planning new ones. Bioaerosols of concern during composting are like those from other organic dusts and they consist of microorganisms (actinomycetes, bacteria and fungi), arthropods, protozoa and organic constituents of microbial and plant origin. Major concerns are the fungus *Aspergillus fumigatus* (AF), cell walls of gram-negative bacteria (endotoxins), β-1,3 glucans from the cell walls of fungi and mycotoxins. These biological materials are found in aerosols generated from a wide variety of organic wastes including grass clippings, wood chips, food and household wastes, agricultural wastes and sewage sludge. This report describes the dispersion of inhalable organic dust in and around composting facilities as well as the possible health effects of the microbial constituents as they relate to infection, allergy, inflammation and annoyance. Special emphasis is given to the opportunistic fungus, *Aspergillus fumigatus*, which has been the subject of specific concern in several jurisdictions involved with planning, siting and permitting of composting facilities. The role of bacterial endotoxins and mycotoxins and their association with composting and noncomposting activities/sources are also reviewed and evaluated. The common natural source exposures to AF and bacterial endotoxins in air and in organic materials and dusts are compared to the exposures at and around composting sites. In addition, this report highlights other aspects of bioaerosols that are important to the evaluation of possible health effect concerns, but which are not fully answerable at present because additional basic data are needed.

Executive Summary

Recycling of biosolids and the organic fractions of municipal solid waste is increasing because of the benefits that can arise and because the disposal alternatives, e.g., landfilling and incineration, are unpopular, too costly, or legislatively restricted. Composting is one of the major treatment processes used to transform wastes into agriculturally useful products. The potential health risks associated with exposure to biological aerosols (hereinafter referred to as bioaerosols) generated from the processing and handling of composted organic materials are an important concern in jurisdictions evaluating existing compost installations or planning new ones. Other potential health concerns associated with composting of biosolids, municipal solid wastes, and certain industrial wastes, such as plant uptake of heavy metals and worker exposure to synthetic and volatile organic and inorganic compounds, have been reviewed and evaluated by numerous other investigative teams, and are thus not part of the assessment reported here.

In January 1993, the Composting Council assisted the U.S. Environmental Protection Agency (EPA), U.S. Department of Agriculture (USDA), and National Institute of Occupational Safety and Health (NIOSH) in convening a two and one-half day workshop at which twenty five scientists and engineers reviewed, discussed, analyzed and debated the concerns, facts, and current status of the question, *"Do bioaerosols associated with the operation of biosolids or solid waste composting facilities endanger the health and welfare of the general public and the environment?"* The collaborative efforts of that workshop and subsequent reviewers' comments have led to the development of this report.

Bioaerosols of concern during composting consist of microorganisms (actinomycetes, bacteria, and fungi), arthropods, protozoa, and organic constituents of microbial and plant origin. While much public concern has focused on the fungus *Aspergillus fumigatus* (AF), workshop participants recognized that other biological constituents in compost feedstocks and compost could be of concern. Such other biological constituents have led to significant exposure effects in workers in other occupational settings where organic materials and dusts are aerosolized in large quantity and often are of greater concern where ventilation is limited. The reporting of the occupational exposures by the workshop is included as an important point of reference and is not meant to imply in any way that the levels of exposure or response from composting operations and compost will be of similar magnitude and effect.

Risks from secondary pathogens like AF, respiratory irritants, and allergenic components are the major emphasis in this document, since the risks associated with primary pathogens, like bacteria, viruses and helminth ova, have been reviewed and evaluated by others.

Significant amounts of research data on exposure concentrations and responses to airborne endotoxins (i.e., the cell walls of gram-negative bacteria), thermophilic actinomycetes, and other fungal spores in occupational settings exist. Such reports are featured in this review to provide a more inclusive (but by no means exhaustive) picture of the exposures and responses that are possible in worst case occupational settings. Limited information is available on inhalation exposures and responses to β-1,3 glucans (constituents of the cell walls of fungi) and mycotoxins, but these entities are included because they augment other response processes associated with organic dust exposure syndromes. The bioaerosols mentioned above are also found outside of the occupational setting in dust generated from a wide variety of organic wastes including grass clippings, wood chips, food/household wastes, agricultural wastes, and biosolids, even in the absence of planned, high temperature, aerobic composting.

Neighborhood exposure to bioaerosols from composting operations is generally less than occupational exposure. However, the biological constituents in commercially prepared composts are of similar type to those in homeowner and noncommercial endeavors. Hence, the potential responses that may result from inhalation of bioaerosols from composts are the same as those that can result from inhalation of a variety of other organic dusts. The responses can vary and are host- and dose-dependent, i.e., some individuals may respond to concentrations that do not affect others. The responses can range from mild cases of inflammation, to allergy, or to serious tissue or systemic infection by secondary pathogens. There are several responses that intergrade between the mild/benign and the serious extremes. Inflammation responses can be stimulated nonimmunologically by irritants or immunologically by immune system mediators. Inflammation reactions can be mild and localized as with Mucous Membrane Irritation (MMI), or more generalized, as with Organic Dust Toxic Syndrome (ODTS), or more intense, as with Hypersensitivity Pneumonitis (HP). The intense HP responses result from respiratory exposure to extremely high spore concentrations, e.g., $10^8/m^3$, after a period of sensitization, which may consist of repeated exposures to much lower concentrations, e.g., 10^5-10^6 spores/m^3. The HP response is characterized by an allergic component as well.

Allergenic responses also involve mediators that stimulate inflammation, consequently the distinction between inflammation and allergy is less certain. Like inflammation responses, allergic responses can also present a broad range of symptoms, e.g., from mild itching, watery eyes/nose, to coughing and sneezing, to wheezing or more severe respiratory distress, as with asthma. Saprophytic fungi and pollen are well known types of aeroallergens involved in respiratory allergy and asthma. Allergic rhinitis (i.e., nasal congestion due to immune system sensitivity to allergen(s)) is a common, benign response in which a wide variety of airborne allergens have been implicated.

At present, neither minimum threshold levels nor dose-response data are available for AF, β-1,3-glucans, mycotoxins, or enzymes that stimulate inflammatory, allergic, asthmatic, or infectious processes in humans. However, individual cases that involve such agents in adverse respiratory reactions have been reported in the medical literature. These are considered as verified observations that warrant attention in the evaluation of health effects and in the design of future response studies, but they are not predictive about what will happen at the community or population level. For evaluation at that level, statistically well-designed epidemiologic study results would be needed to help establish dose-response impacts and allocate risk among the various sources of environmental exposure.

The verified health effects data, that have been observed for occupationally exposed individuals, have shown that infection (i.e., invasive growth of pathogenic microorganisms into body tissues, organs, or systems) caused by opportunistic (secondary) pathogens indigenous to organic dusts from any source is *extremely rare*, even among workers who are exposed continuously to high concentrations of various bioaerosols. When such invasive or systemic, opportunistic infections occur they usually occur in individuals whose immune defense systems are very severely compromised (functionally abnormal) because of genetic or acquired conditions. Such individuals are at risk to infection from microbes in the general environment, which contains natural sources of these organic dusts and associated microbes. Immunocompetent, corticosteroid managed asthmatics are susceptible to a specific response known as Allergic Bronchopulmonary Aspergillosis which involves the growth of *Aspergillus* species in the airways (but not the lung tissue *per se*).

None of the published or unpublished reports to which this workgroup had access either directly or through computerized databases such as Medline, Toxline, Agricola, CAB abstracts, Biological abstracts, Biosis, and CAIN, provided any dose-response data for AF, other fungi in composts, β-1,3 glucans, mycotoxins, enzymes, viruses, or bacteria in terms of inflammation, allergy, asthma, or opportunistic infections. However, based on considerable volumetric air sample data involving indoor, occupational endotoxin exposures and responses, the International Committee on Occupational Health has suggested threshold response ranges for gram-negative bacterial endotoxin as follows: 1,000-2,000 ng/m^3, organic dust toxic syndrome (ODTS); 100-200 ng/m^3, acute bronchoconstriction; and mucous membrane irritation, 20-50 ng/m^3. These endotoxin exposures are relatively high in comparison with outdoor nonoccupational settings, such as in a residential community. In the absence of threshold response ranges for AF and other constituents of composts, we examined what some typical community and neighborhood exposures might be.

Published airspora* studies contain both qualitative and quantitative data confirming that the microorganisms found at compost sites, in the compost products, and their various feedstocks are also found in the ambient air environment, and, as such, should be considered as part of the total airspora. The quantitative studies show that, although concentrations may be higher at compost sites during vigorous movement of the compost, certain natural sources as may be encountered by the public during daily activities may generate very high concentrations of certain fungi and actinomycetes, notably *Aspergillus fumigatus* (AF) and *Thermoactinomyces vulgaris*. Outdoor airspora concentrations, including AF, vary seasonally; peak seasons differ by locality. Reported concentrations of AF in outdoor air range from 0-686 colony forming units (CFU)/m^3. In general, the outdoor airspora is dominated by the saprophytic fungi, i.e., *Alternaria, Cladosporium, Aspergillus*, and *Penicillium*. The concentration of thermophilic actinomycetes in outdoor air is typically so low that any concentrations above 10 CFU/m^3 strongly suggests that self-heating organic material had been aerosolized nearby the sampler site. For this reason, thermophilic actinomycetes can be regarded as indicator organisms in studies of aerial dispersion of compost bioaerosols.

Indoor air, while somewhat seasonally variable, can also contain high levels of bioaerosols dominated by *Penicillium* and *Aspergillus*, during interior housekeeping; and bioaerosols increase during indoor housekeeping activities. Indoor occupational exposures in agricultural environments where organic dusts are generated, i.e., grain elevators, barns with moldy hay, and mushroom production facilities, represent the most intense exposure situations. It is noteworthy that even these extreme exposures have not led to any increased *infectious* diseases by AF in exposed worker populations.

Bioaerosol monitoring data from several biosolids composting operations, which differ in design and feedstock, were compared to each other and to the ambient natural airspora data. The highest concentrations of aerobic bacteria, thermophilic (heat loving) fungi, and AF were detected directly on the composting sites during peak operations. As expected, concentrations of these microorganisms in air downwind from the centers of the composting sites were less than the peak values on-site, and in most cases less than or nearly similar to those at the upwind sites, (i.e., not significantly different from normal ambient exposure as if the composting facility were not present). Yard waste composting sites also produce AF and thermophilic actinomycetes aerosols, that on average are similar to those from outdoor biosolids composting facilities. There is almost no data on other bioaerosol constituents downwind of any composting site whether it be for processing biosolids, yard waste or other organic material.

To the extent that it is desirable to mitigate bioaerosols, design, siting, and operational factors are important tools. Controlling temperature and moisture of actively composting materials and stored compost and feedstocks, and timing and minimization of mechanical agitation during favorable atmospheric conditions, will abate dust and minimize the growth and proliferation of bioaerosol agents. Site enclosure, biofilters, compost scrubber piles, and site topographic and landscape design may be used in various combinations to abate bioaerosol transport downwind. Buffer distances to the surrounding community will depend on facility size, design, and operational factors. Current bioaerosol monitoring data and data from a few experimental studies

* Fungal and actinomycete spores/propagules collected from the air; identified by microscopic morphology, by in vitro culture method(s), and/or biochemical/serotaxonomic characteristics

provide the basis for estimating source strengths, and downwind concentrations associated with particular design and operational parameters. Models are helpful for predicting downwind concentrations of bioaerosols from area sources of bioaerosols, but are not overly precise.

Several conclusions reached by the working group included:

1) The general population is not at risk to systemic (i.e., whole body, generalized, as in circulatory, lymph etc.) or tissue infections from compost associated bioaerosol emissions.

2) Immunocompromised individuals are at increased risk to infections by various opportunistic pathogens, such as *A. fumigatus,* which occurs not only in compost but also in other self-heated, organic materials present in the natural environment.

3) Asthmatic and 'allergic' individuals are at increased risk to responses from bioaerosols from a variety of environmental and organic dust sources, including compost. *A. fumigatus* is not the only or even the most important bioaerosol of concern in assessment of risk for ODTS, MMI, and HP (extrinsic allergic alveolitis) associated with exposure to dust from organic materials. The amounts of airborne allergens that sensitize and subsequently incite asthmatic or allergic episodes cannot be defined with current information available, especially given the wide variation in host sensitivity, the numerous sources of natural environmental exposure, and the diversity of constituents and bioaerosols. Prospects for such precise definition are limited in the short-term because of these factors.

4) In spite of the fact that some types of bioaerosols can cause occupational allergies and diseases, and that some of the same types of bioaerosols are present in the air at facilities that compost organic materials, available epidemiological evidence does not support the suggestions of allergic, asthmatic, or acute or chronic respiratory diseases in the general public at or around the several open air and one enclosed composting sites evaluated.

Hence, the answer that emerged to the question posed at the beginning of the workshop is: "*Composting facilities* ***do not*** *pose any unique endangerment to the health and welfare of the general public.*" The major basis for this conclusion is the fact that workers were regarded as the most exposed part of the community and where worker health was studied, for periods of up to ten years on a composting site, no significant adverse health impacts were found. In addition, in most cases the measured concentrations of the targeted aerobic bacteria, thermophilic (heat loving) fungi, and AF bioaerosols in residential zones around composting facilities showed that the airborne concentrations of bioaerosols were not significantly different from background, (i.e., as if the composting facility were not there). A likely reason that the bioaerosol levels were not significantly different from ambient is because the naturally decomposing self-heating organic matter on which these subsequently aerosolized microbes thrive are widely distributed throughout the environment.

5) Occupational exposure to bioaerosols on composting sites may be significant, depending on the circumstances at the site, operational characteristics, and worker proximity. Compost site workers are clearly more exposed to compost bioaerosols than are the surrounding populations. However, as already stated, worker populations at such facilities thus far have not shown any significant differences in overall body or respiratory fitness as compared to nonexposed persons. On the other hand, adverse health effects have been observed in a few workers at such commercial facilities as those for producing mushrooms or processing wood chips and bark. This suggests that future worker studies should include systematic assessments for Mucus Membrane Irritation, Organic Dust Toxic Syndrome ODTS, HP (extrinsic allergic alveolitis), and related disorders in low, chronic exposure situations, i.e., situations in which exposures

of 10^4-10^5 CFU/m^3 are generally present.

6) Because of continuing public concern, and because of the wide range of potential respiratory responses to organic dusts, additional study would be helpful to further verify this apparent lack of adverse health impact from composting facilities. Two kinds of studies (epidemiological and annoyance studies) would be helpful for defining potential impacts of bioaerosols from any source, composting or otherwise. Epidemiological studies would help define dose-response relationships and if carefully planned and conducted could perhaps document clearly any negative health effect impacts on a community population near a compost site. Such epidemiological studies are expensive and difficult and have not yet been conducted around composting facilities. If such epidemiological studies are conducted, they should include nonsubjective measurements like pulmonary function measurements, serology to antigens from compost bioaerosols and microbial serotypes in the exposure environment, full medical histories of individuals, and other measures appropriate to quantitate irritant responses to organic dusts.

7) Annoyance studies are much easier to conduct; they can and have yielded useful information at far less cost. If carefully planned and conducted in communities near compost sites and coupled with environmental measurements of actual exposures, these studies can help document annoyance as related to the presence or absence of bioaerosols and other factors such as malodor, irritation, malaise, noise, visual concerns, and traffic. The procedures for assessment of annoyance are available and could be valuable to community impact evaluation processes because they offer a systematic mechanism for recording observations (olfactory or otherwise), corroboration, correlation, and interpretation. Augmentation of annoyance studies with a limited number of nonsubjective measurements could help in the separation of correlation into cause and effect.

Introduction and Purpose

In recent years, as composting* has gained increasing acceptance as a process for transforming significant portions of municipal solid waste into stable, agriculturally useful organic material, waste management planners have had to balance their evaluation of technological solutions against concerns about public health and safety. Many of the concerns associated with other waste management practices also have been raised in conjunction with the currently expanding compost industry. For example, citizens have resisted construction of waste management facilities in their neighborhoods because of concerns about possible impacts on property values (due to aesthetics), increased neighborhood traffic, noise, odor, water pollution and airborne dust.

Without doubt, odor issues have been the foremost public concern associated with planned or operational composting facilities. However, citizens groups recently have raised concerns about possible health effects associated with inhalation of airborne dust transported from nearby facilities. Like other organic dusts, airborne dust from compost operations contains materials of animal, vegetable and microbial origin; airborne dust is readily generated during standard processing operations.

This report focuses on the dispersion of inhalable organic dust in and around composting facilities as well as on the possible health effects of the microbial constituents as they relate to infection, inflammation, allergy and annoyance. Special emphasis will

* Composting is a controlled, aerobic, high temperature, biological decomposition process which converts solid organic matter into a humus-like mixture through the growth and activity of mixed populations of actinomycetes, other bacteria, and fungi that are indigenous to the various organic wastes that are composted (Golueke, 1992).

be given to the opportunistic fungus, *Aspergillus fumigatus* and to bacterial endotoxins, and mycotoxins, and their association with composting and noncomposting activities/sources. The common natural source exposures to AF and bacterial endotoxins in air and in organic materials and dusts will be compared to the exposures at and around composting sites. In addition, this report will highlight other questions that are important to better understand the possible health effects issues which are not fully answerable at present because additional basic data and information are needed.

Composting: Scope and Process

The U.S. Environmental Protection Agency (USEPA, 1989) has challenged communities in the U.S. to reduce and recycle at least 50 percent of its municipal solid waste by the year 2000, and many states have established similar recycling goals. Most states consider composting of yard trimmings and food scraps as a form of recycling and are, therefore, implementing composting plans to achieve recycling goals. This reflects recognition that as much as 40 percent of household "waste" consists of compostable food scraps and yard trimmings. As a result, composting has increased, and so have some of the perceived and actual problems associated with the activity. Additional information about the scope of the composting industry and various technical approaches are described and referenced in the Appendix to this report.

Compost Bioaerosols: Characteristics and Properties

By the very nature of the product, compost contains large amounts of organic materials of biological origin. When processed properly, i.e., with minimal odor production, the product will contain less than 20 percent moisture and be easily friable. In fact, the lower water content and workable texture are some of the advantages of the material for horticultural and agronomic uses. During ordinary handling of the organic feedstocks (leaves, wood chips, grass clippings), composts and screened products, some of the biological components can be released into the air. General descriptions of a variety of these components are provided below.

Procedures for appropriate collection, measurement and quantification of bioaerosols vary according to the environment being sampled, but the most reliable and useful methods are volumetrically based, i.e., collection of particles and molecules present in a known quantity of air. Thus, results are reported in terms of milligrams (mg) of the specific material/m^3 of air. In the case of viable microorganisms, results are reported as colony forming units (CFU)/m^3 of air. A colony forming unit is a microbiological term used to refer to a microbial colony that grows on nutrient agar in a petri dish; the colony may have started from one or more (as in a tight cluster) spores, hyphae, bacterial cells or organic particle(s) in which the microbe(s) reside. In the case of bacterial cells and viruses, death rate and inactivation are sensitive to fluctuations in the air temperature, moisture, UV radiation and temporal and spatial distance from the emitting source (Gregory, 1973). Spores are typically more resistant to these variables.

General Definition, Characteristics and Properties

Compost bioaerosols may contain actinomycetes, other bacteria, fungi, arthropods, protozoa and organic constituents of feedstock materials (Table 1). Microbial products include endotoxin, microbial enzymes, β-1,3-glucans and mycotoxins. The focus of this report will be on inhalable microbial particles and their constituents as they relate to infection, inflammation, allergy and annoyance. Although many different types of fungi occur in composted materials and various ones may serve as potential allergens, the primary focus of concern has centered on *Aspergillus fumigatus* because it can also be involved with infection under special circumstances which are described in the Responses section.

Aspergillus fumigatus

A. fumigatus, one of the most prevalent Aspergillus species, has been isolated from soils worldwide including Antarctica and all other continents. It has been isolated from temperate and tropical zone soils, humus, and from extreme habitats such as drilling cores from Japan at 1,800 to 2,100 foot depths, deserts, caves and mines. It is associated with soils of numerous crop plants and is reported from bird's nests, bird droppings, chicken roosts, dung of cattle and horses, hay, fodder, corn, straw, grass and compost (Domsch *et al.*, 1980), from refrigerator and bathroom walls (Wyngaarden and Smith, 1988), and from building ventilation systems in which molds have had a chance to grow (Seabury *et al.*, 1973).

It is also one of the most frequently found fungal species in airspora surveys. It is able to grow and survive over a wide range of temperatures (12-50°C), relative humidities and substrates (Millner, 1985). Some of its physical features include typically columnar conidial ('spore') heads which macroscopically appear drab, olive green and velvety to floccose. Individual spores (conidia) are small (2 µm in diameter) and can be carried for some distance by very light wind currents; if inhaled, the spores can enter the lungs (Gregory, 1973).

TABLE 1.
Compost feedstocks as sources of bioaerosols.

	Most Important Biohazards							
				Enteric	Allergenic			
Feedstock Category	AF	Endotoxin	TA	Bact/Vir.	Fungi/	Bact/	Mites	Other Specific Biohazards
Yard waste (including grass clippings, brush, leaves, wood chips)	+	+	+	-	+	+	+	Allergenic pollen, terpenes, resins, lectins, phenols toxalbumin.
Food/Household waste (MSW)	+	+	-	+	+	+	+	
Food Processing Winery waste (grapemarc) and cheese	+	+	+	+	+	+	+	
Fisheries (shellfish)	+	+	+	+	+	+	+	Allergens of crustaceans
Agricultural Wastes (cotton gin & textile waste, garden wastes sugarcane/pineapple)	+	+	+	+	+	+	+	Deep mycoses pollen, terpenes, resins, lectins
Biosolids	+	+	-	+	+	+	+	
Animal Wastes								
Carcasses	-	+	-	+	-	-	-	
Manures	-	+	-	+				
Barnyard manure	+	+	+	+	+	+	+	

+ = present; - = not present

Bacterial Endotoxin

Bacterial endotoxin is the chemically complex portion of the outer layer of cell walls of gram-negative bacteria. Endotoxins are very heat stable, lipopolysaccharide-protein complexes (Rietschel *et al.*, 1993) that are released into the environment during cell growth and after the cell dies (Windholz *et al.*, 1976; Bradley, 1979). In the airways, intact (living or dead) bacterial cells can be engulfed by macrophage cells which process them and release the endotoxins (Duncan *et al.*, 1986). Endotoxins increase the activity of macrophages which leads to a series of inflammatory events described below (Burrell and Rylander, 1981; Rylander and Snella, 1983).

Gram-negative bacteria and their endotoxins are ubiquitous; they are found in the soil, water and in other living organisms throughout the world. Organic dusts are a common source of airborne endotoxins (Olenchock, 1990). The first reports on endotoxins in organic dusts dealt with dust in cotton mills (Cavagna *et al.*, 1969), followed by studies from the UK (Cinkotai, 1976) and Sweden (Rylander *et al.*, 1985). Endotoxin was detected in water from contaminated humidifiers (Rylander and Haglind, 1984) and then in a variety of agricultural environments. However, they can also be found in many other environments, including office buildings and libraries where humidification systems are used (Dutkiewicz *et al.*, 1988).

Agricultural environments have been the most frequently evaluated because worker exposure to large amounts of organic dust and its constituents is a frequent and commonly reported factor associated with the onset of pulmonary symptoms. Thus, endotoxins have been measured in organic materials and dusts generated in very diverse agricultural environments, such as occur during handling of stored grains, silage, hays, straw and animal bedding material (Olenchock *et al.*, 1990a); composted wood chips (Olenchock *et al.*, 1991) and stored timber (Dutkiewicz *et al.*, 1992); tobacco; baled cotton (Olenchock *et al.*, 1983); mushrooms, including production materials such as manure, compost and spawn (Olenchock *et al.*, 1989); swine confinement units (Donham *et al.*, 1989) and poultry confinement and processing facilities (Lenhart *et al.*, 1990); horse and dairy cow barns (Olenchock *et al.*, 1992; Siegel *et al.*, 1991). In other industrial settings endotoxins have been measured in association with humidifiers, air conditioners, cooling towers and other water associated processes (Dutkiewicz *et al.*, 1988; Rylander *et al.*, 1978; Flaherty *et al.*, 1984); dusts generated during processing of cotton, wool and flax (Castellan *et al.*, 1987; Kennedy *et al.*, 1987; Ozeami *et al*, 1987; Rylander and Morey, 1982); waste disposal (Nersting *et al.*,1991; Sigsgaard *et al.*, 1990), sewage and sewage composting (Mattsby and Rylander, 1978; Lundholm and Rylander, 1980, 1983); animal feed production (Smid *et al.*, 1992a,b); and biotechnology (Olenchock, 1988; Palchak *et al.*, 1988).

Glucans

Fungal cell walls contain the polymer β-1,3-glucan which is a polysaccharide composed of glucose units joined by β-1,3-linkages. This polysaccharide is also found in cereals (barley and oats) and in certain bacteria. In the lung, β-1,3-glucans depress macrophages (Rylander, 1993b) which compromises their normal reactions to other agents such as endotoxins and antigens (Fogelmark *et al.*, 1991; COD Report, 1991d,1993).

Mycotoxins

Mycotoxins are toxic metabolites of fungi that may be present in mycelium, excreted into the substrate or found in spores (Sorenson *et al.*, 1987; Wicklow and Shotwell, 1983). In general, mycotoxins are heat stable, nonpolar, low molecular weight compounds (MW<1000) (Wyllis and Morehouse, 1977). Mycotoxins may be cytotoxic, mutagenic, teratogenic, carcinogenic and/or immunotoxic (Ciegler *et al.*, 1981) and certain mycotoxins have been shown to be acutely toxic to alveolar macrophages (Gerbarick and Sorenson, 1983; Gerbarick *et al.*, 1984; Sorenson *et al.*, 1985; Sorenson *et al.*, 1986) and in the lung (Sorenson *et al.*, 1982).

Mycotoxic fungi are ubiquitous and have been found and quantified in stored grains (Olenchock *et al.*, 1990b; Parker *et al.*, 1988), silage (Dutkiewicz *et al.*, 1989; Morey *et al.*, 1989), hay (Shen *et al.*, 1990) and straw (Shen *et al.*, 1990). Workers are known to be exposed to aflatoxin during harvesting of corn (Burg *et al.*, 1982) and aflatoxin has been measured at 143 ppb in airborne dust around combine harvesters (Popendorf *et al.*, 1985). However, the health effects which may result from ingestion or inhalation of aflatoxin by workers is unknown (Merchant, 1982).

Organic Dust: Exposure Effects

Considerable information is available on human health effects which result from exposure to microbes and other biological components in organic dusts. Inhalation is the major exposure route; consequently, the effects on the lung have received the greatest attention. Some reports demonstrate, however, that systemic effects may also occur, either as a result of ingestion of material cleared from the lungs or through release of bioactive substances from the cells of the lung into the blood. These cellular reactions are part of the normal response of the human system to biological and biochemical agents.

Early reports of the respiratory effects of organic dusts and associated microbes emphasized the situations where symptoms occurred (e.g., farmers lung and grain handlers' and pigeon breeders' diseases). It is now realized that these different lung diseases* associated with organic dust inhalation are similar and that they can be classified according to pathogenic mechanisms (Rylander and Peterson, 1990).

Inflammation

Inflammation in the tissue exposed to airborne microbes can be caused by several components associated with microbes. Bacterial endotoxins from gram-negative bacteria, proteases, water soluble forms of fungal β-1-3-glucans and mycotoxins are the most studied of such agents; others are probably also present.

Inflammation responses to inhaled organic dust can range from relatively mild, almost benign, to severe. Inflammation responses are nonimmunologically mediated, although the symptoms can resemble the same that are manifested in immunologically mediated responses such as allergenic processes. Numerous observations of individuals in various occupational settings have been accumulated and suggest a continuum of responses. These responses are summarized by general and specific types in Table 2, along with their major symptoms, and some of the references which provide details of each response type.

Rylander (1993a) noted that repeated exposures to organic dusts in occupational settings can cause *mucous membrane irritation* (MMI), which is characterized by irritation (itching and watering) in the eyes, nose and throat (Richerson, 1990). The under-

* "Disease" was defined by Campbell *et al.* (1979) as the sum of the abnormal phenomena displayed by a group of individuals in association with a specific set of characteristics by which they differ from the norm in such a way as to place them at a biological disadvantage. Organic Dust Toxic Syndrome and Hypersensitivity Pneumonitis fulfill these criteria. Mucus Membrane Irritation and the intermittent symptoms (cough and sputum) associated with grain dust exposures may or may not fulfill the criteria (Richerson, 1990).

TABLE 2.
General relationships between types of responses, specific designations, and symptoms resulting from inhalation of dust from organic materials*

Type of Response	Specific Designated Response	Major Symptoms	Dusty Organic Materials**/(Endotoxin)	References with Summaries
Inflammation (Nonimmunologically Mediated Specific IgE's Normal)	Mucous membrane irritation (MMI)	Irritation (itchy, watery) of eyes, nose, and throat, including dry cough; no elevated IgE	Cotton, compost and grain dust/(0.02-0.05)	Richerson, 1990, 1993
	Acute bronchoconstriction	Contraction of bronchial smooth muscles resulting in reversible narrowing of the airways; acute decrease in FEV_1 after exposure	Cotton, grain, animal and compost dust /(0.01)	Castellan *et al.*, 1987
	Chronic bronchitis	Increased secretion of mucus with productive cough persisting over time	Wood, grain, cotton, tea dust /(0.1-0.2)	Kilburn, 1986
	Toxic pneumonitis (organic dust toxic syndrome)	Influenza-like with fever, chills, muscle and joint pains, fatigue, headache	Cotton, grain, animal dust 'sick' buildings, mycotoxin/(1-2)	Rylander and Peterson, 1990, COD, 1991 b, c
	Nonallergic asthma (irritant receptor type)	Chest tightness/ pressure; pulmonary eosinophilia; specific IgE's normal	Grain, wood, green/dried plant and coffee bean dust	Salvaggio *et al.*, 1986
Allergy (Immunologically Mediated; Specific IgE's)	Hypersensitivity pneumonitis (allergic alveolitis)	Granulomatous pneumonitis, often with radiographic evidence of lung fibrosis when exposures are repeated frequently	Moldy hay & straw, thermophilic actino-mycetes/fungi, amoebae, animal proteins, humidifier reservoirs	Fink, 1986 Pepys, 1969 Edwards *et al.*, 1976
	Allergic asthma	Chest tightness/ pressure, pulmonary eosinophilia	Grain, Wood, green/dried plant and coffee bean dust	Salvaggio *et al.*, 1986
	Allergic rhinitis	Itchy, watery eyes, sinuses and throat; sneezing; histamine release	Pollen, fungal spores, proteins, enzymes, insect debris	Salvaggio *et al.*, 1986: Burge, 1985, 1990
Infection	Necrotizing pneumonia -invasive, systemic	Abnormal x-rays/CT scans; isolation of microbes from normally sterile tissues or body fluids (see Appendix for Invasive Aspergillosis)	Specific bacteria and fungi	Denning and Stevens, 1990, Meeker *et al*,1991, Zuk *et al*.,1989
	Allergic bronchopulmonitis -noninvasive, nonsystemic	Microgranulomas on chest x-rays; dyspnea 4-6 hrs after exposure to agent; decreased FEV_1; microbe-specific IgE in serum (see Appendix Case Definition of ABPA as example)	Aspergillus and possibly other microbes	Stevens, 1992

*See text for descriptions and details of symptoms. Distinctions between certain manifestations of inflammation and allergy are unclear (e.g., allergic vs. nonallergic asthma and MMI vs. allergic rhinitis) without data on the presenting symptoms, clinical tests and patient history, including exposure circumstances.

** Some of the reported dusty organic materials, and *proposed* threshold levels (μg/m^3) for endotoxin (COD) 1991, b,c) where data exist.

lying mechanism involves an increase in secretion of inflammatory mediators. MMI can develop after several weeks of exposure to rather low levels of the causative agent. Persons with MMI and who also develop an increased reactivity in the airways may develop bronchoconstriction, i.e. a narrowing of the airways and respiratory deficit. It is not yet known whether continuous MMI in connection with high exposure levels will progressively develop into *chronic bronchitis*, characterized by excess mucus production, increase in mucous glands and changes in the rheological properties of the mucus. Chronic bronchitis usually develops after several years of exposure to probably relatively high levels of the inciting agent. No data are available for microorganisms, but for air pollutants, several μg/m^3 or more are required to initiate chronic bronchitis.

In the lung after inhalation exposure, the initial stage in the inflammatory response is the activation of macrophages. These cells secrete a series of inflammatory compounds, some of which are chemotaxic and cause the migration of neutrophils from the blood into the lung tissue (Henson and Murphy, 1989). The neutrophilic invasion together with fluid leaking from the capillaries causes a *toxic pneumonitis*, which if severe enough will be recognizable clinically as the organic dust toxic syndrome (ODTS), a nonallergenic process (do Pico, 1986; Von Essen *et al.*, 1990). This reaction, which occurs within hours after exposure, is clinically recognized by fever, influenza-like symptoms and fatigue. Examples of ODTS are pulmonary mycotoxicosis (Emanuel *et al.*, 1975; May *et al.*, 1986), grain fever (Malmberg *et al.*, 1988; Malmberg and Rask-Andersen, 1988) and mill fever (Trice,1940).

Reports on cases with *acute haemorraghic pneumonitis* (Cresia *et al.*, 1990) have been related to extremely high, acute exposure levels of spores ($10^{9-10}/m^3$). Whether this was caused by mycotoxin or β-1-3-glucan in the spores is not known. ODTS is caused by a single peak exposure which may be of short duration. *Proposed* threshold levels are 10^9 spores/m^3 and 1 µg endotoxin/m^3 (COD, 1991b; Rylander, 1987). Data on acute alveolitis, pneumonitis or ODTS caused by AF do not exist, but experience from animal experiments (Fogelmark *et al.*, 1991) suggests that the threshold for this species could be 10^7-$10^8/m^3$, i.e., lower than for other common spores such as conidia of *Penicillium*.

A particular form of granulomatous pneumonitis, *hypersensitivity pneumonitis*, was first observed among farmers and later in workers in a variety of moldy environments (Lacey and Crook, 1988; Richerson, 1983, 1993). The disease requires a *chronic* exposure to molds and/or thermophilic actinomycetes which cause a lymphocytosis in the airways without clinical symptoms. This response has been referred to as extrinsic allergic alveolitis (Edwards and Al-Zubaidy, 1977). In connection with exposure to very high spore concentrations, on the order of $10^9/m^3$ or more, an acute disease with fever and respiratory impairment can develop. It is unclear whether this is a specific reaction or an ODTS caused by endotoxin contamination on the fungus spores, mycotoxin, or some other constituent of the fungi. Chronic, low level exposures to airborne fungi, such as that which occurs in barns with moldy hay, may in rare cases lead to fibrosis which is observable on lung radiographs (Richerson, 1993; Lacey and Crook, 1988); such exposures can range from 10^5-10^7 spores per cubic meter. Each exposure pattern can be exclusively related to a particular form of disease.

Allergy

The precise distinction between inflammation and allergic disease is by no means clear. Recent evidence from cell toxicology demonstrates that the same inflammatory cells are involved in both processes and that asthma is largely an inflammatory disease (Henson and Murphy,1989). Allergy in a strict sense describes the immunologic reaction to a small amount of material in the environment, after a period of exposure which sensitizes specialized cell systems. Organic dusts contain many antigenic materials, including fungal β-1-3-glucans, gram-negative bacterial endotoxins, pollen and various proteins, all of which are potent modulators of the immune system and may enhance or depress the reaction to allergens (antigens).

Asthma is characterized by an intensive reaction to very small amounts of the agent to which sensitization has taken place, although nonimmune-mediated sensitivity to unspecified irritants can elicit asthmatic episodes in some individuals. During the asthmatic attack, substances which cause inflammation are liberated from activated cells and a chronic stage of inflammation with the same characteristics as described above develops. An elevated, short-time exposure can cause an acute asthmatic attack, toxic pneumonitis. A long-term exposure, but not necessarily at high levels, is required for sensitization.

Persons at risk are those with a genetic predisposition to react to allergens in the environment, i.e., to become sensitized to natural products. Approximately, six percent of U.S. citizens have asthma (NCHS, 1992). In occupational exposures, it is now known that several host factors have been recognized as contributory to such responses as grain dust induced lung disease. These susceptibility factors include atopy, smoking, intermediate alpha-1-antitrypsin deficiency and nonspecific bronchial responsiveness (Chan-Yeung *et al.*, 1992). Viral infections also may be involved in susceptibility to HP although more research is needed to confirm this finding (Cormier *et al.*, 1994).

The most common fungal allergen sources are the saprophytic microfungi, e.g., *Mucor*, *Rhizopus*, *Cladosporium* and *Aspergillus*. For two of the common molds regarded as the main allergenic fungi, threshold concentrations for evoking allergic symptoms are estimated to be 100 *Alternaria* spores/m^3 and 3000 *Cladosporium* spores/m^3 (Gravesen, 1979). No data are available for Aspergilli, but it is reasonable to estimate that sensitization can occur at similar concentrations.

Infection

Infection caused by airborne microbes in organic dusts can occur either from human pathogens or from organisms that are not true pathogens but invade the tissue of particularly sensitive individuals. Infection due to pathogens in organic dusts is rare even among highly exposed workers. Studies have been made on persons exposed to biosolids in wastewater treatment facilities in the U.S. and in Sweden (Clark *et al.*, 1983, 1984; Lundholm and Rylander, 1980, 1983). No indications of an increased risk of infection were found except under extreme exposure conditions such as when a person who did not know how to swim fell into a sewage water tank and inhaled large amounts of the water.

Among the organisms that are not primary but rather secondary pathogens, AF is of particular interest. It is often referred to as a secondary or opportunistic pathogen because it colonizes and infects persons who are immunocompromised or otherwise debilitated by a preexisting medical condition. AF is a common organism in the general environment; levels up to several hundred/m^3 have been reported. Because the spores are easily inhaled and expectorated, the isolation from sputum cannot be considered diagnostic for disease caused by aspergilli (Pepys *et al.*, 1959). The nearly universal occurrence of circulating *Aspergillus* antibodies (Bardana *et al.*, 1972a,b) reflects the ubiquity of this fungal antigen in the environment. Several investigators have found AF antibodies in healthy persons (Jameson, 1969; Pepys, 1969; Reed, 1978). Furthermore, commercial house dust extracts used for allergy testing contain antigens common to AF (Bardana, 1974). Positive serology to AF is thus not, in and of itself, diagnostic of an adverse health response to AF antigen but rather a marker of exposure.

The lung has a large capacity to defend itself against microorganisms and even very high numbers of inhaled spores may not cause any effects. Occasionally, AF may cause widespread invasion of the tissue. These events require that normal defense mechanisms be compromised, e.g., after severe viral infections or because of drug treatments that suppress the immune system. Reactions to AF are based on the prior health status of the individuals as follows:

Immunocompetent

Healthy individuals with normal lungs typically tolerate even very high numbers of inhaled spores without succumbing to infection. The exact nature of the defense mechanism is not known but cellular and mechanical defenses are probably involved. Healthy individuals with abnormal lungs, e.g. with pulmonary cavities from tuberculosis or sarcoidosis, can have aspergillus colonies in the cavities or airways (see Appendix II, ABPA, and Table 2). The prognosis of such cases depends on the general health and pulmonary status of the patient (Glimp and Bayer, 1983).

Immunocompromised

If the immune defense system in humans malfunctions, there is increased risk of infection. Persons receiving immunosuppressive drugs, high levels of corticosteroids or antibiotics, or who have hematologic malignancies or suffered trauma/burns have a decreased immunity and are in this category. In such persons, AF from the general environment may colonize the lung airways, initially growing saprophytically with formation of "fungus balls" or aspergillomas (= mycetomas). There is a strong antibody response to this growth, but clinical symptoms may be absent for many years. If the balance between immune defense and growth is further distorted, invasive growth may take place, and this leads to a generally fulminant and fatal situation.

Immunodeficient

Persons particularly at risk to infection from common pathogens are those with a genetically determined impairment of the immune system. These impairments "are termed immunodeficiency diseases and afflict, in varying degrees, approximately one in every 500 U.S. citizens." (NIAID, 1991, p.13). Acquired immunodeficiency disease (HIV/AIDS) also increases a person's risk to a variety of primary and secondary pathogens.

General Effects and Reactions

Exposure assessment is further complicated by the nature of the contaminants. The same types of microbes found in composting facilities also are present in the normal environment, sometimes in high concentrations. Levels of up to 4.5×10^5 fungal spores/m^3 were reported in studies of domestic interiors in the UK (Hunter *et al.*, 1988). Consequently, it is extremely difficult, if not impossible, to conclude that measured levels at particular sites cause specific types of *noninfectious* disease in individuals unless more information is available about the antigen sensitivity of those individuals.

Annoyance Reactions

Annoyance can be defined as a feeling of displeasure with an environmental factor, which is known or believed to have an influence on health (Borsky, 1971).

The extent of annoyance in a population can be studied using standardized questionnaires via interviews or mail. The investigation is generally presented as a survey on environmental conditions in general; questions are posed on a variety of possible sources of annoyance, e.g., noise from road traffic, air pollution, presence of industry, and general satisfaction with the environment on the site. Assessing the extent of annoyance in populations around composting plants would be appropriate in evaluation of their impact on the population. In this approach, the extent of annoyance in a population is not determined by the number of complaints, since complaints are dependent upon many factors unrelated to exposure, such as the persistence in accessing the appropriate authorities to deal with the matter, evaluation of the impact of registering complaints and community responsiveness to issues. Thus, this approach can assist with objective assessments. In addition, dose-response relationships can be obtained by studying respondents chosen from areas with different exposure levels. These can be calculated or measured. A nonexposed population would be included for reference. This approach appears not to have been used yet at compost facilities.

In Sweden, health authorities have used 10 percent very annoyed as a threshold for emissions in densely populated areas. When the extent of annoyances exceed 10 percent, requests are made to decrease the emissions (Rylander, pers. comm.).

Exposures: Nonoccupational

Current Perspectives on Airborne Exposure to Potential Allergenic and Pathogenic Fungi, Especially Aspergillus fumigatus

The air that we breathe is a very complex environment filled with constantly changing microorganisms, parts of microorganisms and organic molecules. The amounts and kinds of biological particles can change several orders of magnitude with wind, precipitation and season. Air contains spores of most of the thousands of known species of fungi and bacteria, most of which are not associated with the composting process. The natural environment of outdoor and indoor air contains all of the bioaerosols that are of concern in composting; they are present in variable amounts. *Aspergillus fumigatus* and thermophilic actinomycetes are components of this airspora (environment) and their natural occurrence is recorded in surveys cited herein.

In support of a comparative approach to exposure assessment, a review is presented herein on published reports of ambient levels of fungi found in both outdoor and indoor environments, with emphasis on AF. Exposure assessment involves measuring the actual or potential exposure of humans to harmful agents. Exposure to aerosols of composting materials and particularly of microorganisms represents a complicated pattern with regard to duration and concentrations. An acute (temporary) exposure to a very high concentration can be present for a very short time period, followed by considerably lower concentrations or no exposure at all during the following time periods. A chronic (long-term) exposure can last for several weeks or years. When the exposure is within or below the average range of background concentrations found in the natural environment, compost bioaerosols do not constitute additional exposure. In this review, only reports of volumetrically measured airspora are included.

Avocational exposures to many of the bioaerosols outlined in this report can potentially occur through a variety of activities. Some common activities that provide for potential exposure include lawn mowing, gardening, home landscaping and potting of household plants. Walking through an arboretum or nature trail likewise causes exposure to airborne fungi and bacteria. Environmental sample concentrations for AF and thermophilic actinomycetes obtained using Andersen viable particle samplers as previously described (Millner *et al.*, 1980) are shown in Tables 3 and 4.

Aspergillus fumigatus is the primary species of concern because of its predominance in the composting process and its multiple potential health effects, but *Paecilomyces variotii* Bain, *Mucor pusillus* Lindt, *Humicola grisea* var. *thermoidea* Cooney and Emerson, *Humicola lanuginosa* (Griff and Moubl) Bunce and other thermophilic species are found both in self-heating situations in the natural environment as well as at composting facilities (Cooney and Emerson, 1964; Kane and Mullins, 1973).

TABLE 3.
Seasonal counts of viable *Aspergillus fumigatus* particles in air in the Washington, D.C. Metropolitan Area during 1979-1980.

	Seasonal Counts (CFU/m^3)			
Site	Fall	Winter	Spring	Summer
Lawn				
during mowing	1	5	2	0
with mulch	75	2	6	686
under trees	3	0	5	4
of hospital	2	0	0	0
of park	8	4	24	2
Wooded Area				
arboretum	4	1	6	136
nature trail	56	0	10	8
road side	1	5	2	3
Agricultural				
corn field	1	0	0	4
barn	2,070	105	352	5,550
barnyard	44	0	35	4
poultry coop	21	93	2,060	6
mushroom house	88,700	740,000	580,000	67,100
brush pile	1	1	25	5
Refuse				
municipal dump	6	2	0	5
supermarket dumpster	2	0	0	12
Greenhouse				
potting room	868	1,350	1,070	9,810
low humidity	NS	11	312	1
high humidity	NS	0	152	2
Pool — indoor				
Library-stacks	171	0	0	0
Attic	NS	1	1,160	125
Zoo-birdhouse	5	0	42	2
Boiler room	30	38	1	1
Reference Sites				
School playground	6	1	12	9
University parking lot	7	1	2	4
Shopping center	11	1	7	3

A. fumigatus is one of the most commonly found aspergilli and has been isolated from soils worldwide including temperate and tropical soils, humus and even from some extreme habitats such as subsurface drilling cores (1,800 to 2,100 ft. depths), deserts, caves and mines (Domsch *et al.*, 1980). It is associated with the soils of numerous crop plants and is cultured from bird's nests, bird droppings, chicken roosts, dung of cattle and horses, hay, fodder, corn, straw, grass and compost (Domsch *et al.*, 1980).

Airborne concentrations of AF in natural environments are reported in numerous studies in conjunction with emission tests at composting facilities, around hospitals and other sites (Domsch *et al.*, 1980). The concentration of AF in the natural environment is low in comparison to other fungal allergens, such as *Cladosporium* and *Alternaria*, but AF is more common when compared with most other fungi capable of being human pathogens. Larsen and Gravesen (1991) reported 0-204 CFU/m^3 for all aspergilli (eight percent of the total fungal airspora) in Denmark. They found peaks of

TABLE 4.
Seasonal counts of viable thermophilic actinomycetes in air in the Washington, D.C. Metropolitan Area during 1979-1980.

	Seasonal counts (CFU/m^3)			
Site	Fall	Winter	Spring	Summer
Lawn				
during mowing	2	2	7	0
with mulch	0	0	0	1
under trees	0	0	5	2
of hospital	0	5	0	1
of park	0	8	2	12
Wooded Area				
arboretum	5	0	5	5
nature trail	0	2	4	5
road side	0	1	4	0
Agricultural				
corn field	2	2	1	5
barn	NS	18	0	5
barnyard	NS	132	1	51
poultry coop	0	29	43	1
mushroom house	204	24,600	35,800	3,470
brush pile	1	4	10	5
Refuse				
municipal dump	1	4	2	6
supermarket dumpster	1	1	0	1
Greenhouse				
potting room	13	0	1	0
low humidity	NS	2	12	2
high humidity	NS	0	4	0
Pool — indoor	11	10	3	1
Library-stacks	0	2	4	7
Attic	NS	0	2	4
Zoo-birdhouse	5	1	4	8
Boiler room	4	0	0	1
Reference Sites				
School playground	3	3	3	3
University parking lot	2	1	2	2
Shopping center	2	2	3	3

total viable fungi in July and August, whereas the peak for Aspergilli was in November. They used a IAP Slit-Sampler with VB agar incubated at 25°C.

Mullins *et al.*, (1976) examined average monthly levels of AF in Cardiff, Wales and reported an average for the year of 33 CFU/m^3 and a peak of 537 CFU/m^3 with the Andersen sampling technique. In contrast to Larsen and Gravesen (1991), Mullins *et al.*, (1976), reported higher levels in winter months with a peak in February. Solomon and Burge (1975) reported that less than eight percent of outdoor air contained AF when there were no sources of self-heating matter in the surrounding area. They found levels of 150 CFU/m^3 and less with peaks in the early spring and fall in the U.S. They emphasized that the U.S. data from Michigan is different in amount and peak times from previous English studies. In subsequent studies outside and within a Michigan clinical center, Solomon et at., (1978) found that AF concentrations were similar to those in Cardiff, Wales (Mullins *et al.*, 1976) except that there was no peak in the winter. Later, Mullins *et al.*, (1984) made a direct comparison of air outside of hospitals in Cardiff, Wales and St. Louis, Missouri, in the U.S. They reported very similar yearly patterns and amounts between 0-50 CFU/m^3 except that the peak month was October for St. Louis and November for Cardiff. They further noted that the "*A. fumigatus* concentrations are no higher than those recorded for *Cladosporium* which suggests that conditions for abundant growth of *A. fumigatus* are rare."

Jones and Cookson (1983) sampled air (with Andersen samplers) in the vicinity of a proposed sewage sludge composting site near Washington, DC. They reported 0-7,220 CFU/m^3 of mesophilic fungi (geometric mean 273); 0-193 CFU/m^3 thermophilic fungi (median 2.1); 0-71 CFU/m^3 of AF (median 1.0); 4.2-1,640 CFU (aerobic bacteria)/m^3 (geometric mean 79); 0-5.7 CFU (fecal streptococci)/m^3 (median 0) and no fecal coliforms. They found a November/December peak.

Millner (1985) reported background concentrations for different urban and suburban situations. Low concentrations of AF, i.e. < 10 CFU/m^3, were reported for lawns during mowing, under trees, in front of a hospital and in a park. When the lawn had a mulched area, higher concentrations of AF were found, i.e., 686 CFU/m^3, in summer and fall. Wooded areas also had relatively low concentrations of AF, i.e., 1-10 CFU/m^3, except for a nature trail in fall with 56 CFU/m^3. A school playground, university parking lot and shopping center, likewise had relatively low concentration of AF, i.e., < 12 CFU/m^3. The study also detected very high concentrations of AF in agricultural, home and greenhouse situations.

Domestic Interiors: AF and Other Fungi

There are several studies on the normal fungal airspora of households (most recently reviewed by Summerbell *et al.*, 1992; Flannigan *et al.*, 1991). Many of these studies examined households for the production of agents capable of eliciting allergic reactions in atopic individuals and therefore are questionable indicators of reference values. Much of the older literature on fungal content of household air uses data obtained by the open petri dish settling plate technique. Settling plate studies provide results that are of limited value in assessing exposure because that sampling technique tends to oversample particles of large aerodynamic diameter and settling velocity (and undersample the respirable size particles). The viable particle settle plate sampling technique simply demonstrates that some airborne microbes are capable of landing, germinating and growing on agar plates; settle plate data cannot be used to quantitatively differentiate between outdoor and indoor spore levels or between different concentrations of microbes present. Hence, the method is inappropriate for use an an indicator of exposure and the potential for respiratory health effects.

Another aspect of sampling technique that strongly influences interpretation and comparison of data is the dependence of the technique on the culturability and viability of the microbes collected in the sampling device. To obtain microbial counts for the air sampled by the Andersen, slit and impinger samplers, the microbes collected must be viable and culturable on the nutrient media used. Because viable microbes constitute only a portion of the total airborne microbial content, the techniques which rely on viability and culturability will tend to underestimate the microbial content. In addition, impactor (air to agar) samplers, are subject to rapid overloading of the agar surfaces in very dusty interiors, and this limits sample time. Under such circumstances, the All-Glass Impinger (AGI-30; Davies 1971) is commonly used since collected microbes can be subsequently dilution plated, subjected to immunoassays or other suitable detection techniques which take advantage of the aqueous matrix.

Outdoor airspora commonly contains fungi associated with degrading plant matter such as *Cladosporium, Alternaria and* other mesophilic saprophytic fungi. Indoor mycoflora consists mainly of *Penicillium, Aspergillus* and other species. While the presence of both groups of fungi fluctuates, indoor species appear to fluctuate less dramatically than outdoor mycoflora and have a population peak in the winter, with Penicillia generally more abundant than Aspergilli (Flannigan *et al.*, 1991; Hunter *et al.*, 1988). However, both appear to survive in greater numbers indoors than outdoors on carpeting, wood and other organic substrates when provided with adequate moisture. As might be expected, the indoor rather than the outdoor mycoflora is more abundant in winter in locations that have killing frosts, extended periods of freezing and snow. Indoor exposure to fungi in winter has increased in recent times primarily because of airtight building construction. It is unclear whether this is true in more moderate or tropical climates, or even if there is a good comparative survey of indoor air prior to the use of energy conservation measures.

Fungi have been implicated in the induction of allergies and asthmatic episodes. These episodes have been correlated with the aerial dispersal of spores by activities such as vacuuming, construction and dust movement. However, when "moldy" and "clean" homes were compared for fungal numbers, it was found that they did not differ significantly in spore numbers recovered (Hunter *et al.*, 1988). This resulted in part from the high variation in the number of spores recovered per sample, but it was also a result of room-to-room variation and sampling time in the same room. Rooms with visible mold growth had higher recovered populations of fungi (median value 2,673 CFU/m^3). Rooms in "moldy" houses, except for those with visible mold, had levels similar to those in apparently clean houses (median values of 360 CFU/m^3 and 236 CFU/m^3, respectively). "Clean" houses occasionally had levels as high as "moldy" houses for no apparent reason (23,070 versus 21,790 CFU/m^3, respectively).

It must be noted that these reports are not specific for AF; routine assays specifically for this fungus in indoor environments are limited in number. The levels of AF in a forced hot air heated house and an office were found to be negligible (<512 CFU/m^3) (ERCO, 1980). Millner (1985) reported that the concentrations of AF usually obtained from indoor air were <175 CFU/m^3. Most frequently, "indoor" sites such as an attic, library or boiler room, had AF concentrations between 0 and 50 CFU/m^3 (Table 3). The occasional high concentrations of AF (approx. 1,100 CFU/m^3) were associated with disturbances that would increase the movement of dust. It is interesting to note that similarly high concentrations of AF were found in potting rooms (Millner, 1985); potted plants have been implicated as the source of AF inoculum in nosocomial, i.e., hospital borne, infections (Flannigan *et al.*, 1991).

The literature shows few studies that have included volumetric indoor measurements of AF. Evaluations to date indicate that the fungus can be present indoors, but is not necessarily the major component of the airborne mycoflora. The fact that 13 percent of tested outpatients reacted positively to AF antigen (Hendrick *et al.*, 1975) and that similar percentages were found in tested samples from blood donors (Belin and Malmberg, 1986) indicates that the AF antigen is widespread. Activities that increase indoor dust movement, such as vacuuming, construction, repair and air ventilation, would also increase exposure.

Solomon (1975) measured fungi in and immediately outside several midwestern homes during two seasons, frost free and subfreezing. *Aspergillus fumigatus* was found in 26 homes at a level of 40 CFU/m^3 during the frost free period and similar levels in 80 homes during subfreezing weather. A subsequent study (Solomon, 1976) reported that *Aspergillus fumigatus* was recovered in 31 percent of 47 homes, with a range of 1-

946 CFU/m^3 and a mean of 24.4 CFU/m^3.

Hirsh and Sosman (1976) conducted a one year survey of mold growth in 12 homes. *Aspergillus fumigatus* was one of the most common molds isolated. It was the most common mold found in basements; the second most common in bathrooms; and fourth and fifth most common in front rooms and bedrooms, respectively. Aspergillus was significantly more frequent in homes with pets in comparison to other molds.

Su *et al.* (1992) sampled 150 households in Topeka, Kansas using Andersen samplers. They found that *Aspergillus fumigatus*, *Penicillium* spp. and other fungi were present in a significant number of homes. These fungi were primarily associated with homes with gas stoves for cooking and basement crawl spaces. The authors attributed this to increased relative humidity in these places.

Occupants (people and pets) and their level of activity (moving or stationary) significantly influence the indoor air concentration of fungi, however, this parameter has not been considered in many of the studies to date.

Other Microorganisms

A study of bacteria in background air by Jones and Cookson (1983) reported the presence of aerobic bacteria at 4.2-1,640 CFU/ m^3 (geometric mean = 79 CFU/m^3), fecal streptococci at 0-5.7 CFU/m^3 (median: 0 CFU/m^3) and no fecal coliforms. The study was conducted in a suburban area of Washington, D.C. near the proposed site for a biosolids composting facility (now known as WSSC Site II).

Thermotolerant and thermophilic actinomycetes are typically sampled with Andersen samplers and enumerated from colony counts obtained from plates incubated at 44°C. *Streptomyces* spp. are particularly abundant but *Actinobifida, Microbispora, Micropolyspora, Saccharomonospora, Saccharopolyspora, Streptosporongium, Thermoactinomyces and Thermonospora* are all possible components of air (Millner, 1985) although there are no published quantitative measurements of individual species. Millner *et al.* (1980) reported from 0-59 CFU/m^3 thermotolerant/thermophilic actinomycetes in background air samples collected at a Beltsville, Maryland site unaffected by composting.

Exposures: Occupational

Noncompost Sites

Much information is available concerning the presence of biohazards in industrial environments. These data are predominantly related to agriculture and to processing agricultural materials. General pertinent reviews are available and include presentations of such topics as agents, diseases and prevention/control (Rylander *et al.*, 1986); work related respiratory diseases and their occurrence, environmental factors, immunological and lung function studies and prevention/socioeconomic aspects (Terho *et al.*, 1987); and health effects, worker risk and symptomatology related to organic dusts and lung disease (Rylander and Peterson, 1990).

No quantitative surveys of AF specifically in office or manufacturing environments are available. Based on results from other ambient surveys, AF concentrations in air of office and manufacturing centers would be expected to be comparable to that in houses, unless free moisture and warm temperatures conducive to fungal growth were present. Wood processing operations such as those at sawmills and pulp/paper factories are primary candidates for concern with respect to potential industrial exposures (other than waste handling) that could present a risk of exposure to AF.

Agricultural

Agricultural exposures to microbes are extensive and often similar to those expected at composting facilities. Exposure to moldy hay, organic or grain dusts have been associated with decreased lung function, chronic bronchitis and farmer's lung. The development of farmer's lung has been related to a chronic exposure to large amounts of respirable, microbially colonized dusts in enclosed barns. The symptoms become more severe as the winter progresses and a thermotolerant microflora develops in the molding hay. The implicated causal agents are certain thermophilic actinomycetes: *Micropolyspora faeni* and *Thermoactinomyces vulgaris* and *T. viridis*. Other environments in which the exposure to thermophilic microbes is similar to that described for farmer's lung are sugar cane processing areas where bagasse is handled, grain handling and clean out and renovation of mushroom houses. The latter three situations have led to descriptions of bagassosis, grain handler's lung and mushroom picker's lung, in the medical literature.

Although AF specifically has not been shown to be involved in farmer's lung, *Aspergillus umbrosus*, occurred in significantly greater numbers along with the thermophilic actinomycetes in a Finnish study of farmers reporting symptoms of chronic bronchitis or farmer's lung (Kotimaa *et al.*, 1987). One report in this supplement also included a measure of the level of microbes such as AF, *A. umbrosus* and thermophilic actinomycetes in the air of barns. Although mean values for AF in air were slightly higher, the researchers found no significant difference in AF concentrations in the barn air of farmers with chronic bronchitis and in barns of asymptomatic farmers (Kotimaa *et al.*, 1987) suggesting an influence of individual susceptibility.

Other measures of AF levels in hay barns have been recorded as low as <70 CFU/m^3 (ERCO,1980) or significantly higher, i.e., 100 up to 5,500 CFU/m^3 (Millner, 1985). The higher levels reported by Millner (Table 3) were similar to those reported in the Finnish studies (Kotimaa *et al.*, 1987). Air measurements of AF which used radioimmunoassays (RIA) for AF have also been conducted in poultry barns during the bedding chopping operation which generated the highest measurements of AF antigen, 70 ng/m^3 (Pratt *et al.*, 1990). These are not comparable to other types of volumetric measurements for AF (CFU/m^3 values) because RIA measures the presence of the antigen which does not require the viability of the microbe. Lack of corresponding viable count data (CFU/m^3) limits appropriate comparison of this study data to that of other studies in which only volumetric concentrations of viable microbes are reported. Other poultry houses in which airborne AF have been measured showed generally low levels (<100 CFU/m^3), except during the spring when 2,060 CFU/m^3 were found (Table 3).

In summary, the available data on airborne AF levels in agricultural occupations show that measurements are highest during mechanical agitation in enclosed structures such as barns, animal holding pens or mushroom houses, especially where fresh air exchange is limited or nonexistent. It is noteworthy that these data show that human exposure has not significantly increased the occurrence of AF infection in farmers; farmers do, however, show higher levels of antibody to AF than do a cross section of blood donors (Belin and Malmberg, 1986). Also, as might be predicted, the tested farmer population had a greater amount of antibody to common, outdoor fungi that are associated with degrading plant material, e.g., *Botrytis, Alternaria, Paecilomyces* and *Penicillium*, compared to the blood donor control group (Malmberg *et al.*, 1985). This increase in antibody levels is, however, an indication of exposure rather than a marker of disease risk.

Mushroom Production

Several studies have examined the biological agents associated with mushroom production. Suspected causes (fungi, bacteria, other organic materials) of mushroom workers' pneumonitis are described in a review (Lockey, 1974). In a study of various phases of the mushroom industry, all materials, from chicken manure to whole mushrooms, were found to be contaminated with endotoxins (Olenchock *et al.*, 1989). Precipitating antibodies were found in both ill and non-ill workers to extracts of the different bulk materials and IgG antibodies were detected to antigens in a panel of HP agents, including *A. fumigatus*, *A. niger* and thermophilic actinomycetes by enzyme linked immunosorbent assays (ELISA). Although there was no association with disease, antibodies were evidence of biomarkers for exposure and suggest variation in individual susceptibility. Kleyn *et al.* (1981) reported that the total microbial count in airborne dust of stationary bed mushroom houses was 333 CFU/m^3, with 90 percent or more of the isolates belonging to the genus, *Streptomyces*. Fungal spores constituted five percent or less of the airborne dusts. Precipitating antibodies in workers' sera were found against *Bacillus licheniformis, Micropolyspora faeni, Thermoactinomyces vulgaris, Aspergillus fumigatus and Humicola grisea*. Finally, in a study of a specialty mushroom, it was reported that high levels (>10^6/m^3) of 'Shiitake' mushroom spores were found in the growing rooms (Sastre *et al.*, 1990).

Mushroom production facilities can contain very dense concentrations of fungal aerosols during the cleaning operations after harvest: 67,000 to 740,000 AF CFU/m^3 (Millner, 1985). As mentioned above, mushroom house workers can experience an hypersensitivity pneumonitis after exposure to high concentrations of the thermophilic microflora in aerosolized mushroom compost (See also Table 4).

Timber Processing

Specific studies describe the levels of biological agents in industrial situations, e.g., bacteria, fungi and endotoxins were quantified in air of five large wood processing plants and organisms were described in stored timber logs in Poland (Dutkiewicz, 1989). Airborne bacteria and fungi were found at levels of 10^2-10^4 CFU/m^3 and the concentration of endotoxins were observed at levels in the range of 0.24-40.0 µg/m^3. Predominant bacteria included *Enterobacter* sp., coryneform bacteria, and, although the levels were low, *Thermoactinomyces vulgaris*. Predominant fungi included *Penicillium* sp., *Cladosporium brevicompactum* and *Aspergillus fumigatus*. Although microbes within the air of the sawmill were not quantified, types and quantities of gram-negative and positive bacteria, yeasts and filamentous fungi were exhaustively described from stored timber in the U.S. (Dutkiewicz *et al.*, 1992).

Maple bark handler's disease has resulted from a sporadic exposure to a fungus associated with dead maple trees. Also, wood handlers in sawmills in British Columbia have reported occasional respiratory irritations. Inland workers, handling hemlock and fir, reported more symptoms of irritations than did coastal workers who handled red cedar (Enarson and Chan-Yeung,1990). The differences in microbial concentrations among different tree species and between heartwood, sapwood and bark (Dutkiewicz *et al.*, 1992) indicates the possibility for differing exposures to the type and quantity of microbial dusts. Those workers involved in debarking or processing of sapwood wastes into fiberboard or chipboard are also those exposed to high volumetric quantities of bacteria and fungi including AF (12,700, 52,800 and 65,200 CFU/m^3 for total fungi for heartwood, sapwood and bark respectively, described as predominantly *Penicillium* and *A. fumigatus*) (Dutkiewicz, 1989). This is relevant to composted wood chips, dust from which may support a considerable load of fungal spores, e.g., 1.4×10^6 CFU/m^3 fungi predominantly *A. fumigatus, A. niger, Penicillium* spp., *Rhizopus stolonifer, Cladosporium* sp. *and Trichoderma* sp. (Olenchock *et al.*, 1991). Measurements of fungi in the air at wood processing facilities have mostly been made in Scandinavian countries which are using wood as a fuel substitute for oil. Air sample analyses provide data on total viable fungi and on total fungal spore (viable and nonviable) concentrations (10^4 - 10^5 /cu. m.) , but do not numerically single out the AF portion of the airspora (Jäppinen *et al.*, 1987; Kolmodin-Hedman *et al.*, 1987). This reflects the recognition that AF is not the only or even the most important bioaerosol of concern in assessment of risk for ODTS, MMI and extrinsic allergic alveolitis associated with exposure to dust from chipped wood and bark. There is one report that includes a measurement for AF in a paper pulp factory, <12 CFU/m^3 (ERCO, 1980).

In summary, industrial exposures to bioaerosols can be quite intense, especially in the wood processing industry. The most significant levels of exposure in these environments are associated with the dust from handling moldy bark and sapwood. Levels are high and are comparable to those in moldy hay exposures, but do not appear to result in fungal pathogenesis, i.e., tissue infection. Data are insufficient to support a specific role for AF exclusively, but exposure to fungal antigens may be responsible for the respiratory complications cited since the measured levels of thermophilic actinomycetes (farmer's lung antigen) are generally low in wood processing exposures.

Cotton Dust

There are several important studies which show a close relation between the extent of different health effects and the amount of endotoxin in airborne cotton dust. In studies in cotton workers, relationships have been found for chest tightness (Cinkotai *et al.*, 1976) and decreases in FEV1 (a measure of pulmonary function) over the workshift (Rylander *et al.*, 1985; Sigsgaard *et al.*, 1992). Other studies that have been performed in experimental cardrooms with cotton workers (Rylander *et al.*, 1983; Rylander and Haglind, 1986) and with previously unexposed subjects (Castellan *et al.*, 1987) using up to 32 different samples of cotton from widely divergent geographic locations show similar relationships. A linear regression model of these data was used to calculate a threshold of *zero effect* for acute FEV_1 at 9 ng/m^3. A level of 33 ng/m^3 was defined as the threshold of acute effect in another study (Haglind and Rylander, 1984).

Associations between airborne endotoxin concentrations and chronic lung disease also have been reported. In an epidemiologic study of 443 cotton textile mill workers in two textile mills in China, a dose-response trend was observed between current endotoxin levels and chronic bronchitis (Kennedy *et al.*, 1987). Results indicated that exposures from 1-20 ng/m^3 constituted an adverse respiratory health effect in exposed workers.

From a separate epidemiologic study in the Netherlands, 315 animal feed workers related symptoms and lung function changes to present and historic endotoxin exposures more than to gravimetric dust levels (Smid *et al.*, 1992a,b). These investigators reported that lung function changes occurred at levels of airborne endotoxins of as little as 0.2 ng/m^3.

Other Estimations

Systemic and respiratory effects are thought to be the result of inhalation of endotoxin-laden organic dusts. The International Committee on Occupational Health, through its Committee on Organic Dusts reported that endotoxin may provoke different reactions when the exposure occurs at different levels (Rylander *et al.*, 1989). The Committee report states that ODTS is elicited at a level of 1000-2000 ng/m^3, acute bronchoconstriction occurs at 100-200 ng/m^3, and Mucous Membrane Irritation may occur at endotoxin levels of 20-50 ng/m^3. It is not known whether even lower concentrations trigger responses in sensitive individuals.

Compost Site Case Summaries

Large-Scale Composting Facilities

Currently there are over 200 biosolids composting facilities, 17 solid waste composting facilities and over 3,000 yard waste composting facilities in the United States (Goldstein *et al.*, 1994; Steuteville, 1994). Since the inception of sludge composting in 1976, there have been several studies on the effects of composting on bioaerosol production in relation to worker and public health in and around facilities (Millner *et al.*, 1977; Hampton Roads Sanitation District, 1981; Lees and Tockman, 1987; Clayton Environmental Consultants, 1983; ERCO, 1980; Kothary and Chase, 1984). The data have indicated that at distances of 250 to 500 feet from compost facility perimeters the airborne concentrations of *A. fumigatus* were at or below background concentrations. Presently, there are no published or documented studies on bioaerosols at solid waste composting facilities in the United States, however, there have been several studies in Europe (Boutin *et al.*, 1987; Lundholm and Rylander, 1980; Clark *et al.*, 1983). Data is also meager for yard waste composting or agricultural composting sites.

Washington Suburban Sanitary Commission (WSSC)

Several studies have been conducted at the Montgomery County Regional Facility first located at Dickerson, Maryland, and later at Site II, Silver Spring, Maryland, from

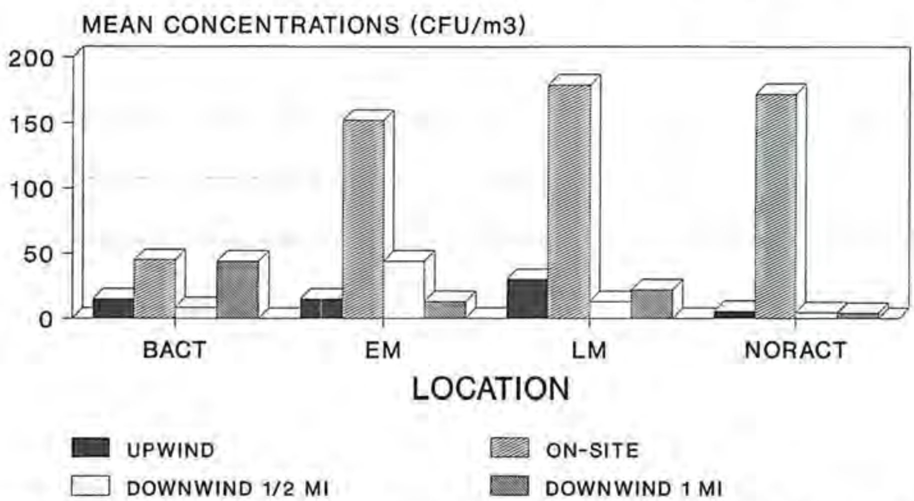

Figure 1. Concentrations of *Aspergillus fumigatus* at a biosolids facility in Dickerson, Maryland. Source: Cookson, 1983
Legend: BACT= before daily activity; EM= early morning w/o screening; LM= late morning w/o screening; NORACT= normal activity

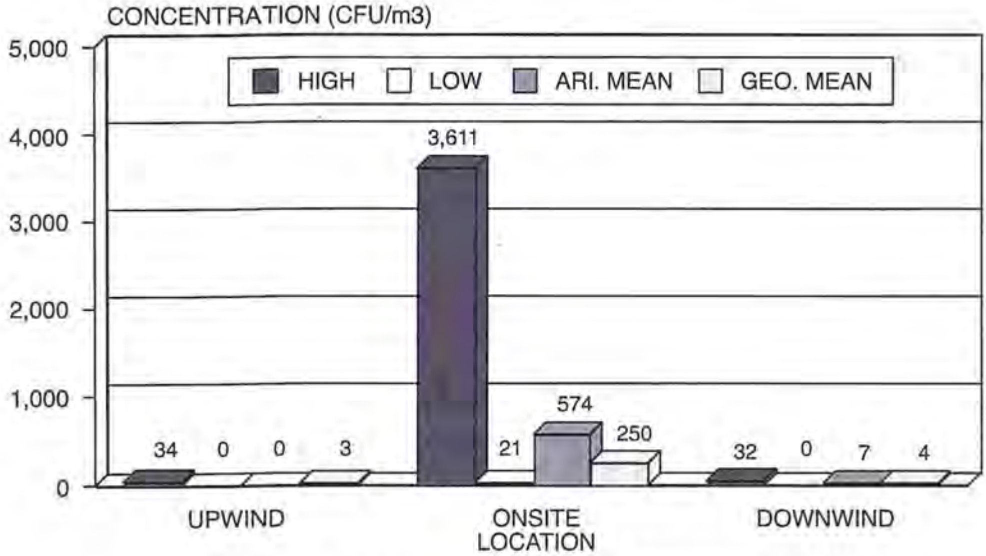

Figure 2. Concentration of *Aspergillus fumigatus* at or near WSSC Site II, 1990-1991
(Data from 12 locations) Source: General Physics Corporation, 1991

1978 to 1991 (Cookson *et al.*, 1983; Lees and Tockman, 1987; General Physics, 1991).

The Dickerson site was totally open with mixing, composting, curing and screening performed outdoors on a paved area (Figure 1). During composting activities the concentration of *A. fumigatus* was the same for both the upwind and downwind locations. These concentrations were comparable to background concentrations reported in the literature.

Studies at Site II began in 1983 (Lees and Tockman, 1987). During the period 1983 to 1986 the site was partially enclosed. Mixing and composting were done under cover, curing was totally in the open and screening was enclosed. The data reported by Lees and Tockman (1987) indicated that since the start of composting operations no increase in the frequency of or in the mean airborne concentration of *A. fumigatus* has occurred at community based monitoring stations. The geometric mean concentration for all 1,427 *A. fumigatus* samples was 3.4 CFU/m^3, with the maximum concentration at 88 CFU/m^3. The geometric mean directly at the compost facility was 22 CFU/m^3, with the maximum concentration being 144 CFU/m^3.

During 1990 and 1991, General Physics Corporation conducted further investigations on levels of *A. fumigatus*, thermophilic fungi, aerobic bacteria and mesophilic fungi. The data for *A. fumigatus* and thermophilic fungi are shown in Figure 2. The downwind sites were located 1,000 feet to 8,600 feet from the Site II perimeter.

An employee health surveillance program was established in 1987 at Site II (Chesapeake Occupational Health Services, 1991). There was no evidence of adverse health effects related to the exposure to *A. fumigatus* during the past five years.

Westbrook, Maine

A comprehensive monitoring of *A. fumigatus* was conducted for the Portland, Maine Water District in 1979 and 1980 at Westbrook (ERCO, 1980). All site activities were performed in the open on a paved surface. The highest concentration was found at 30 meters from the site center. At 90, 150 and 1,500 meters, levels of *A. fumigatus* were at background levels (Figure 3).

Windsor, Ontario, Canada

A comprehensive air sampling program was conducted in 1983 at the composting site, wastewater treatment plant and surrounding areas (Clayton Environmental Consultants, 1983). At distances greater than 400 feet the airborne concentrations of *A. fumigatus* were below 20 CFU/m^3 (Figure 4).

Solid Waste Composting Studies

Lundholm and Rylander (1980) reported that workers at an experimental refuse compost facility had a higher incidence of subjective symptoms, such as nausea, headaches and diarrhea. Eleven employees were evaluated. Two reported nausea, one reported fever, five had headaches and four had diarrhea. This was attributed to possible exposure to endotoxins.

Rylander *et al.* (1983) studied exposure to aerosols of microorganisms and endotoxins in sewage treatment and composting plants in the United States and Sweden. Data from composting plants showed average airborne dust levels ranging from 0.1 to 12.0 mg/m^3. The highest levels (median 10.6 mg/m^3) were found in the screening areas. The lowest levels were near compost piles. The respirable proportion of gram-negative bacteria was in the range of 50 to 60 percent. They concluded that too little information is available to establish dose-response relationships which might be used to suggest standards. Rylander *et al.* (1983) suggested that a level of up to 1,000 gram-negative bacteria /m^3 and 0.1 ug/m^3 of endotoxins should be considered as safe until additional information is available. More recently, the International Committee on Occupational Health has recorded 0.02-0.05 ug/m^3 as sufficient to elicit an MMI response.

Clark *et al.* (1983) studied the airborne gram-negative bacteria, endotoxins (lipopolysaccharide dust) and *Aspergillus fumigatus* at four Swedish composting

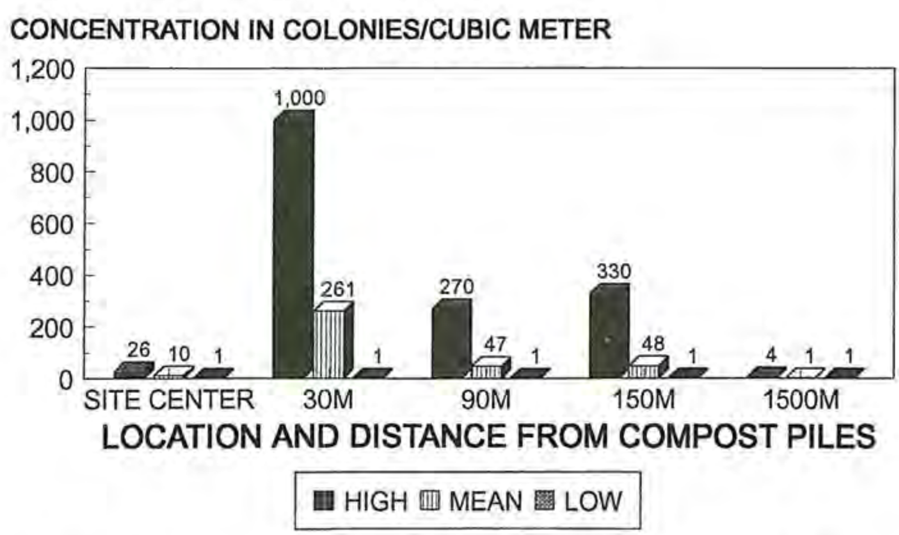

Figure 3. Concentration of *Aspergillus fumigatus* at the Westbrook, Maine Composting Facility
Source: ERCO, 1980

plants. Three plants composted a mixture of solid waste and biosolids. The fourth composted biosolids and wood chips. Both indoor and outdoor sites were sampled at various operational locations. A considerable range of microbial concentrations were found in all plants. Airborne concentrations of gram-negative bacteria ranged from 0 to 3.7×10^5 CFU/m^3. Refuse hoppers, waste processing areas and screening areas had the highest concentrations, i.e., 0.15×10^5 to 3.7×10^5 CFU/m^3 with medians of 0.43×10^5, 0.94×10^5 and 0.96×10^5 for the respective areas. In most cases, more than half of these airborne concentrations were in the respirable size range. Endotoxin values ranged from 0.001 to 0.042 ug/m^3, well below the suggested safe levels of 0.1 ug/m^3.

Yard Waste Studies

Zwerling and Strom (1991) reported on a study in four communities in New Jersey. They found high airborne concentrations of *A. fumigatus* on-site during activity and concentrations equivalent to low background levels during periods of no activity. During high activity, AF concentrations at the composting sites exceeded 5×10^3 and at some places 7×10^4 CFU/m^3. However, during periods of work activity the concentrations dropped significantly at 100 m (300 ft) and 500 m (1500 ft) downwind. At 100 m downwind, the airborne concentration was at 354 CFU/m^3 and at 500 m it was 86 CFU/m^3. These numbers were within the range typical of background concentrations.

A recent report on AF at a Connecticut yard waste composting site reported concentrations ranging from 0 to 2,648 CFU/m^3 on-site and 0 to 11 CFU/m^3 downwind at distances of 500 feet to 1 mile (Figure 5.). The downwind measurements were similar to levels found at background sites located remotely from the facility (E&A Environmental Consultants, Inc., 1993).

Aerobiology specialists at the New York State Biological Survey analyzed air samples collected at four locations on and around a large yard waste composting facility at Islip, N.Y. (ICF). Continuous samples were collected from August-October, 1992 us-

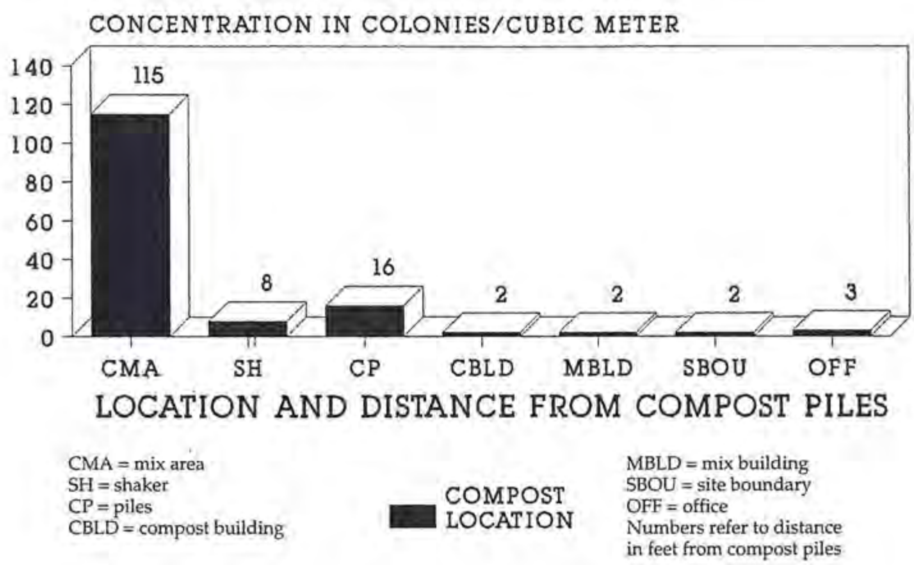

Figure 4. Concentration of *Aspergillus fumigatus* at West Windsor, Canada
Source: Clayton Environmental Consultants, Ltd., 1983

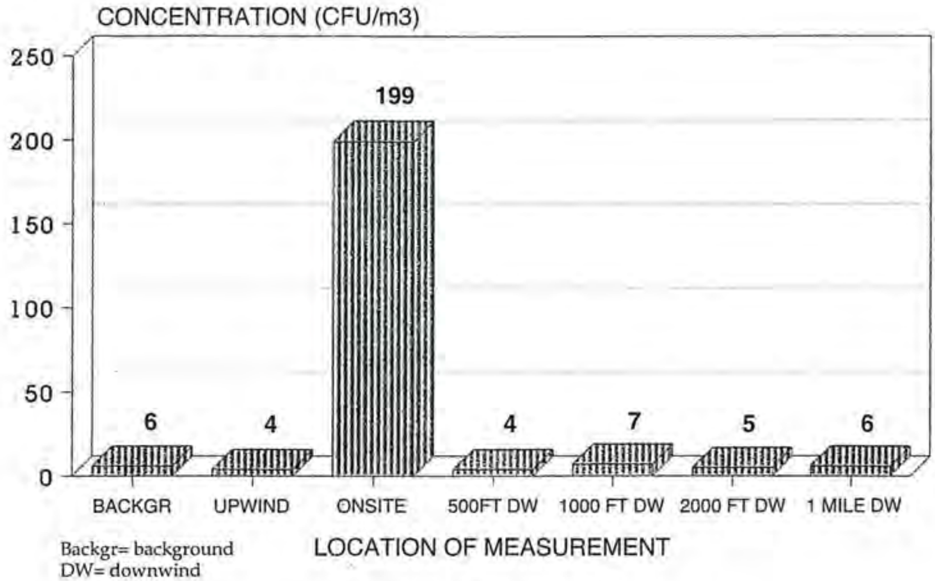

Figure 5. Average concentration of *Aspergillus fumigatus* at or near a Connecticut yard waste facility
Source: E & A Environmental Consultants, Inc., 1993

ing a Burkhard spore trap and were analyzed for total (viable and nonviable) fungal spores and for *Aspergillus fumigatus* (AF). Periodic air samples were also collected concurrently for viable AF and thermophilic actinomycetes with an RCS sampler by Suffolk County Health Department. Volumetric spore counts were obtained for the ICF; Union Ave., a residential neighborhood about 500 m downwind of the ICF (under prevailing summer wind conditions); an airport site about 800 m upwind of the ICF; and at Fisher Ave., Islip Terrace, about six miles (10 km) upwind of the ICF. Total airborne spore concentrations were similar at all four sample sites. The average "background" AF airborne concentrations (at Fisher) were 65 spores/m^3 and mean airborne AF concentrations at ICF and Union were 710 and 300 spores/m^3, respectively (J. Haines and L. Syzdek, pers. communication). Average viable airborne AF were 56 CFU/m^3 at Fisher and 600, 81 and 20 CFU/m^3 for ICF, Union and the airport. Mean viable thermophilic actinomycete concentrations were 36 CFU/m^3 at Fisher, and 480, 110 and 33 CFU/m^3 at ICF, Union, and the airport respectively (J. Haines and L. Syzdek, pers. communication). Allergy and asthma symptoms that were reported by Union and Fisher community participants in a concurrent diary study, were evaluated and analyzed by the New York State Health Department. Analyses showed that symptoms were not significantly associated ($P>0.05$) with airborne concentrations of spores in the two neighborhoods (E. Horn, pers. communication). However, symptoms were significantly associated ($P<0.05$) with an 'environmental factor', which was a derived variable, i.e., a multivariate correlate of temperature, ozone and ragweed pollen.

Ultimately, it appears that a clear resolution to a number of questions about possible health effects associated with siting a large yard waste composting facility within relative close proximity to residential communities will not be achieved using the Islip or other previous study data. The statistical power needed to distinguish significant health effect trends will require a very large number of symptom (diarist) respondents and objective measures of health effect responses wherever possible, along with hourly spore counts, even if only for a relatively short period of time, e.g., 4 weeks. Thus, the existing studies provided explicit site data as well as guidance for improved study designs for the future.

Individual Case Studies

There have been very few reported cases of health effects in workers, nearby residents or other persons associated with composting.

Kramer *et al.* (1989) reported on a case of a young man who was an asthmatic for 16 years and who was treated with immunotherapeutic agents. The individual resided 250 feet from a municipal leaf composting site and developed allergic bronchopulmonary aspergillosis (ABPA) which was related to *A. fumigatus*.

Zuk *et al.* (1989) reported that a young man who worked as a gardener for 14 years contracted a fatal locally invasive pulmonary aspergillosis in the absence of predisposing conditions.

One particular human exposure which received multidisciplinary scientific examination involved a case of severe respiratory illness that developed in a person after shoveling two truckloads of composted wood chips (Olenchock *et al.*, 1991). The lung disease was described as an acute hypersensitivity pneumonitis (HP) or organic dust toxic syndrome (ODTS), (Weber *et al.*, 1993). Bulk materials and airborne dusts (obtained through subsequent reenactment) were tested for the presence of bioaerosol agents. Endotoxins (98.9 to 934.7 endotoxin units (EU)/mg, bulk dust; 636.5 EU/m^3, inspirable dust; 771.89 EU/m^3, respirable dust) were quantified. Viable airborne total bacterial levels were 6.3×10^5 CFU/m^3; gram-negative bacteria, 2.9×10^5 CFU/m^3; thermophilic actinomycetes, 3.2×10^2 CFU/m^3; and total fungi 1.4×10^6 CFU/m^3. In addition, predominant fungi were identified in the bulk materials and airborne dust as *Aspergillus fumigatus, A. niger, Penicillium* spp., *Rhizopus microsporus, R. stolonifer, Absidia* sp., *Cladosporium* sp. and *Trichoderma* sp. Specific antibodies to *A. fumigatus* and *A. niger*, which were biomarkers of that exposure, were detected in the blood serum of the affected individual. Biomarkers for effect, i.e., HP or ODTS, were observed clinically in the patient.

Facility Design and Mitigation of Exposure

Factors Contributing to Exposure

The primary exposure of potential concern is inhalation of bioaerosols and derived products emitted from compost facilities. Health risks might only occur at or around active compost sites where susceptible human receptors are present along with material that contains biologically active agents that may become aerosolized. Factors which may contribute to exposure can be classified as: 1) physical and meteorological characteristics and 2) operational characteristics.

Physical and Meteorological Characteristics

Meteorological characteristics at a site, in conjunction with topography, may affect the exposure of workers and nearby public to bioaerosol emissions from compost facilities. If the design goal is to maximize diffusion and distribute aerosols over a large area (so as to decrease atmospheric concentration), then the facility design should attempt to utilize winds and higher points of release. If the design goal is to keep the mass of airborne material close to the facility, then composting operations should be shielded from winds and preferably emit aerosols at low heights, or even from elevations below surrounding sensitive areas. Existing atmospheric diffusion models may be used to estimate the impact of facility emissions on sensitive receptors (Millner *et al.*, 1977; Lighthart and Frisch, 1976; Lighthart and Kim, 1989).

Operational Characteristics

Limited data are available to quantitatively evaluate the effectiveness of various operational characteristics on bioaerosol emissions. In the past, facility operations focussed on process efficiency, achievement of pathogen kill and odor control. However, there are data that are relevant to the outdoor static pile composting of sewage sludge utilizing fresh and recycled wood chips as bulking agents. The emission rate for AF spores released from woodchip/sewage compost handled by front end loaders was determined (Millner *et al.*, 1980); mechanical agitation of compost material was a major source of airborne emissions. This suggests that reduced bulk movement of compost and use of dust control measures will minimize bioaerosol releases. The study also suggests that few of the aerosolized microbes originated as wind blown losses from static piles of compost. This was consistent with the situation in the U.K. (Mullins *et al.*, 1976) in which 170,000 CFU/g were recovered from compost, with only an average of 33 CFU/m^3 recovered from the air alongside the compost heap. In tests in the U.S. during mechanical agitation of compost by a front end loader (FEL), downwind concentrations of thermophilic actinomycetes and fungi were 150-200 times greater in the immediate working area.

At least a few other mechanisms are identified that will contribute to increases in airborne bioaerosols losses: mechanical agitation of wheels and tires of equipment; physical handling of the materials, and downdrafts onto dust-laden traffic surfaces. High levels of AF are also associated with FEL movement of stored/stockpiled wood chips, other vehicular movement across dust covered surfaces and screening of compost (21 day) piles. Curing the compost for one month or more can markedly reduce levels of AF found (Millner *et al.*, 1977). It must be stressed that the results from the Beltsville static pile method are very specific for this process method and materials handled. It would be misleading to generally apply these results to other composting processes and materials without evaluating the potentially critical differences, i.e., size of the overall operation and site, the amount and frequency of organic dust generation sources, the feedstocks, the pile configuration and overall process and site management . Other types of composting facilities should be studied to determine the effect of operational characteristics on bioaerosol emissions.

Mitigation Through Facility Siting, Design and Operational Changes

When siting new facilities, critical evaluations should be made of several factors including the proximity to residences and public facilities and meteorological/topographical parameters that contribute to off-site transport of bioaerosols. The proximity to residences and public places should also be a key consideration when upgrading composting facilities. Required buffer areas can be greatly reduced with enclosure, good management practices and increased mechanization of the facility. The layout of composting activities associated with bioaerosolization, particularly material handling processes, should be located downwind or as far as possible from sensitive receptors. From the engineering perspective, the design principle of compost facilities should closely follow the natural biological process, requiring minimal intervention or handling of composting materials. Dispersion modeling of bioaerosol emissions may be helpful, although such models are predictive in nature and may generate results that are highly uncertain (Millner *et al.*, 1977; Lighthart and Kim, 1989).

Good management practices for the operation of compost facilities are well defined in state and federal regulations. These practices have primarily considered operational efficiency, pathogen kill, production of a good compost quality and dust and odor control. As noted above, data support the contention that an open or an enclosed static pile sewage sludge facility utilizing virgin and recycled wood chips does not contribute to a significant elevation of bioaerosol levels off-site. We believe that additional studies on other types of compost facilities are needed to determine the effectiveness of the following operational methods which should lead to reduced bioaerosol emissions in the event that is prudent to do so with respect to the protection of public and worker health: 1) Use of added moisture in the composting materials and/or area water spraying to control all particulate emissions from the operation (EPA Guidelines for Controlling Fugitive Emissions OAQPS RTP-NC, 1978); 2) Mechanical agitation (handling) of materials with a high potential for creating bioaerosols should be minimized consistent with the need to maintain other controls; 3) Agitation of compost materials should be timed to coincide with the stage of the material when: a) the potential for release of bioaerosols is minimal, b) the potential for off-site dispersal is minimal and/or c) the receptor populations are least; and 4) Temperature and moisture conditions of bulking agents should be managed to minimize formation of bioaerosols.

Site Enclosure

In addition to careful attention to good management practices, the use of enclosures and managed air streams may need to be considered, particularly at sites in close proximity to potentially sensitive populations. Careful attention will need to be paid to worker exposures and protection in such circumstances. Data available from the WSSC Site II studies (Lees and Tockman, 1987; General Physics Corp., 1991) indicates that on-site AF levels increased 11-fold when the site was enclosed. Prior to enclosure (4/1/83 - 5/31/86), AF were 22 CFU/m^3 (geometric mean) on-site. After enclosure (May 1990 - April 1991), AF increased to 250 CFU/m^3 (geometric mean). In October 1991, Chesapeake Occupational Health Services reviewed the health surveillance data maintained for Site II workers from its inception in 1987 and found "no evidence of adverse health findings related to exposure to AF" (Chesapeake Occupational Health Services, 1991).

The use of filters has been evaluated primarily for effectiveness of odor control. The use of biofilters or chemical scrubbers (used primarily to control odors in enclosed facilities) has not been evaluated specifically for their capacity to retain bioaerosols. Considerable data exists relating to the efficacy of electrostatic precipitators and dry bag houses in removing particulates from industrial stack emissions. However, the efficiency of bioaerosol removal with these technologies remains untested. We recommend that biofilters and scrubbers be evaluated for their bioaerosol removal efficiency. The design of such studies should consider the fact that previous investigations (Mullins *et al.*, 1976; Millner *et al.*, 1980) have shown that *static* compost piles exposed to low or moderate levels of atmospheric turbulence do not release a continuous stream of AF spores into the air. Furthermore, AF, unlike, some other fungi, does not have an inherent mechanism for forcible ejection and propulsion of its spores (conidia) into the surrounding atmosphere; this fungus depends on external mechanical movements for dispersal of its spores.

Dispersion Control

Site modifications can be used to enhance or inhibit the dispersion of bioaerosols to minimize off-site effects. Berms may be built and/or trees planted at strategic locations on the site to alter wind dispersion patterns and entrainment of bioaerosols generated by the facility. Tree barriers have an aesthetically pleasant appeal around waste treatment facilities and have often been suggested for visual benefit as well as the benefit of reducing dispersion of airborne microorganisms from the facilities. Experimental evidence for a forest barrier benefit was produced by Raynor *et al.*, 1974 in their very detailed study of particulate dispersion into a 90 percent pine forest having a stem density of 1,474 trees per hectare and a mean tree height of 10.5 to 13 m (over the years of the study) at Brookhaven National Laboratory, Upton, New York. They demonstrated that "the forest edge modifies dispersion primarily by changing local meteorological conditions and flow patterns and secondarily by direct removal of particles," i.e., by impaction and deposition onto foliage. Particulate plumes moving unobstructedly over open terrain are significantly broadened, both horizontally and vertically, when they encounter a forest edge; this in effect dilutes the concentration of particulates in the plume. The amount of broadening is influenced by the foliage density (Raynor *et al.*, 1974). Dense foliage at the edge would have the same effect as a solid object, i.e., pronounced vertical dispersion, whereas in a forest with open trunk space at the edge maximum penetration and minimum broadening of the plume would occur with much channeling of air into the subcanopy level. They also found that "the intensity of turbulence within the forest reaches a maximum at midcanopy level." In addition to this study, there is considerable knowledge and experience showing that vegetative windbreaks are very effective controls for wind erosion, particularly in the Great Plains regions of the U.S. Air dispersion models currently available (Turner, 1974; Gifford, 1961; Pasquill, 1961) should be useful in the evaluation of this issue at local sites.

Buffer Distances

In general, the specification of appropriate buffer distances depends on the site location, design, local micrometeorological conditions and emission controls. No setback may be necessary for totally enclosed facilities, if all activities are enclosed and ventilation control is provided. A number of sewage sludge composting facilities have been empirically evaluated. Studies at the closest residence (0.4 and 0.5 miles) to the WSSC Site II and Dickerson in Maryland suggest that bioaerosols are not elevated above background.

Airborne AF levels were measured at the WSSC Site II prior to operation as 0-42 CFU/m^3. When WSSC Site II was operated as an open facility, airborne AF were measured at or below 43 CFU/m^3 in three years of operation. However, slightly elevated levels of AF were detected at the nearest off-site receptor (about 500 feet from the active composting pad). When the site was enclosed, AF levels were similar to prior background. Zwerling and Strom (1991) have measured airborne levels of AF at varying distances from several yard waste composting facilities at different stages of operation. The facilities represent varying levels of management expertise. Sampling was also conducted at the Islip Composting Facility in Islip, New York which was handling yard waste and a complete report has been compiled by the investigators (Department of Health, 1994). We are not aware of any others.

Limitations To Determinations Of Exposure

Environmental Sampling Data Needed

In order to evaluate the impact of bioaerosols on populations living and working in areas near composting facilities, more data are needed about the natural, ambient concentrations in air of compost process-associated microbes (of concern as potential pathogens and allergens to humans). Statistically significant and consistent increases in natural concentrations in air are inherently difficult to measure in the outdoors because of the multitude of environmental variables that influence individual sampling events. Time averaged data, from multiple sites in an area would be desirable. Technical limitations to the analysis of spore collections currently limit the number to samples that can be analyzed, primarily because the expertise for the microscopic analyses is in short supply. Data also are needed regarding the prevalence of thermophilous and thermotolerant actinomycetes and fungi for more regions of the U.S.

Lack of suitable sampling technology has limited the study and understanding of bioaerosols. Therefore, if the labor cost of generating large data bases containing information on airborne fungi, actinomycetes and bacteria could be reduced, a much clearer understanding of the atmosphere in and around composting facilities as well as the natural environment would be available. Results obtained with Andersen samplers require considerable interpretive skill and are restricted to a single sample for a set time period. In very dusty situations, the agar collection surface can rapidly become overloaded; thus, sample times in dusty environments may need to be quite short. This requires more frequent sample events. The biotest handheld sampler eliminates the need for large numbers of plates of media but requires interpretation and is restricted to a single time period. The Burkard impaction type sampler runs continuously and makes an ongoing record that can be analyzed for any point in time, but microscopic analysis of the spore collection requires intensive use of a high resolution microscope with difficult and subjective identification. The Burkhard sampler has a 50 percent collection efficiency for particles with an aerodynamic diameter of approximately 2.5 µm; consequently the Burkhard may have a suboptimal collection efficiency for small, individual spores such as those of *Penicillium* and *Aspergillus* spp. Slit samplers using media plates are both continuous over time and readable on the surface of the media, but they suffer from high labor input necessary to maintain media and the inability to detect nonviable spores which may be allergens.

A continuous volumetric sampler which is based on objective detection techniques rather than subjective interpretation is needed. The ideal sampler for monitoring compost facilities and neighborhoods would generate data on specific bioaerosols such as AF on-site, automatically read the data and transmit it to a database. A sampler that continuously collects airborne particles so that daily and hourly fluctuations can be detected with molecular or immulogical probes would be ideal. This would be a monitor which could detect problems as they happen so that they might be corrected. The Burkard or other impaction samplers can generate a plastic strip with all particulates 2 µm and longer. This sample might be treated with immunofluorescent antibodies to specific fungal spores and the results could be read easily. Bacteria and actinomycetes would require sampling technology adjusted to the smaller particle sizes involved.

Most downwind collections of bioaerosols have been very patchy, temporally and spatially. With brief samples taken monthly, weekly or daily, the detailed nature of the bioaerosols cannot be elucidated. It is a hit or miss pattern in the complicated nature of a diffusing, rising, turbulent bioaerosol plume which may miss a target sampler (or person) entirely or which may deposit a heavy concentration of material onto it. Continuous data over a season or year would be desirable, instead of intermittent samples. Total bioaerosol inhalation is important for allergic response. It is the dispersal over time that is important rather than a few spot samples. More downwind measurements are needed to soundly recommend setback distances of compost facilities from population centers.

Specific aspects of the microbial ecology of composting are incompletely understood. What is the location within the pile that produces fungal spores as opposed to fungal vegetative growth? What is the colony configuration of the compost pile? Are the organisms that are present genetically and immunologically uniform? If so, then fungus or actinomycete spores can be identified as to their site of origin. Are different bioaerosols emitted from different composts? Are unique allergens or pathogens produced by food wastes, feedstocks, fruit pomaces, yard wastes and sewage sludge?

Quantitative data are needed on the effects of compost management techniques on bioaerosols. In order to manage a compost facility with minimum emissions of bioaerosols, the effect of turning a static pile at shorter or longer intervals, the effect of hotter or cooler inner and outer pile temperatures, the effect of air movement, the effect of H_2O content and other parameters need to be known.

Risk Assessment

Risk assessment is traditionally divided into the following components: hazard identification, exposure characterization, exposure response analysis and risk characterization. Elements of the first two components of this process, hazard identification and exposure classification, have been addressed in the previous sections of this report. In particular, the hazards associated with bioaerosol exposures include inflammation, allergy and infections from primary and secondary (= opportunistic) pathogens. The principle remaining question is: At what exposure levels do these health effects occur? Thus, this section focuses on discussion of studies that specifically evaluate the risk of exposure to bioaerosols among workers and the community, and what is known about the relationship between exposure levels and response.

Exposure Assessment of Bioaerosols at Composting Facilities

Exposure pathways are one of the first considerations for a risk assessment evaluation (Goldsmith and Berglund, 1974). The mechanisms for transport from composting operations are both direct and indirect. Direct transport results when composting material is transported off-site by individuals or equipment. Compost is essentially pathogen free and is a lower infectious agent risk to workers then is sewage sludge. Other microbial organisms are considered comparable to typical levels found in wood mulching and other soil conditioning materials. Thus, direct transport has not been considered a significant exposure route.

The indirect transport mechanisms include water runoff and air suspension. Water runoff controls, collection and discharge to sewage treatment facilities are standard practice. Thus, exposure by the water route is unlikely. The only potential exposure transport mechanism that requires detailed consideration is air suspension and transport to populations as a bioaerosol.

The transport of bioaerosols was evaluated by WSSC Montgomery County Regional Composting Facility, Silver Spring, Maryland using computer generated air dispersion models as predictors of downwind distance for maximum bioaerosol concentrations. Field sampling was performed twice monthly at upwind, on-site and the predicted maximum downwind locations for a full year. The numerous environmental and atmospheric conditions that influence the transport of bioaerosols were factored into the predictions. Many parameters that have a major influence are site specific including micrometeorological conditions, the elevation of the bioaerosol discharge from the compost site, the size of the facility and the bioaerosol release rate. Release rate is a function of the facility design and treatment controls. Thus, generalizations on transport and health significance from one facility may not apply precisely to another. Each requires a specific risk assessment evaluation. However, most data indicate insignificant bioaerosol transport from a well operated and designed compost facility. Viable airborne microorganisms were analyzed by groups at Site II: total aerobic bacteria, mesophilic fungi, thermophilic fungi and AF. Of the four groups, three did not demonstrate elevated downwind concentration at a 95 percent confidence level. The downwind aerobic bacterial concentration was elevated at the 95 percent confidence level. Downwind concentrations had a geometric average of 160 CFU/m^3 and the upwind concentrations averaged 83 CFU/m^3.

However, the data for mesophilic fungi and AF do not demonstrate higher downwind than upwind concentrations at sampling locations that should yield maximum off-site concentration.

For this 400 wet ton per day sewage sludge composting facility, the transport mechanism is not sufficient to expose an off-site population to levels of AF that are above those measured in nature and that occur as part of the common airspora. If the transport mechanism is insufficient to expose a population group, then further evaluation is unnecessary and close relationship data is not required.

Dose Response Information

This section presents an overview of the state of knowledge of dose response information available on compost related bioaerosols. Because of the apparent complexity of human and animal immune response to biological agents, clearly defined effect levels are not presently available for the vast majority of compost related bioaerosols. Limited occupational data exist regarding worker exposure to certain bioaerosols. To the extent that these occupational data enable an assessment of acute and chronic health effects, they are incorporated. It should be recognized that, while occupational data are generally more useful than animal dose response data in assessing the relative health effects among the nonworker population, they are not directly applicable without adjusting for a higher exposure frequency to account for 24 versus 8 hours and for sensitivity among individuals in the general population.

Endotoxin

Based on experience from field studies of workers in cotton mills, swine confinement buildings and paper mills, guidelines for endotoxin exposure have been suggested (Rylander,1987) for the various health effects which may appear.

Acute Effects

In 1989, the International Commission on Occupational Health (ICOH) published suggested occupational health criteria for acute effects to endotoxins (Rylander *et al.*, 1989). Three discrete health effects were identified which ICOH felt warranted exposure level criteria. Table 2 shows the different types of responses that can result from inhalation of organic dusts, the symptoms and the suggested threshold levels of endotoxin that would protect against possible acute effects including (1) Organic Dust Toxic Syndrome (ODTS), (Toxic Pneumonitis), (2) Broncho-Constriction (BC) and (3) Mucous Membrane Irritation (MMI).

Chronic Effects

ICOH also provided criteria recommendations on permissible endotoxin levels for workers exposed to endotoxins in the cotton textile manufacturing and animal feed industries (Rylander *et al.*, 1989). Based on adverse respiratory effects (particularly broncho-constriction), ICOH suggested the following exposure levels:

Industry	Permissible Endotoxin Concentration (ng/m^3)
Cotton Mills	1.0-20
Animal Feed	0.2-470

In a recent study, Sigsgaard *et al.* (1990) assessed occupational health effects of workers at a garbage sorting facility in Denmark. A range of threshold limit values (TLVs) were proposed for endotoxins (0.1 to 0.2 µg/m^3);gram-negative bacteria were not to exceed 1,000 CFU/m^3 on average for an eight hour work day; and total bacteria were suggested to be maintained at a level ranging from 5,000 to 10,000 CFU/m^3 (Sigsgaard *et al.*, 1990).

Aspergillus fumigatus

There is an absence of dose-response information available characterizing either acute or chronic human health effects associated with exposure to AF in compost related bioaerosols. Available data qualitatively associate AF concentrations with the presence or absence of clinical health effects. There is an apparent lack of data correlating specific exposure levels to observed health effects. Nevertheless, until such quantitative studies are completed (if at all possible), the lack of compost worker health effects suggests that the highest exposure group (albeit "healthy") are not at increased risk.

Occupational Studies

There are two studies on workers exposed to bioaerosols at composting facilities and the results from these studies are inconclusive. Lees and Tockman (1987) conducted a formal study of respiratory effects among a group of workers employed at a compost facility (WSSC Site II) in Montgomery County, Maryland. The records used were collected by the Maryland Department of Health and Mental Hygiene and not by the study investigators. A total of 31 people with at least one follow up visit were included in the analysis. The average length of time between the preemployment and follow up examination was approximately 3.7 years. Information from pulmonary function testing, questionnaires and chest x-rays were evaluated. The investigators (Lees and Tockman, 1987) did not find any significant differences between the preemployment results and the follow up tests. These results must be viewed in the light of the small number of workers involved and the relatively short period before the follow up examination.

There were some statistically nonsignificant differences in this study that were notable. Workers at the follow up examination reported a higher percentage of allergies, asthma, 'lung trouble' and shortness of breath than at the preemployment examination. Based on pulmonary function test results, a higher percentage of workers demonstrated obstructive lung function patterns at follow up. However, abnormal pulmonary function results were very high in both the preemployment screening and follow up studies with no consistent pattern of abnormal results which make these results suspect. Finally, the report cited two cases which showed abnormal chest x-rays that could be consistent with *Aspergillus* infection, but the individuals were negative for *Aspergillus* serum antibodies.

The second study (Clark *et al.*, 1984) included 84 workers from four facilities who were directly involved at the composting sites with various stages of the process. The study also included 157 workers who were classified as having an intermediate level of exposure and who were occasionally involved in the compost process or whose job locations were within 100 m of a composting activity and 133 controls who were not involved in the compost operations or whose job locations were greater than 100 m from the site. A cross sectional study was performed on these workers which included pulmonary function testing, chest x-rays, serologic tests and culturing of *A. fumigatus* from the throat and nose. An excess of nasal, ear and skin infections, and of eye and skin irritation was observed in the compost workers relative to the control group. However, the same conditions were present in even higher numbers in the intermediate exposure group than it was in the compost group. The results were contrary to expectations since it was assumed that the compost group had higher exposures to bioaerosols than the intermediate exposure group. The study clearly demonstrated elevations of AF in the nose and throat of compost workers, providing evidence of exposure but no evidence of infection. There were also indications of increased white blood cell count, eosinophils and hemolytic complement among compost workers, which is indicative of a low level inflammatory response.

There was one case report of aspergillosis in a worker exposed to moldy wood chips (Conrad *et al.*, 1992). In this case, a subject with chronic granulomatous disease (CGD) was occupationally exposed to AF spores while shoveling moldy wood chips and subsequently developed a fatal pulmonary infection caused by AF. This case is noteworthy in that the subject's congenital immune defect placed him at risk of infection and the authors conclude that such patients should be advised to avoid occupational environments where exposure to high spore concentrations is possible.

Summary and Recommendations for Further Research

The primary goal of this collaborative workgroup was to evaluate the results from the few available quantitative studies that might answer the question of what levels of bioaerosols are "safe" and what levels of protection are adequate for occupational and public health. A second goal was to clearly identify and to whatever extent possible, prioritize future research needed to fill existing gaps in the data.

There is little doubt that if traditional dose response modeling and quantitative risk assessment could be performed, more robust conclusions could be derived from the data. However, differences in human immune responses preclude the likelihood that specific minimum effect levels will be developed. There are some dose-response data for endotoxin. However, direct experimental resolution of the dose-response issue of microbial bioaerosols may not be feasible, especially in terms of human populations. This information would be valuable in determining the relative risk to the general population, the segments of the population that are at increased risk because of their preexisting medical/immunological/genetic conditions or predispositions.

The following conclusions represent the consensus of this committee after their review of the existing scientific and technical literature/reports that deal with exposures to compost bioaerosols and the health effects associated with them:

There is little reason for concern about the risk of potential infections from exposure to *A. fumigatus* among healthy individuals in either the general population (defined as nonoccupational exposure) or workforce exposed to composting bioaerosols.

There are subpopulations within the general population and workforce that may be at increased risk from exposure to composting bioaerosols. Of particular concern, immunocompromised and/or immunosuppressed individuals (e.g., chemotherapy recipients, organ transplant recipients, AIDS patients, individuals with congenital defects and children with cystic fibrosis who may be at increased risk of infection) may have greater susceptibility to colonization and infection by *A. fumigatus*.

Atopic/asthmatic individuals may be at increased risk for developing allergic reactions to various components of composting bioaerosols. A variety of common components of aerosols (e.g., pollen, fungal spores, house dust) are associated with allergic reactions or can induce asthmatic reactions.

Compost worker exposures to bioaerosols may be sufficiently high in certain circumstances to increase the risk of some adverse health effect. Although convincing evidence for an increase in risk has not been documented in any of the studies performed to date, the designs of these studies have limitations that make it difficult to draw definitive conclusions.

There is currently a total lack of dose-response data with which to quantify the risks for components of compost bioaerosols, with the possible exception of endotoxin.

Although there is dose-response information for endotoxin from gram-negative bacteria, there is currently inadequate exposure data to characterize the risk of exposure. Available data suggests that the risk of exposure to the general population may be minimal.

Available epidemiologic studies of both the workers and the general population are inadequate solely to determine whether or not significant risk exists from exposure to compost bioaerosols.

It appears that nonatopic individuals can become sensitized by constant exposure to bioaerosols. This is an area which warrants further investigation.

Epidemiological investigations to address both issues of hazard identification and dose response to bioaerosols are needed, in the occupational and in the general populations, who are either exposed to leaf, biosolids and/or garbage composting. The feasibility of conducting the following types of studies should be explored:

1) Longitudinal studies of occupational cohorts that include: a) quantitative estimates of levels of exposure to the various pathogens contained in the bioaerosols, b) medical history and questionnaire data and c) measurements of pulmonary function, chest x-rays and d) changes in antibody levels to specific antigens made from a pool of known serotypes from that specific environment. This type of study would hopefully provide the critically needed information on dose-response relationships.

2) Longitudinal cohort study that is community/population based and includes: a) medical history and questionnaire data, b) measurements of pulmonary function, chest x-rays and c) changes in antibody levels to specific antigens made from a pool of known serotypes from that specific environment.

3) Case control study of laboratory confirmed cases using Aspergillus isolates obtained within the vicinity of the composting facility. Controls might be other patients from hospitals or other health care facilities that were the source of the cases. The controls might be matched to the cases on other risk factors (e.g., age and sex). Information on residential exposures including indoor air sampling as well as outdoor ambi-

ent air would be collected for both cases and controls.

4) The development and implementation of a questionnaire to solicit information from residents living near composting facilities, as well as residents in neighborhoods where no composting facilities exist. The questionnaire should be structured as a general environmental health questionnaire and not specifically "targeted" at individuals residing around composting facilities. The questions may include inquiries of noise, odor, vibration, as well as specific health interests to assess specific allergy, history of immunosuppressive drug utilization and a general health history of significant illnesses/medical conditions among residential members. This type of research tool and approach has been successfully utilized in Sweden and in New York State in residential areas surrounding manufacturing facilities.

Appendix I

Composting: Scope and Process

Most urban areas of the U.S. currently face serious problems in safe/effective management of wastes, especially two major municipal wastes, i.e., sewage sludge and municipal solid waste (refuse). The limitations to traditional waste management practices are acute. Many landfills and incinerators have closed and new disposal facilities are increasingly difficult and costly to site and operate. In 1990, nearly 196 million tons, or 4.3 pounds per person per day of municipal solid waste (MSW) were generated. After materials recovery for recycling and composting, discards were 3.6 pounds per person per day. Virtually all of these discards were combusted or sent to a landfill. Without any additional source reduction, the amount of waste generated in 1995 will reach 208 million tons; by 2000, waste will near 222 million tons, or 4.5 lbs. per person per day. The per capita figure for the year 2000 represents a five percent increase over 1990 levels (USEPA, 1992). The current annual production of sewage sludge in the United States is approximately 7.7 dry million metric tons or 64 lbs. of sewage sludge per capita (USEPA, 1990).

Composting is considered an economically and environmentally desirable treatment option for wastes because this controlled biological decomposition process converts solid organic matter into a humus-like mixture. The process depends on the growth and activity of mixed populations of actinomycetes, other bacteria and fungi that are indigenous to the various organic wastes that are composted (Golueke, 1992). Composting can be conducted under either aerobic (with oxygen) or anaerobic (without oxygen) conditions (Finstein *et al.*, 1980); however, the aerobic mode is generally preferred since it proceeds more rapidly, is less apt to generate malodors and provides for greater thermal reduction of primary pathogens. The humus-like product is a stable, organic material which is used in agriculture, horticulture and landscaping.

A properly operated composting system accelerates the natural decomposition and stabilization of organic matter by optimizing conditions for biodegradation. Organic materials containing N and P are microbially mineralized such that the N and P are released in plant-available forms, pathogens are destroyed after three days exposure to 55°C and with proper process control and preventative measures for odor treatment malodors can be abated. Destruction of primary, human pathogens by high temperature composting, particularly with recyclable organic resources such as sewage sludge and municipal solid waste, contrasts with the direct land application of sewage sludge which does not completely eliminate existing pathogens within the material.

Compost Systems

Composting is a time honored practice that recently has been mechanized (e.g., shredding equipment, blowers, specially designed containers) and computerized to improve process control, pathogen destruction, odor reduction and product stabilization and quality. Several methods of composting are available (as described below); they are sometimes combined. The fundamental methods are:

Static pile. A pile of blended proportions of various organic materials is constructed (often over perforated pipe or blocks) and air is introduced by positive or negative flow. The mass and pile geometry contribute to heat retention. Sometimes the "static" piles are broken down, remixed and a new pile constructed to continue the process. The static pile can be used indoors or outdoors and is most commonly applied to biosolids composting.

Turned windrow. In contrast to the static pile, windrows (elongated piles of organic material) are turned at regular intervals with either a front end loader or a windrow turning machine. Water or additional organic materials can be added to the windrows during turning to maintain optimal composting conditions. Turned windrows can be constructed indoors or outdoors, with the outdoor method being the most common for composting leaves, grass and brush.

In-vessel. In contrast to static pile and windrow systems, in-vessel composting systems process wastes in containers equipped to control critical conditions, e.g., aeration and agitation. Rotating drums, similar to cement mixers and horizontal or vertical tanks, are the most common in-vessel systems. More recently, tunnel reactors, a type of horizontal tank which has been used for many years by mushroom growers, are being used to compost solid wastes. Retention times for organic material in a vessel depend on the particular technology, but range from 6 hours to several weeks. Most in-vessel systems also utilize static pile or turned windrow methods to accomplish further degradation and stabilization after the material is removed from the vessel. The vessel may or may not be installed in a building, depending on the climate and type of system. Because of their higher capital costs, vessels are most commonly applied to larger quantities of biosolids and/or solid waste.

Hybrid. It is common to find some combination of the above systems, particularly the in-vessel and one of the other approaches. Many turned windrow systems also utilize static piles for final curing and stabilization of the humus. Many of these systems, particularly those housed indoors, utilize chemical scrubbers or biofilters to minimize potential odor dispersal.

Scope of Current and Future Compost Facilities

In the U.S., there were over 2,200 leaf and yard facilities at the end of 1992. At the current rate, the number is expected to approach 3,300 by 1994. In addition, there are over 200 biosolids facilities and 17 mixed municipal solid waste facilities. According to recent trends, there are growing numbers of composters of single stream organic wastes from paper mills, supermarkets and restaurants. These facilities range in size from 20 tons per day for leaf and yard facilities to 500 tons per day for municipal solid waste facilities. In addition, agricultural wastes are composted at numerous sites either on or around farms.

Regional Distribution of Composting Facilities

The Composting Council estimates that as of April, 1993, there are approximately

2,500 composting facilities in the U.S. The Council has begun a database of facilities; this database currently contains about 1,300 entries, most with partial information. The vast majority of facilities compost yard wastes. About 150 compost biosolids, another 30 compost source separated organics (i.e., food waste, yard waste, soiled paper) and 20 extract compostables from mixed waste. Facilities that compost manures and other primarily agricultural wastes have not yet been characterized. Currently, 47 percent of facilities are in the northeast, 27 percent in the midwest, 16 percent in the west and 10 percent in the south. This corresponds roughly to the population distribution in the U.S.; anecdotal evidence suggests most facilities are in suburban areas. To date, 25 states have enacted legislation to encourage composting by banning part or all of their yard wastes (brush, grass clippings, garden trimmings, leaves, prunings, shrubbery and small wood materials) from landfills; nine of those states are in the northeast, 10 are in the midwest, seven are in the south and one is in the west.

In addition, USDA is increasing its efforts in composting as directed by the 1990 Farm Bill (FACTA, 1990, Section 1456). To encourage on-farm composting, the Soil Conservation Service (SCS) developed a standard for on-farm composting (USDA, 1990) that established minimum requirements for design and operation of facilities that handle livestock and poultry manure, dead animal carcasses and food processing wastes. Also, SCS has developed technical support guidance about on-farm composting.

Since 1990, the National Association of Conservation Districts has consistently urged USDA's Agricultural Soil Conservation and Stabilization (ASCS) to cost share the use of compost and/or livestock manure (the crop nutrient value) and has supported the concept of urban/rural waste cocomposting. Some much needed economic incentives to stimulate more on-farm composting of the rural/urban wastes is needed, i.e., assistance in terms of ASCS cost sharing the equipment needed to start an on-farm composting operation. Cost sharing will stimulate use of composting as an alternate animal manure management practice.

Appendix II

Case Definitions for Diseases Caused by Aspergillus Fumigatus

(Excerpted with permission from the "Final Report of the Aspergillosis and Composting Medical Advisory Panel", April 4, 1994, Santa Clara County, Public Health Department, Division of Disease Control and Prevention, San Jose, California)

I. Invasive Aspergillosis

A. *Aspergillus* sp. isolated by culture from a normally sterile site (blood or tissue); culture of sputum is not acceptable.

B. Mycetoma (aspergilloma) diagnosed by sputum culture and chest or sinus radiograph or computed tomography scan.

II. Allergic Bronchopulmonary Aspergillosis

Definite cases meet ALL of the following criteria.

Possible cases have asthma and five of the six remaining criteria.

A) Asthma, i.e. evidence of reversible air flow obstruction defined by: $FEV_1/FVC < 0.70$

B) Evidence of immediate skin reactivity, i.e., a wheal and flare reaction, to *Aspergillus fumigatus* antigen (intradermal injection or "prick" test).

C) The presence of *Aspergillus* - specific IgE in serum.

D) Quantitative serum IgE>400 IU/ml, or IgE>250 IU/ml plus evidence of fluctuation with disease activity.

E) IgG or precipitating antibody to *Aspergillus.*

F) History of peripheral eosinophilia (absolute eosinophil count> 500 cells/mm^3).

G) History of pulmonary infiltrates documented by chest radiograph.

III. Acute Allergic Alveolitis (Hypersensitivity Pneumonitis)

Criteria A and (B, C or D) must be met.

A) Fever and severe dyspnea four to six hours after exposure to a source of *Aspergillus* OR episodic fever and dyspnea and high serum IgG precipitating antibodies to *Aspergillus.*

B) At the time of symptoms, either diffuse micronodular infiltrates by chest radiograph OR restrictive ventilatory defect documented by pulmonary function tests.

C) A positive response to an inhalation provocation test using *Aspergillus* as the antigen.

D) Lung histopathology with mononuclear inflammatory cell infiltrates in alveoli and interstitial spaces documented by lung biopsy.

IV. Asthma Induced by Aspergillus

Criteria A, B, C and D must be met for a definite case; criteria A, B and E must be met for a possible case.

A) Recurrent or intermittent symptoms consistent with asthma including wheezing, dyspnea, cough or chest tightness.

B) Documentation of reversible or variable airway obstruction (improvement of at least 10 percent in FEV_1 with bronchodilator; 2) at least 20 percent variability in serial peak expiratory flow rate (PEFR) measurements in a 24 hour period; 3) Positive inhalation challenge testing with methacholine or histamine (20 percent fall in FEV_1 produced by five inhalations of 8 mg/ml or less).

C) Temporal association between episode of asthma and known exposure to *Aspergillus.*

D) Positive wheal/flare to *Aspergillus* or positive *Aspergillus* specific IgE RAST in absence of reaction to other allergens.

E) Positive wheal/flare to *Aspergillus* or positive *Aspergillus* specific IgE RAST

NOTE: Allergic asthma due to Aspergilli exposure usually occurs in atopic persons, is rarely solely due to Aspergilli exposure and occurs less often than hay fever.

V. Aspergillus Sinusitis

Criteria A and B must be met:

A) Isolation of *Aspergillus* species from sinus culture

B) Severe sinus CT scan abnormalities

VI. Allergies (A Case Definition Was Not Developed)

While persons with sensitivity to *Aspergillus* may have a skin test reaction or IgE levels to *Aspergillus* antigens, these tests alone are not definitive and the contribution of fungal exposure to allergy is difficult to evaluate.

IgE skin testing correlates with biological activity. RAST testing is an immunoassay and is less sensitive than skin testing. MAST testing evaluates antibody levels to a panel of antigens. Detection of antibodies in sera indicate exposure and are not diagnostic of an adverse health response.

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