Aspergillus, Aspergillosis, and Composting Operations in California

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INTRODUCTION

Californians have been moving rapidly to implement the mandated solid waste diversion goals of the Integrated Waste Management Act (Act) of 1989. The Act allows, and encourages, local governments to use composting to help them attain the diversion goals. Thus, since 1989 many local jurisdictions and the private sector have planned and/or implemented composting operations.

As a part of the process of implementing the Act, the state's Local Enforcement Agencies (LEAs) for solid waste management have been addressing the siting and operation of new and expanded composting facilities, and are continuing their routine compliance investigations and enforcement actions at existing composting facilities. All these facilities may utilize a wide variety of potentially valuable secondary organic materials such as green waste (yard waste), food waste, industrial waste, agricultural waste, sewage sludge, and mixed municipal solid waste, and represent both a facility management challenge for LEAs and an economic opportunity for local governments and entrepreneurs. The presence of Aspergillus fumigatus, a ubiquitous fungus which is both a normal and integral part of the composting process and a potential health risk to certain high-risk individuals, compounds that challenge.

The primary audience for this technical bulletin is the officers of the state's local enforcement agencies, but staff hope composting facility operators and local government officials will also find it useful. The bulletin underwent peer review with professional staff of three state agencies: California Department of Health Services, Office of Environmental Health Hazard Assessment, and the Integrated Waste Management Board (see Acknowledgements).

This bulletin was produced as a direct result of the expressed need of several LEAs for information on Aspergillus fumigatus, its potential adverse health effects, and its role and management in composting operations. The scientific information in the bulletin, particularly the "best management practices" described in Section 6, are offered to LEAs to help guide them in their interactions with composting facilities and their professional decision-making. This bulletin is not r a Board policy nor a set of regulations or standards.

The bulletin is divided into several parts, in which headings are worded as commonly asked questions about Aspergillus fumigatus and composting:

1. What is the Aspergillus organism and its life cycle?
2. What are the common sources of exposure to Aspergillus?

3. What is the disease called aspergillosis?

4. What are the levels of Aspergillus spores in the ambient environment, and in composting operations?

5. What are the potential health hazards of Aspergillus in the ambient environment and in composting operations?

6. What "best management practices" can reduce ambient air exposure to Aspergillus spores?

7. How do the state minimum standards for composting facilities help reduce exposure to Aspergillus?

8. How can one identify (diagnose) an Aspergillus problem in a composting operation?

9. How does one monitor and sample for Aspergillus spores in the ambient environment?

10. Conclusions

1. WHAT IS THE ASPERGILLUS ORGANISM AND ITS LIFE CYCLE?

Aspergillus fumigatus is a fungus and one of many microorganisms which bring about the everyday decay of leaves, wood and other organic matter in our environment. It may be found virtually everywhere on earth, and, although we are all exposed to it regularly, it does not normally cause disease. Our bodies' immune system normally acts as if it were an innocent visitor, unless it invades tissues. In that event, the immune system responses will protect us from infection, very much as it does from pathogenic bacteria or viruses.

Aspergillus fumigatus, a fungus in the Class Deuteromycetes (also known as Fungi Imperfecti), is, of a multitude of Aspergillus species in the world, the one most suited for growth in humans. The fungus is an aerobe, that is, it prefers aerated microhabitats for growth and reproduction, but is capable of surviving at low levels of oxygen (Foster 1949:162, Hawker 1950:104, Lilly and Barnett 1951:88). Aspergillus fumigatus normally obtains its nutrients from decaying organic matter (i.e., it is saprophytic), but can obtain nutrients from living cells (i.e., it can be parasitic). The life cycle is normally saprophytic; invasion of tissues is incidental to its normal life cycle (Sinski 1975).

Spores (also called conidia), one of the stages of the fungus' life cycle, are the resistant form of the fungus, and the form responsible for dispersal in the ambient environment. These asexual spores are borne on special structures called conidiophores (see Figure 1), from which they are released into the atmosphere. The spores are very light in weight and therefore are easily spread by air currents. Also, the spores' small size -- 2.0 to 3.5 micrometers average -- allows them to gain access to the alveolar space in the lungs (Sinski 1975, Rippon 1982). The spores resist desiccation by means of thick cell walls and cell membranes (Sinski 1975).

Hyphae (singular: hypha; a mass of hyphae is a mycelium) are the vegetative, growing, long and filamentous forms of the fungus. They comprise another stage of the life cycle: the hyphae generate the conidiophores. The hyphae invade decaying organic matter and, in rare cases, living tissues.

Aspergillus fumigatus can germinate at approximately 80% relative humidity (RH), but its growth is more optimal at approximately 98% RH (Panasenko 1967). The moisture content of the medium upon which the fungus occurs is also important in germination and growth.

Aspergillus fumigatus has been characterized as one of the most frequently found fungal species in airborne spore (airspora) surveys (Composting Council, 1993:9) The organism can readily grow and reproduce in a wide range of temperatures, from about 12o C to 50-55o C. Because it is able to live in temperatures ranging from less than 20o C to more than 50o C, it is classified by Cooney and Emerson (1964) as a thermotolerant fungus, in contrast to thermophilic fungi which by definition do not survive in temperatures below 20o C.

Aspergillus fumigatus is a normal and integral part of the composting process, participating with other microbes in the final breakdown of compostable materials to a finished product, stabilized compost (Boutin and Moline 1987). An enlightening description of microbial population dynamics occurring during composting was offered by Kramer et al. (1989).

> "During composting, organic materials are decomposed by the growth of mesophilic organisms. During the process, heat is generated because of fermentation and results in the elimination of mesophilic organism[s] because of their thermolability. Thus, the substrate becomes ideal for growth of thermotolerant and thermophilic organisms [such as A. fumigatus] because of the lack of competition by relatively thermolabile organisms initially colonizing the compost."

See Figure 2 for a hypothetical diagram of the typical phases of maximum Aspergillus concentrations during the composting cycle.

2. WHAT ARE THE COMMON SOURCES OF EXPOSURE TO ASPERGILLUS?

In the ambient environment, Aspergillus fumigatus is commonly found in a great range of sites and materials, including soils, moldy grains, straw and hay, bark and woodchips, house dust, and sewage sludge. The spores are very common in bird droppings, and are found in dung of cattle, horses and sheep (Raper and Fennell 1965, Millner et al. 1977, Kwon-Chung and Bennett 1992).

Inhalation of spores is the most common route of human exposure.

A number of everyday activities indoors and outdoors can provide exposure to A. fumigatus, including lawn mowing, gardening, home landscaping, potting of household plants in soils, raking leaves (Sporik et al. 1993) and walking through an arboretum or along a nature trail. One author (Kowal et al. 1978) suggested mowing a lawn may be the most common source of exposure to A. fumigatus for residential dwellers. Residential or occupational exposure also can occur from contaminated air conditioners, construction dust (Bodey and Vartivarian 1989, Staib 1992, Kwon-Chung and Bennett 1992), and improperly managed compost piles in backyards or commercial operations. In Kansas, Aspergillus spp., Penicillium spp. and other fungi were primarily associated with homes with dirt floor crawlspace basements and homes with gas stoves (both offer moist environments; gas combustion generates water vapor and CO_2)(Su et al. 1992).

3. WHAT IS THE DISEASE CALLED ASPERGILLOSIS?

Aspergillus fumigatus is the Aspergillus species most pathogenic to humans (Sinski 1975, Mackenzie 1988). Four disease entities (described in Box 1) can result from exposure to sufficient quantities of A. fumigatus spores (Rosenberg 1993).

Three basic mechanisms of pathogenesis are responsible for illness: immune hypersensitivity of the patient to antigens present in the fungus or its spores; saprophytic colonization of air spaces in sinuses, bronchi or lungs; or invasion of tissues by fungal mycelia (Kwon-Chung and Bennett 1992).

No one has yet demonstrated a clear dose-response curve (Maritato et al. 1992), a threshold spore concentration, or duration of sensitization needed to cause any of the four disease entities described in Box 11. Also noted in Box 1, in the literature reviewed by staff only two cases of illness, one of acute bronchopulmonary aspergillosis (ABPA) in a pre-disposed (asthmatic) individual in the USA and one of hypersensitivity pneumonitis (HP) in a compost worker in Belgium, have been linked to a commercial composting facility. However, in microbiology, like toxicology, "the dose makes the poison". Thus, while we have do not have good data on infective doses of these organisms, it is reasonable to expect that increasing the potential dose increases the likelihood of eliciting a response, even in otherwise normal people2. Therefore, in preventing or reducing health risks from composting facilities, it is important to reduce worker exposure to spores by utilizing a set of best management practices (discussed in Section 6, below).

There are individuals who, due to special circumstances, may be at higher risk of one of the four types of aspergillosis. For example, indoor sources of Aspergillus spp., including A. fumigatus, have been responsible for infecting high risk hospitalized patients, patients who are immunocompromised or suffer certain other serious illnesses discussed in Box 1. The sources include indoor potted plant soil (potting soil), uncontrolled dust from nearby construction activities, and hospital air ventilation systems (Bodey and Vartivarian 1989, Staib 1992).

BOX 1: Aspergillosis Disease Entities

About 3-5% of the U.S. population suffer from extrinsic (allergic) asthma (Reed 1981). About 20% of the U.S. population is genetically predisposed to react to allergens in the environment (Burge 1988). In the first type of aspergillosis illness, people with this predisposition may develop this form of asthma upon becoming sensitized to Aspergillus species. Asthmatics may find their asthmatic condition aggravated upon exposure to A. fumigatus.

In the second disease entity seen, some people develop allergic bronchopulmonary aspergillosis (ABPA), a condition in which Aspergillus spores germinate and the resultant mycelial growth can potentially block the bronchi (Vaughan 1993). Patients may cough up small, brown plugs of mycelia. There is no invasion of tissue. However, the patient may suffer lung fibrosis and may, over time, become more susceptible to other lung diseases. In one case of ABPA (Kramer et al. 1989), exposure to a nearby

(250 ft. distance) commercial leaf composting operation "...might have contributed to the development of [the patient's] disease", an individual who was already asthmatic (clinically, "atopic").

The third disease entity, related to ABPA only because it is immune-mediated, hypersensitivity pneumonitis (HP) (also called extrinsic allergic alveolitis) is often associated with repeated exposure to an identified -- often occupational -- source of high levels of antigen. Only 5 to 10% of persons regularly exposed to the wide range of allergenic agents which typically produce HP actually develop the disease (Rosenberg 1993). Only one case of HP has been reported in compost plant workers (Vincken and Roels 1984), occurring in Belgium. A case of

HP caused by A. fumigatus occurred in a patient in Japan who cultivated vegetables in a poorly-constructed home greenhouse (Yoshida et al. 1993).

The fourth disease entity, invasive aspergillosis (IA), is seen in people whose normal immune systems are compromised by other serious diseases such as leukemia, lymphoma, carcinoma, tuberculosis, emphysema, or diabetes; or by use of immunosuppressive drugs (often used with organ or bone marrow transplant operations); or by large doses of corticosteroids. In IA, there is an actual invasion of lung tissue or skin, and often dissemination by means of blood to other parts of the body. The prognosis for IA is grave.

Serious illness or deaths from aspergillosis in patients without any predisposing conditions are quite rare. One reported case of "fatal local invasive pulmonary aspergillosis [IA from A. fumigatus]... [occurred] in a previously fit young adult patient who had no predisposing factors other than exposure to fungal spores in his occupation as a gardener." The researchers (Zuk et al. 1989) could find only one similar case in adults in the previous 30 years; in that case the causative organism was Aspergillus niger, not A. fumigatus. Ten separate cases of IA in children, caused by A. fumigatus, have also been reported (Strelling et al. 1966). At least five of the children lived in agricultural environments, where A. fumigatus is common.

In summary, in the literature reviewed by staff only two cases of illness (discussed above), one of ABPA in a pre-disposed (asthmatic) individual in the USA and one of HP in a compost worker in Belgium, have been linked to a commercial composting facility.

4. WHAT ARE THE LEVELS OF ASPERGILLUS SPORES IN THE AMBIENT ENVIRONMENT, AND IN COMPOSTING OPERATIONS?

Ambient Environment.

Figures 3-4, based on preliminary data compiled by the Composting Council (1993: Table 3), show the measured ambient air concentrations of spores (number of spores/m3 of air sampled) in the ambient environment (neighborhoods, yards), in homes, and in certain workplaces.

Outdoors.

In the outdoors, the Aspergillus group of fungi is generally less prevalent than the fungi Alternaria and Cladosporium, although it is the most common group of outdoor airborne fungi among those that can be pathogenic to people. Aspergillus fumigatus concentrations outdoors rarely exceed 150 spores/m3 (US EPA 1991).

Indoors.

A. fumigatus has been found to be among the most common molds found indoors (Kothary et al. 1984: Tables 2-4). The fungus appears more common in autumn and winter in North America and Europe (Larsen and Gravesen 1991; NRC 1981). In clean houses, indoor airborne concentrations of A. fumigatus spores range from 0-200 spores/m3, typically (NRC 1981). In a study of 68 homes in a cross-section of southern California homes (Kozak et al. 1979), only 2.9% of the homes had A. fumigatus, where the airborne spore concentrations ranged from 0-5 spores/m3, with a mean of 0.2 spores/m3.

People living in some homes are at higher risk than others. For instance, in one study Aspergillus spp. were significantly more frequent in homes with pets, in comparison to homes without pets (Hirsh and Sosman 1976). Homes with neglected potted plants, or faulty air conditioning systems (e.g., dirty ducts and air filters) are also a higher risk environment.

Composting Operations.

A. fumigatus usually occurs in a layer of mycelia found from about 5-40 cm. (2-16 in.) inside a compost pile; concentrations are greatest at about 5-15 cm.(2-6 in.) inside a pile (Gotaas 1956, Boutin and Moline 1987).

Figure 5 provides a list of concentrations of A. fumigatus spores at several composting facilities in North America. Concentrations at composting operations are quite variable and often, but not always, higher than concentrations in the ambient air of residential areas (e.g., Kothary et al. 1984). A study of ten commercial compost facilities in the USA (ChemRisk 1991) found airborne concentrations of A. fumigatus at the active site of operations to be, on the average, 10-fold higher than background levels, but the concentrations fell off sharply within 500 feet of the operational site. If the nearest human receptor is located beyond the point at which concentrations fall to background levels, there is no elevated exposure occurring.

The concentrations of airborne A. fumigatus spores were measured at four enclosed composting plants in Sweden. Sampling sites in the plants were selected to be representative of worker locations for both waste processing and compost manipulation. Operations included municipal solid waste (MSW) and sludge composting, with and without wood chip bulking agents. At interior sampling sites close to actual composting operations, A. fumigatus airborne levels ranged from 1 x 102 to 6 x 106 CFU/m3, with a median concentration generally less than 1.26 x 105 CFU/m3 (Clark et al. 1983).3

The use of bark or wood chips (e.g., as a bulking agent for sewage sludge composting) typically raises the on-site level of airborne A. fumigatus spores (Millner et al. 1977, Millner et al. 1980, Clark et al. 1983). In one study in Maryland, A. fumigatus levels in sewage sludge rose from 102 or 103 CFU/DGW4 to 2.6-61.0 x 106 CFU/DGW when mixed with wood chips which were stockpiled for various lengths of time. The increase appeared to be caused by wood chips stored in moist piles which were allowed to generate heat (Millner et al. 1977).

Increased A. fumigatus spore concentrations have also been observed in screened compost; this may be due to re-inoculation by spores as compost passed through contaminated screens multiple times (Olver 1979); others have suggested that multiple screenings may break up spore clusters, releasing more spores.

5. WHAT ARE THE POTENTIAL HEALTH HAZARDS OF ASPERGILLUS IN THE AMBIENT ENVIRONMENT AND IN COMPOSTING OPERATIONS?

Ambient Environment.

Several researchers (Raper and Fennel 1965, Sinski 1975, Olver 1979, Epstein and Epstein 1985, Epstein and Epstein 1989, Maritato et al. 1992, Epstein 1993) have presented persuasive arguments for the lack of health risk from A. fumigatus for exposed healthy people, whether they are working in a composting facility or living nearby. Typical of this widespread view, Emmons et al. (1977:289) noted:

> "In routine autopsy examinations of the lungs of individuals dying from other causes, colonies of Aspergillus may be found in bronchi which exhibit little or no evidence of inflammatory reaction."

As well, Olver (1979) stated:

> "The fungus [A. fumigatus] is encountered by most people in a wide diversity of environments. The mere presence of the fungus within the human body is very common and is not necessarily indicative of a diseased condition."

Composting Operations.

One should recognize that composting facilities do represent sites where there is a massive culturing of Aspergillus fumigatus organisms in relatively small areas compared to most "natural" or background circumstances. Thus, without dust control, there is an elevated risk of exposure to spores for workers at compost facilities. In a worst-case scenario, a respiratory model developed by Boutin et al. (1987) estimated that a completely unprotected worker shovelling mature compost at a highly contaminated site could inhale 25,000 to 30,000 viable spores per hour. However, elevated exposure is not automatically synonymous with an elevated health risk for compost workers (or neighboring communities). Epstein (1993) discusses several composting facilities in the USA in which health monitoring (physical exams) of compost workers has been conducted; the results of the physical exams did not reveal any illnesses directly associated with composting. As discussed in Section 6, dust exposures at composting facilities are readily controllable, and control benefits and protects both facility workers and nearby residences.

However, many public health specialists, scientists, and engineers in North America and Europe believe that properly operated composting and co-composting operations present little health risk to normal compost facility employees, and negligible if any risk for nearby residences (Millner et al. 1977, Clark et al. 1983, Epstein and Epstein 1985, Boutin and Moline 1987, Maritato et al. 1992). Diaz et al. (1992) stated:

> "The existence of hazard from the spores of A. fumigatus [at commercial composting facilities] is yet to be demonstrated. The infectivity of the spores is low. Consequently, any danger posed by it would be of significance only to the unusually susceptible individual. Nevertheless, prudence indicates that an open-air compost plant should not be sited in close proximity to human habitations."

Further information on the potential health effects from composting may be obtained from:

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6. WHAT "BEST MANAGEMENT PRACTICES" CAN REDUCE AMBIENT AIR EXPOSURE TO ASPERGILLUS SPORES?

Reducing the dispersal of A. fumigatus spores appears to be the best way to reduce exposure and help protect the health of compost workers and the neighboring communities.

Board staff believes that the suggested management practices discussed below, can help reduce the dispersal of spores into the air. Staff believes these practices are suitable for all commercial aerobic composting operations (whether they be windrows, aerated static piles, or the various types of in-vessel reactors: vertical, horizontal, or rotating drum). The best management practices (described below) include:

o Proper composting facility siting, design and construction;

o Facility operational practices;

o Engineering and administrative controls; and

o Use of personal protective equipment.

Board staff believe the reader will recognize these practices are common sense in nature, and focus on a combination of proper composting operations management, dust control, and personal protection to reduce exposure to A. fumigatus. The best management practices are drawn in part from Epstein and Epstein (1989), Composting Council (1993), Tchobanoglous et al. (1993), and D. Krause, CIH, personal communication 1993.

Facility Siting, Design and Construction

o Siting. Some scientists (Millner et al. 1977, Olver 1979, Kramer et al. 1989, Diaz et al. 1992) have recommended that buffer zones may be considered between certain types of composting facilities and nearby residences, hospitals, or schools to reduce the risk of exposure to odors and air contaminants.

Millner et al. (1977) noted: "In consideration of off-site health matters related to air dispersal of spores, a buffer distance between a composting operation and health-care facilities or residential areas may be needed." Olver (1979) noted the "...buffer zone that should normally be provided around the composting site for odor control should work equally well to confine the high conidia levels of the fungus to the processing area". Diaz et al. (1992) noted: "... prudence indicates that an open-air compost plant should not be sited in close proximity to human habitations." Kramer et al. (1989) stated: "Consideration should also be given to locating compost sites similar to the present one [a municipal leaf composting facility] more than 2 miles from residential areas in order to minimize potential microbial contamination of the environment." Only the latter author has recommended a specific buffer zone width.

The Board's current green waste composting regulations (14 CCR Section 17859(a)) require a setback of at least 300 feet of the facility's active compost materials areas from any residence, school or hospital, excluding on-site residences, unless one of three conditions are met. One of these conditions (Section 17859(a)(3)(C)) is that the local enforcement agency (LEA) may approve in writing a variance from this number. Under this subsection the LEA may allow a facility to be sited closer than 300 feet to any residence, school or hospital; alternately, the LEA may require the facility to be sited at a specificed distance greater than 300 feet away from any residence, school or hospital.

In selecting a buffer zone as a mitigation measure for odor, dust or spore exposure, some factors to consider are: variations in wind direction and speeds through the year (windrose data); background (ambient) spore concentrations; spore production, release and transport data; effectiveness of the dust control measures to be used at the site; types of occupied buildings and their distance from the proposed composting facility; types of nearby communities (e.g., retirement or mixed communities) and their health status.

o Enclosed facilities. Indoor (enclosed) buildings can be designed and constructed to reduce spore emissions to the atmosphere (see Engineering Controls, below). Also, certain machinery operations (e.g., tub grinders, trommels, hammermills) which generate high volumes of dust outdoors or indoors may need to be enclosed, physically separating the worker from the source of dust.

o Compacted or paved road surfaces. Compost leachate and runoff may carry and concentrate spores and other pathogens (Kramer et al. 1989). One may compact or pave earthen surfaces for control of dust, compost leachate, and water runoff. Composting process wastewater may be disposed to sanitary sewers or septic tanks, or reintroduced into the compost material.

o Berms and windbreaks. Placement of planted berms and windbreaks (trees) may change ambient wind direction, directing it to flow away from nearby homes.

Facility Operations

o Proper aeration and mixing. Regular and uniform (thorough) blending and mixing of windrows will aid proper composting, as will a proper initial blending of wastes in aerated static piles. Bulking agents should be of a quality to minimize the formation of airspora (bioaerosols).

In a careful study by Millner et al. (1980) of windrow and compost pile operations where waste was manipulated with and without use of a front-end loader, there was an observed paucity of windspread spores from undisturbed compost piles (range 0-14 spores/m3; average 2.2 spores/m3), when compared to the mechanically agitated piles and windrows (range 1390-5020 spores/m3, from 3-60 m downwind). Spore counts of A. fumigatus dropped off very rapidly (as measured 3 m downwind from the pile), from 1390 spores at peak agitation to 39 spores, within 15 minutes after mechanical agitation ceased.

This study, among others (Kothary et al. 1984), indicates that static aerated piles may put fewer spores into the air than a windrow operation with its need for regular mechanical agitation. The study also found that the use of front-end loaders (or other machines which mix and disturb compost) put significant amounts of spores into the air for short periods of time.

o Moisture control. Optimal windrow or aerated static pile moisture content is 50 to 60%. Moisture levels of $<25\%$ reduce biologic activity in compost (including reproduction of A. fumigatus). Moisture levels $>60\%$ reduces porosity and increase the likelihood of anaerobic conditions. The latter conditions favor malodor generation and lower windrow or pile temperature. The application of water to control dust during windrow turning will not normally adversely affect moisture levels, since water for dust control is usually applied as a fine spray (little water volume).

o Temperature control. Optimal temperatures for thermophilic composting are 55o to 60o C.; or 30o to 38o C. for mesophilic composting. Proper aeration maintains aerobic conditions in compost piles, and helps maintain proper temperature and moisture for composting.

Under U.S. Federal regulations (40 CFR Part 503), the Process to Significantly Reduce Pathogens (PSRP) in sewage sludge composting operations requires that solid waste be maintained at 40o C. for at least 5 days, and 55o C. or more for 4 hours during this period. In the Process to Further Reduce Pathogens (PFRP) using the aerated static pile and in-vessel processes, the solid waste is maintained at 55o C. or more for 3 days. In the PFRP for windrows, the solid waste is maintained at 55o C. or more for at least 15 days.

All these processes will help limit A. fumigatus populations in compost. Cured, processed sludge compost allowed to achieve uniform temperatures of at least 60o C. is nearly devoid of viable A. fumigatus spores (Millner et al. 1977).

o Dust control. Use of water sprays, water mists, or approved sprays, as well as the reduced bulk movement of compost, will help control fugitive dust and spores (Millner et al. 1977). Most spores become airborne by the movement or mixing of compost, not by entrainment on the wheels of vehicles on site (Millner et al. 1977), thus dust control of windrows and piles undergoing mixing is important. Windrow and pile turning on windy days is not advisable.

o Odor control. Malodor is only a signal of generally poor composting operations, not a specific sign of A. fumigatus problems. One may control malodors by aeration, mixing, and moisture control, as discussed above. Use of biofilters may supplement these basic operational methods for odor control, but their ability to control spores is unknown. (Also see pH control.)

o pH control. The optimal pH range for composting is 7 to 7.5. The pH varies over the period of composting from an initial reading of pH 5 to 7, dropping to pH 5 or less during the initial days of composting, rising to pH 7 to 8.5 during the thermophilic stage, and returning to pH 7 to 8 during the cooling

stage. Anaerobic conditions may allow the pH to become too low (<5), favoring organic acid formation (and accompanying odors). Nearly as objectionable is a high pH (>8.5), which favors release of nitrogen in the form of gaseous ammonia (Tchobanoglous et al. 1993).

o Facility, vehicle and equipment cleanlines.: Soap and washdown will result in a reduction of dust and spore levels in the air. Interiors of vehicles may be routinely inspected and cleaned, and cab air filters inspected and replaced as needed.

o Operator training. All facility operators and compost workers may be trained in methods of control of dust and Aspergillus.

Engineering and Administrative Controls, and Personal Protective Equipment

o Engineering controls. Changing the work process (design and use of ventilation systems, machinery, and vehicles) can minimize the employees' potential exposure to Aspergillus spores. This may include installation of suitable building ventilation, with filters if needed. One may also use vehicle in-cab ventilation and filtration. Scrubbers, bag houses, and electrostatic precipitators have not been evaluated for spore control (US EPA 1991).

o Administrative controls. Changing work assignments (job rotation, reduced task times) can minimize the length of time of the employees' potential exposure to Aspergillus spores.

Baseline physicals (medical exams) may be appropriate for employees (see Clark et al. 1983, Maritato et al. 1992, Epstein 1993). The baseline physical may include a one-second forced expiratory volume (FEV1) and forced vital capacity (FVC) test. The initial medical history report, taken with the baseline physical, may cover whether or not the employee has any inherited immune defects, immunocompromised states, or other serious health conditions (asthma, carcinoma, diabetes, etc.), in order not to put a high-risk person into an elevated exposure environment in the workplace (Epstein 1993). Annual physicals may be appropriate for highly-exposed employees or employees with health problems (Epstein 1993).

o Personal protective equipment. Not every type of compost facility employee may need to use personal protective equipment. For people working where high spore exposure may occur (e.g., individuals who turn compost piles or move compost), correct use of protective clothing (Boutin and Moline 1987), gloves, and respirators (Millner et al. 1977, Kothary et al. 1984) is important. Showers and clothing change facilities may be made available to these workers (Boutin and Moline 1987). Facility operations should, of course, be in full compliance with Occupational Safety & Health Administration (OSHA) standards.

7. HOW DO THE STATE MINIMUM STANDARDS FOR COMPOSTING FACILITIES HELP REDUCE EXPOSURE TO ASPERGILLUS?

The state's current adopted green waste composting regulations are found in 14 CCR Chapter 3.1, commencing with section 17851. The use of setbacks and general dust control measures helps to reduce potential exposure to A. fumigatus.

The current green waste composting regulations (14 CCR Section 17859(a)) require a setback of at least 300 feet of the facility's active compost materials areas from any residence, school or hospital, excluding on-site residences, unless one of three conditions are met, as discussed above under Siting issues.

The current green waste composting regulations also include requirements for general dust control, including design requirements (14 CCR 17873); however, no specific operational standards or guidelines are given. General control measures for A. fumigatus and Aspergillus flavus (another species present in North America) are required for both exempted and non-exempted composting facilities (14 CCR 17875(a)).

8. HOW CAN ONE IDENTIFY (DIAGNOSE) AN ASPERGILLUS PROBLEM IN A COMPOSTING OPERATION?

The presence of very foul odors in a compost operation is an indication of poor composting practice. However, foul odors alone are NOT a necessary or sufficient condition for the presence of high levels of A. fumigatus spores, though they may raise the level of suspicion of poor operating practices.

No simple field tests (cultural assays, bioassays, immunological assays) for identification of Aspergillus spores and mycelia are available. One must rely on proper sampling methods and devices, which are outlined in Introduction to Indoor Air Quality: A Reference Manual (US EPA 1991), and bring samples into the laboratory for identification and testing. Cultural assays (identifying viable organisms - hyphae and spores - in the laboratory, using fungal cultures and knowledge of fungal morphology and taxonomy) and the direct microscopy of spores are the laboratory methods currently used to identify Aspergillus fumigatus. Cultural assays and microscopy should be done by professional mycologists or other specialists. (Also see Section 9 on Monitoring and Sampling, below.)

9. HOW DOES ONE MONITOR AND SAMPLE FOR ASPERGILLUS SPORES IN THE AMBIENT ENVIRONMENT?

As noted above, A. fumigatus is a very common fungus found in nearly all environments, and grass clippings generated during lawn mowing may be responsible for most of the A. fumigatus spore exposure in residential areas in North America. Bearing this in mind, any routine monitoring or special sampling for A. fumigatus spores at compost operation sites should always be compared to "background" levels of A. fumigatus and to other allergenic or pathogenic airspora (Penicillium, etc.), not as stand-alone data.

The standard sampling devices for bioaerosols and airspora, including A. fumigatus include: rotating slit or slit-to-agar impactors, multiple-hole impactors (e.g., Andersen multi-stage samplers), centrifugal samplers, liquid impingers, and filters. Selection of sampling methods and devices depends upon the particular purpose of the sampling, and is always site-specific. The Andersen multi-stage sampler is one of the most frequently used devices to sample air for A. fumigatus5. The American Council of Governmental Industrial Hygienists (ACGIH) Committee on Bioaerosols recommends the multiple-hole impactor or slit impactor be set to collect particles around the one micrometer size range (US EPA 1991).

Before conducting any bioaerosol (airspora) sampling, Board staff recommends that the investigator contact for advice:

Janet Macher, Sc.D., M.P.H., Air Pollution Research Specialist

Environmental Health Laboratory

California Department of Health Services

2151 Berkeley Way

Berkeley, CA 94704,

phone (510) 540-3130

Assistance with laboratory identification of fungal spores, hyphae and mycelia can be obtained from:

Edward Desmond, Ph.D.

Microbial Diseases Laboratory

California Department of Health Services

2151 Berkeley Way

Berkeley, CA 94704,

phone (510) 540-2074

10. CONCLUSIONS

Aspergillus fumigatus spores are very common in our everyday environment in North America. Disease or illness caused by Aspergillus fumigatus is a negligible or low-level risk for healthy people. People's everyday activities (e.g., gardening, potting plants, mowing lawns, walking through leaf piles or raking leaves), their sanitation and hygiene practices (e.g., home cleaning, maintenance of air ventilation and air conditioning systems,) and their occupational exposures (e.g., construction workers undertaking digging and earth-moving) account for the great majority of exposures to this fungus.

The vast majority of ordinary exposures result in no asthma or other diseases. Certain groups of people, particularly people who are asthmatic or suffer from certain other serious diseases, immunosuppressed people, or patients taking high doses of corticosteriods, are probably at an elevated risk of developing illness after exposure to large concentrations of spores.

A properly operated compost facility (windrow, aerated static pile, or in-vessel), with proper moisture and pH levels, aeration, and/or turning and mixing, should not normally present an elevated health risk if the best management practices listed above are followed. To keep ambient dust and spore levels low, operators may use all the siting, design and operational measures listed above, including the utilization of water sprays or mists especially while turning compost, and a refrain from turning compost materials outdoors on windy days. To reduce exposure to fugitive dust and spores, compost facility employees may use appropriate personal protective equipment (e.g., OSHA-approved respirators).

It is important for sludge compost facility operators to follow the existing federal standards for proper sludge composting and co-composting, and for green waste composting operators to follow California's green waste composting facility regulations, in order to keep occupational and residential health risks to a negligible level.

Proactive monitoring of the operations at composting facilities and timely enforcement activities by LEAs and other permitting agencies is important; corrective actions should not wait until complaints are generated.

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NOTE: The authors consulted primary sources in every instance where they were accessable in the time available . Secondary sources are designated by an asterisk (*) before the author's name and a phrase at the end of the reference,

"From: (Author, Date)".

FIGURE 1. DIAGRAM OF MORPHOLOGICAL STRUCTURES OF FUNGI IN THE GENUS ASPERGILLUS

(not included)

FIGURE 2. TYPICAL TEMPERATURE AND pH RANGES OBSERVED IN WINDROW COMPOSTING

(not included)

FIGURE 4. SEASONAL COUNTS OF VIABLE ASPERGILLUS FUMIGATUS PARTICLES IN AIR IN THE WASHINGTON, D.C. METROPOLITAN AREA DURING 1979-1980

(not included)

FIGURE 3. Environmental Exposures to A. fumigatus and Other Mycoflora*.

OUTDOOR	INDOOR	OCCUPATIONAL
Suburban Washington D.C.	Forced hot-air heated house, office	Agricultural:
0-71 CFU/m3	<512 CFU/m3	Hay barns
Denmark (all Aspergillus spp.)	Attic, library stack, boiler room	<70 CFU/m3
0-204 CFU/m3	0-50 CFU/m3	100 CFU/m3
Cardiff, Wales	Disturbed dust and plant potting rooms	5,500 CFU/m3
5 CFU/m3	˜ 1,100 CFU/m3	Poultry houses
33 CFU/m3	Midwestern homes,	<100 CFU/m3
Michigan	40 CFU/m3 (frost-free period),	2,060 CFU/m3
(no self-heating matter nearby)	40 CFU/m3 (sub-freezing period)	(in Spring)
150 CFU/m3	General indoors	Mushroom houses
St. Louis, MO	<175 CFU/m3;	(stationary bed)
(outside hospitals)	0-686 CFU/m3	333 CFU/m3 (with 90% being non-mold spores)
0-50 CFU/m3		Timber processing
Lawn being mowed		102-104 CFU/m3, (Includes all airborne micro- organisms.)
<10 CFU/m3		Debarking
Mulched lawn		12,700 CFU/m3, heartwood;
686 CFU/m3		52,800 CFU/m3, sapwood;
Nature trail in Autumn		65,200 CFU/m3, bark. (Includes all fungi, Penicillium and A. fumigatus predominate.)
56 CFU/m3		Composted wood chips
School playground		1.4 x 106 CFU/m3 (Includes all fungi.)
University parking		
Shopping center		
<12 CFU/m3		
Compost site,		

Compost site, quiescent	(Includes all fungi.)
0-24 CFU/m3	Paper pulp factory
	<12 CFU/m3

*Source: Composting Council 1993, pp. 5, 18-29. [Secondary source. See the Council's draft report for primary sources]. All data are for A. fumigatus unless otherwise noted.

FIGURE 5. Aspergillus Spore Concentrations at Large-Scale Composting Facilities (CFU*/m3).

Site	Minimum	Maximum	Geometric Mean	Notes
WSSC Site II,				Sewage sludge; enclosed
1991				
Upwind	0	34	3.1	2,000 ft. away
On-site	21	3611	250	
Downwind	0	30	4.0	1,000 - 8,600 ft. away
WSSC Site II, 1987				Sewage sludge; open facility
Upwind 0.4 mi.	<1	15	1	
1.0 mi.	<1	15	2.7	
1.1-1.7 mi.	<1	10	1.4	
On-site	<1	133	9	
Downwind 0.4 mi.	<1	35	2	
Downwind 1.0 mi.	<1	37	2.5	
Downwind 1.1-1.7 mi.	<1	34	1.0	
WSSC Dickerson Site, 1981				Sewage sludge; open facility
Upwind	0	100	16	
On-site	0	555	127	
Downwind 0.5 mi.	0	174	20	
Downwind 1.0 mi.	0	228	23	
Islip, NY, 1993				Yard waste; open facility
Mon.-Sat. (operations)	0	32,743 (Spores/m3)	865	
Sun. (no operations)	0	4473 (Spores/m3)	354	
Upwind	0	34	3.1	2,000 ft. away
On-site	21	3611	250	
Downwind	0	30	4.0	1,000 - 8,600 ft. away

*CFU = colony forming units (equivalent to viable spores)

Source: Composting Council 1993