MOST attention given to health aspects at composting facilities in the past has concerned public health, particularly bioaerosols, odor emissions and heavy metals in the finished product. Federal and state regulations have not dealt with worker health. For example, the federal 40 CFR Part 503 regulation, “The Use and Disposal of Sewage Sludge,” as it pertains to composting primarily deals with product use. These regulations target heavy metals and pathogens in the compost product. The regulation pertaining to volatile solids reduction does impact odor production and vector attraction. There are no federal regulations specifically related to occupational health at composting facilities. The Occupational Safety and Health Administration (OSHA) regulations are industrywide and relate to noise and safety issues. Recently, the National Institute of Occupational Safety and Health (NIOSH) issued an Alert concerning Organic Dust Toxic Syndrome (ODTS), with emphasis on farm workers.

There has been relatively little information on occupational health aspects at composting facilities. Recently, several events occurred at composting facilities, whereby workers have questioned health impacts or reported adverse health conditions. Most of the data is not generally available, as it resides in in-house reports or gray literature.

Information on worker health can be very valuable in the future design of facilities and in evaluating the potential health impact to the areas surrounding composting facilities. Workers are the most exposed individuals. Not only are they exposed to more concentrated levels of materials, but they are also more often exposed than the general public. The objectives of this paper are to provide data and insight on occupational hazards with exposure to various biological and chemical agents and to suggest mitigation measures which would reduce potential health hazards to workers.

**OCCUPATIONAL HEALTH HAZARDS**

Employees of composting operations can be exposed to pathogens, bioaerosols, toxic chemical substances (both in the air and from handling materials), heavy metals in feedstocks or compost, and dust generated during feedstock preparation and composting. Occupational health hazards vary with different types of feedstocks and the technologies employed. Table 1 shows the potential exposure to the various hazards in relation to the feedstock and its predominant exposure route.

Primary pathogens, especially in biosolids, can enter the worker through the mouth and pass into the intestines as a result of unclean hands. Bioaerosols and dust can be inhaled. Toxic organics, particularly in municipal solid waste (MSW), can enter the body through the skin as a result of spillage of liquid materials or can be inhaled as vapors into the respiratory system. Consumption and accumulation of heavy metal from wastes is extremely low and does not present a hazard to workers.

High levels of pathogens can be found in biosolids as a result of fecal matter in wastewater. MSW will contain pathogens from fecal matter in discarded diapers and domestic animal fecal matter. Medium levels of pathogens can be found in yard trimmings, resulting from the disposal of domestic animal litter. Bioaerosols will generally be high during the composting of any organic material but are also found in many other types of feedstocks. Toxic organics are generally low in most feedstocks; however, as a result of disposal of hazardous materials (e.g., household hazardous wastes, pesticides, and other chemicals), specific batches of solid waste may contain toxic organics.

The technology and equipment employed can impact the potential for worker health from bioaerosols and dust. Windrow equipment and agitated bed systems will release more bioaerosols and dust than tunnel and static pile systems. Screens have a great potential to release dust. In one enclosed facility where the screen was located in the same area as the composting process, very high measurements of bacteria, *Aspergillus fumigatus* (A. fumigatus), fungi, and other bioaerosols were found in the working areas. Before discussing the data available and mitigation measures, it is important to understand the occupational risk involved with the various hazards.

**PRIMARY PATHOGENS**

Pathogens can be classified as primary or secondary. Primary pathogens can invade and infect healthy persons, whereas secondary pathogens normally infect debilitated individuals. The primary pathogens found in various compost feedstocks are bacteria, viruses, parasites, and nematodes (see...
Data on worker health can help to improve future design of facilities and in evaluating health impact to areas surrounding composting sites.

Table 2). The secondary pathogens of concern in composting will be discussed under the topic of bioaerosols.

Workers handling biosolids, MSW, yard trimmings, and food residuals can be exposed to pathogens. Human fecal matter contains primary pathogens. As a result, untreated biosolids contain pathogens. Many of the pathogens are reduced or destroyed during the treatment of wastewater and biosolids. Biosolids are the result of separating solids from wastewater in order to be able to discharge clean and disinfected effluent into water courses. Therefore, biosolids contain many of the pathogens in the influent wastewater from domestic, commercial and industrial sources. Tables 3 and 4 show levels of some pathogens found in biosolids, MSW, yard trimmings, and food residuals.

When domestic animal wastes are discarded with other MSW, many organisms survive. Yard trimmings containing domestic animal wastes will also have pathogens. Many of these pathogens can grow to high numbers since there are fewer competitive organisms. Several researchers have identified entroviruses in domestic animals (Lundgren et al. (1968)) and isolated 164 viruses from rectal, nasal, and throat swabs of beagle dogs. Most of the viruses identified were coxsackieviruses or echoviruses. Grew et al. (1970) found poliovirus coxsackievirus and adenovirus in domestic animals in Costa Rica.

Early data on pathogens and pathogenic indicators found in MSW have been reported by Pahren (1987) (see Table 3). Fecal Streptococci levels in MSW were higher than in hospital wastes or biosolids. Disposable diapers are a possible source of infectious enteric viruses. These viruses can be stable in the environment for long periods of time.

The composting process is designed to eliminate pathogens and meet the requirements of the federal Part 503 regulations.

**BIOAEROSOLS**

The bioaerosols of concern to workers in composting operations can be secondary pathogens or pathogenic substances. *A. fumigatus* and several of the thermophilic actinomycetes are secondary pathogens of concern to worker health. The pathogenic substances that could impair worker health are endotoxin and organic dust. *A. fumigatus* is a ubiquitous (found everywhere) fungus associated with decaying organic matter. It has been found in every continent, including Antarctica. It is associated with soils, forest litter and duff, bird nests and droppings, manure of cattle and horses, and compost. It has been found in homes, attics, libraries, air conditioners and humidifiers, and building ventilation systems (Millner et al., 1994). *A. fumigatus* spores are small and can be inhaled. *A. fumigatus* is found in commercial soil potting products (Millner et al., 1977) and in wood chip piles in the forest product industry (Passman, 1980). Hirsch and Sosman (1976) studied the occurrence of *A. fumigatus* in homes. They found the fungus in 42 percent of bedrooms, 56 percent of bathrooms, and 85 percent of basements. It was the fourth most common mold in households and was present in all seasons. *A. fumigatus* was more frequently found in homes with pets. Similar data were found by Solomon (1975), who investigated the indoor atmosphere of 150 homes. Slavin and Winzenburg (1977) found the fungus in basements, bedding, and household dust. Some common activities, such as walking in woods or parks, mowing and raking lawns, and potting house plants, expose individuals to *A. fumigatus* and other bioaerosols.

Severe *A. fumigatus* infections from any of the species occur almost exclusively in people who are severely debilitated or immunocompromised (e.g., persons with kidney transplants, leukemia, or lymphoma). Thus, nearly all of the cases reported have been with patients in the hospital environment. Millner et al. (1994) indicated that in healthy individuals with normal functioning lungs, a large number of inhaled spores would not result in infection. To date, there is no known level or dose response of *A. fumigatus* spores which will cause infection.

Bacterial endotoxin is the complex phospholipid-polysaccharide macromolecule of the cell wall of gram-negative bacteria. Since gram-negative bacteria are ubiquitous, so are endotoxins. Organic dust is a common source of endotoxin. In addition to endotoxin, other microorganisms can be present in organic dust. Endotoxin and organic dusts can elicit inflammatory conditions that are either mild or severe. Rylander (1993) indicated that repeated exposure to organic dusts in occupational settings can result in mucous memi-
brane irritation (MMI). This condition produces itching and watering eyes and nose and throat irritation. Recently, NIOSH (1994) requested assistance in preventing a syndrome called ODTS. ODTS can result in respiratory illnesses when there is exposure to high concentrations of organic dust. The syndrome is characterized by fever occurring four to 12 hours after exposure. Other conditions manifested are flu-like symptoms, headache, chills, body aches, and cough (NIOSH, 1994). NIOSH reported agricultural-related cases resulting from workers shoveling composted wood chips and leaves, shoveling wood chips, and handling grain.

Millner et al. (1977) showed that biosolids contained from $10^2$ to $10^3$ colony forming units (CFU) per gram dry weight of A. fumigatus. Wood chips contained from $10^3$ to $10^8$ CFU per gram dry weight of A. fumigatus. St. Pierre (1986) reported that raw biosolids and biosolids cake contained 13 to 16 ng/g and 6.4 ng/g endotoxin, respectively. Millner et al. (1994) provided information on compost feedstocks as sources of bioaerosols (see Table 5). All of the feedstocks contained endotoxin. With the exception of some manures and animal carcasses, all of the other feedstocks contained A. fumigatus.

Two studies in Canada were designed to evaluate bioaerosols in relation to worker health (St. Pierre, 1986; Green Lane Environmental Group, Ltd., 1995). The study in Windsor evaluated bioaerosols throughout the wastewater treatment plant and the composting facility located at the plant (St. Pierre, 1986). This work was instigated by the Ministry of Labor in conjunction with municipal union members working in the wastewater treatment plant. Workers in the dewatering building complained of several symptoms. Workers at the composting site were employees of a private company. These workers did not report any symptoms associated with the biosolids composting operations.

The second study at Sarnia was done at a
yard waste composting facility operated by the municipality. Samples for bioaerosols were taken during two days. Dust levels ranged from 0.11 to 1.15 mg/m³; A. fumigatus levels ranged from 0.4 x 10³ to 7.8 x 10³ CFU/m³; gram-negative bacteria ranged from 0.12 x 10⁶ to 1.6 x 10³ CFU/m³; and endotoxin levels ranged from <0.00019 to 0.047 µg/m³. All airborne levels of total particulate were within the limit established by the Ontario Ministry of Labor. Dust levels were below the Danish occupational limits of 10 mg/m³ and the 15-mg/m³ level for nonspecific dust established by OSHA. Personal samplers were used to assess direct worker exposure. A. fumigatus levels on personal samplers ranged from 0.4 x 10³ to 7.8 x 10³ CFU/m³; gram-negative bacteria ranged from 0.12 x 10⁶ to 1.6 x 10³ CFU/m³; and endotoxin levels ranged from 0.0019 to 0.047 µg/m³. Malmros et al. (1992) proposed threshold limit values (TLV) for gram-negative bacteria and endotoxin. The TLV for gram-negative bacteria was 1,000/m³ of air, and for endotoxin, the TLV was 0.1 µg/m³ of air. The International Committee on Occupational Health has indicated that MMI can occur when endotoxin levels are in the range of 0.02 to 0.05 µg/m³. These recommended TLV values were exceeded on the personal samplers during bagging of raw materials and turning of active composting windrows. The report also provided a bioaerosol control plan.

**OCCUPATIONAL HEALTH CONDITIONS AT COMPOSTING FACILITIES**

**Biosolids**

One of the earliest studies examining health conditions at several biosolids composting facilities was conducted by Clark et al., (1984). The data was highly inconclusive and generally did not show health effects. The authors did indicate that fungal spores in the environment could have adverse effects on workers. In many cases, intermediate workers had higher levels of "abnormal" findings than compost workers. Of the 26 compost workers, one had evidence of skin infections and two had evidence of ear infections and acute or chronic eye and nose inflammation. The authors indicated that these could possibly be related to composting activities. Epstein and Epstein (1985) reviewed this study and indicated that the skin irritations were not statistically significant. One of the ear infections was not compost related. There was no evidence of different pulmonary function tests between compost workers and noncompost workers.

**Table 3. Indicator pathogenic organisms and pathogens in biosolids, MSW and hospital wastes (Pahren, 1987)**

<table>
<thead>
<tr>
<th>Microorganisms (per gram)</th>
<th>Biosolids</th>
<th>Hospital Waste</th>
<th>MSW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total coliforms</td>
<td>2.8 x 10⁶</td>
<td>9.0 x 10⁹</td>
<td>7.7 x 10⁹</td>
</tr>
<tr>
<td>Fecal coliforms</td>
<td>2.4 x 10⁶</td>
<td>9.0 x 10⁹</td>
<td>4.7 x 10⁹</td>
</tr>
<tr>
<td>Fecal streptococci</td>
<td>3.3 x 10⁷</td>
<td>8.6 x 10⁹</td>
<td>2.5 x 10⁹</td>
</tr>
</tbody>
</table>

Severe A. fumigatus infections occur almost exclusively in people who are severely debilitated or immunocompromised — such as persons with kidney transplants, leukemia, or lymphoma.

In fact, workers had an increase in breathing capacities on Friday evening, after an entire week of exposure, as compared to breathing capacities on Monday morning.

A five year comprehensive study (1987 to 1991) was conducted at the Washington Suburban Sanitary Commission Site II biosolids facility in Maryland by Chesapeake Occupational Health Services (1991). During the five years, 242 individuals were screened, with an average of 46 workers participating annually. All 242 blood samples were reported as "None Detected." The data showed that respiratory symptoms of workers decreased or remained unchanged during the five years (see Figure 1). Reports of asthma, bronchitis, ear aches, and shortness of breath were very low. Spirometric findings also were very low. Some of the spirometric findings could be related to smoking history. However, there was no excess frequency of abnormal spirometric findings. The study concluded the following:

There is no evidence of adverse effects related to A. fumigatus; employee health concerns decreased; lung air capacities of employees basically remained unchanged; physical examination findings were stable; chest X-ray results were unremarkable; all biological laboratory analyses for A. fumigatus remained "None Detected."

Several biosolids composting facilities conducted routine examinations of workers. At Columbus, Ohio, routine examinations were conducted every six months from 1982 to 1986. No health conditions related to employment were reported for the 20 employees (Epstein, 1993). At the Fairfax County, Virginia biosolids composting facility, routine examinations were performed prior to hiring employees and every year thereafter since 1984. Tests conducted on employees included pulmonary function tests, chest X-rays, blood tests, routine physicals, hearing
tests, and vision tests. No physical problems have been reported or diagnosed relating to employment at the composting facility. The Hampton Road Sanitation District (HRSD) in Virginia began operating an open biosolids composting facility in 1981. Mixing and screening was done under a covered area. Full physical examinations were provided to employees every two years. The tests included A fumigatus antigen skin tests, pulmonary function tests, chest X-rays, blood tests, urinanalyses, and routine physical tests. No health problems have been reported.

Municipal Solid Waste

There is no published or reported data for MSW composting facilities in the United States. The data from Europe has been predominantly from Denmark. In 1988, Lundholm and Rylander reported on occupational symptoms among compost workers at an MSW/biosolids composting plant. They indicated that household garbage was a major source of gram-negative bacteria. Subjective symptoms such as nausea, headaches, and diarrhea were more common among workers interviewed than the control. Malmros and Petersen (1988) evaluated working conditions before and after modifications were made in a Danish MSW sorting plant. Since MSW composting facilities often use manual and mechanical sorting in the pre-processing step prior to composting, this data can be applied to MSW composting facilities. Workers reported flu-like symptoms, eye and skin irritations, and respiratory problems. Total bacterial count and endotoxin levels were measured (see Table 6).

The initial data suggested that improvements in the plant would be needed to reduce worker exposure to endotoxin and other microbial levels. This was based on the assumption that human dose relation to endotoxin was in the range of 0.1 to 1.0 μg/m³, which incites fever, acute bronchial constriction, and chest pain. Improvements in ventilation and rebuilding the plant greatly improved worker conditions. Malmros (1990) reported on problems with the working environment for several different types of MSW treatment plants. At that time, there were ten large composting facilities in Denmark. ODTS was indicated as a disease among workers. In addition, where biosolids were used, gastrointestinal symptoms were prevalent in workers. Sigsgaard et al. (1992) reported on respiratory disorders in resource recovery workers. Table 7 shows the respiratory symptoms among Danish workers in compost and garbage handling facilities. In all cases, compost workers experienced fewer respiratory symptoms than garbage handlers. The authors also examined gastrointestinal symptoms such as vomiting and diarrhea. These two symptoms were lower in the compost workers than in the garbage handling workers.

MITIGATION MEASURES TO PROTECT WORKERS

Mitigation measures to reduce worker exposure and potential health effects involve three areas: Personal protection; Facility design; and Operational activities.

Personal protection involves education and the use of personal protective devices. Periodic training on health and safety is good insurance. Employees need to be informed of appropriate practices and health issues related to composting. Good common sense behavior is very important. Employees should adhere to precautions such as using protective clothing, including uniforms and boots which are kept at the workplace; Use protective equipment, such as ear plugs, eye wear, hard hats, and dust masks, when appropriate; and Treat and disinfect all cuts, no matter how small.

Facilities need to be designed for the safety and health of employees. The totally enclosed Davenport facility designed by E&A Environmental Consultants, Inc. (see BioCycle, Vol. 37, No. 4, p. 62, “The Big and Small of Biosolids Composting.”) provides 10 air exchanges per hour during working hours. Drainage and clean-out facilities should be provided to re-
A five year comprehensive study of workers at a biosolids composting facility showed no evidence of adverse effects related to *A. fumigatus*; employee health concerns decreased; and physical examination findings were stable.

### Table 4. Microbiological concentration in food residuals, yard trimmings, and wood wastes (E&A Environmental Consultants, Inc., 1994)

<table>
<thead>
<tr>
<th>Indicator organism</th>
<th>Food Residuals</th>
<th>Yard Trimmings</th>
<th>Wood Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicator organism</td>
<td>Food Residuals</td>
<td>Yard Trimmings</td>
<td>Wood Waste</td>
</tr>
<tr>
<td>Total coliform</td>
<td>5.00 x 10^6</td>
<td>8.0 x 10^6</td>
<td>0.00 x 10^6</td>
</tr>
<tr>
<td>Escherichia coli</td>
<td>3.5 x 10^5</td>
<td>8.00 x 10^5</td>
<td>1.20 x 10^6</td>
</tr>
<tr>
<td>Fecal streptococcus</td>
<td>8.0 x 10^4</td>
<td>1.60 x 10^4</td>
<td>1.60 x 10^4</td>
</tr>
<tr>
<td>Enterococcus</td>
<td>1.30 x 10^3</td>
<td>2.30 x 10^3</td>
<td>3.00 x 10^3</td>
</tr>
</tbody>
</table>

**Pathogens**

- *Salmonella* spp.: <0.002
- Staphylococcus: 32.2
- *Listeria* spp.: <0.02

**Parasites**

- Protozoa: Negative
- Negative

### Table 5. Compost feedstocks as sources of bioaerosols

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>AP</th>
<th>Endotoxin</th>
<th>TA</th>
<th>Enteric Bacteria/ Viruses</th>
<th>Fungi</th>
<th>Other Specific Biohazards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yard trimmings</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Food/household waste (MSW)</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Food processing/ winery residuals (grape marc and cheese)</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Fisheries (shellfish)</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Agricultural residuals (cotton gin, garden, sugarcane/pineapple)</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Biosolids</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Animal residuals</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Carcasses</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Manures</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Barnyard manure</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

* = present, - = not present, *Aspergillus fumigatus*, + Thermophilic actinomycetes

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**Eliot Epstein** is president of E&A Environmental Consultants in Canton, Massachusetts and an adjunct Professor of Public Health, Boston University School of Public Health at the School of Medicine.

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