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Occupational and Environmental Health Issues of Solid Waste Management

Special Emphasis on Middle- and Lower-Income Countries

Sandra Cointreau

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PREFACE

An overview is presented of the available health literature for causes of diseases, injuries, and accidents from solid waste management technologies. Illnesses discussed include infectious diseases, allergies, respiratory damage, and cancers. Some diseases are derived from direct ingestion of infectious micro-organisms, others involve infection through contamination of the food chain, whereby animals or other vectors have ingested infectious micro-organisms. Injuries include joint and spinal damage, fractures, puncture wounds, damage to eyes and ears. Accidents include slides from unstable disposal piles, cave-ins of disposal site surfaces, fires, explosions, being caught in processing equipment, and being run over by mobile equipment. The solid waste management technologies discussed include collection, recycling, processing, and disposal technologies.

The information contained in this document will be useful to a wide audience, including:

- City officials who need to develop programs and systems to protect city workers and residents from health risks related to public cleansing activities;
- Environmental groups who monitor government services and interact in permitting procedures through public participation;
- Health practitioners observing work or proximity-related health impacts;
- Solid waste management planners and designers; and
- Lawyers and labor representatives involved in negotiating solid waste contracts or labor agreements.

Significant effort was made to obtain literature from developing countries, supplemented by personal contacts and fieldwork in over 40 countries[1]. Much of that literature is unpublished and considered anecdotal, as it was acquired directly from health practitioners in the field and was not part of a rigorous statistically validated study with peer review. Nevertheless, it has been used judiciously to describe the seriousness of health problems confronted by solid waste workers and waste pickers, particularly in many middle- and lower-income countries.

All of the health issues reported from high-income countries are directly applicable to developing countries, but risk levels can be multiplied in the latter because protective measures are seldom implemented in poorer countries. The handling of wastes involves more manual contact too. Where available, older data is also provided for the high-income countries. Historical health data from high-income countries is often more applicable to developing countries than recent data, because risk reduction, protective measures and pollution control systems now expected in higher-income-countries were largely implemented only in the past 20 years.

Provoked by the many injuries and diseases the author observed at solid waste facilities in developing countries, the background research by the author for this publication has been accumulated over several years. The Waste Management Unit of the World Health Organization (WHO), Regional Office for Europe, encouraged the work to expand her effort to enable this publication to be prepared. The WHO arranged for the peer review and final editing/formatting. The practical follow-up to this publication would be through initiatives to encourage improved record keeping on health impacts, increased research on specific health risks, and greater worker protection.

[1] Sandra Cointreau's work on solid waste in developing countries has included direct field experience in:

- South America and Caribbean: Ecuador and the Galapagos Islands, El Salvador, Jamaica, Haiti, Peru, Colombia, Paraguay, Uruguay, Argentina, Mexico, Brazil, Dominican Republic, Guyana, Trinidad & Tobago;
- Eastern Europe: Romania, Croatia, Montenegro, Hungary, Latvia, Turkey;
- Asia: India, Bangladesh, Pakistan, Sri Lanka, Uzbekistan, Kazakhstan, Thailand, Philippines, South Korea, Vietnam, Cambodia, Indonesia, People's Republic of China;
- North Africa/Middle East: Morocco, Tunisia, West Bank/Gaza, Jordan, Syria, Iraq;
- Africa: Mauritius, Nigeria, Guinea, Ghana, Gambia, Senegal, Tanzania, Mozambique, and Sierra Leone.

OCCUPATIONAL AND ENVIRONMENTAL HEALTH ISSUES OF SOLID WASTE MANAGEMENT: WITH SPECIAL EMPHASIS ON MIDDLE AND LOWER-INCOME COUNTRIES

INTRODUCTION

All activities in solid waste management involve risk, either to the worker directly involved, or to the nearby resident. Risks occur at every step in the process, from the point where residents handle wastes in the home for collection or recycling, to the point of ultimate disposal.

Health risks from waste are caused by many factors, including:

- The nature of raw waste, its composition (e.g., toxic, allergenic and infectious substances), and its components (e.g., gases, dusts, leachates, sharps);
- The nature of waste as it decomposes (e.g., gases, dusts, leachates, particle sizes) and their change in ability to cause a toxic, allergenic or infectious health response;
- The handling of waste (e.g., working in traffic, shoveling, lifting, equipment vibrations, accidents);
- The processing of wastes (e.g., odor, noise, vibration, accidents, air and water emissions, residuals, explosions, fires);
- The disposal of wastes (e.g., odor, noise, vibration, stability of waste piles, air and water emissions, explosions, fires).

This paper discusses both occupational health risks to workers and environmental health risks to residents and workers. Because worker exposure times are shorter than resident exposure times, some risks may be less for workers than for residents. On the other hand, contaminant levels to which workers are exposed can be significantly higher than those that reach residents, thus leading to increased risks for workers over residents.

In developing countries, a significant portion of the waste pickers found at open dumps are children and pregnant women. Confounding this image is the reality that residents around solid waste disposal sites include infants, young children, women of child-bearing age, and seniors. Children are particularly vulnerable to toxins because they ingest more water, food, and air per unit of body weight; their metabolic pathways are less developed to detoxify and excrete toxins; and any disruption during their growth years can easily disrupt development of their organ, nervous, immune, endocrine and reproductive systems. (Landrigan, 1998)

Most diseases have exposure pathways. Most injuries have contact pathways. Interrupting the pathways can reduce risks. In solid waste management this can be achieved by making waste technologies more contained, reducing contaminant emissions, changing working methods, use of protective clothing, and keeping the public and residents a safe distance away from operations. For example, risk of respiratory infection or allergic response to organic dusts can be greatly reduced if transfer stations, composting and recycling process systems are enclosed or ventilated and if workers wear respiratory masks.

Occupational Health Risks

Workers and waste pickers handling solid waste throughout the world are exposed to occupational health and accident risks related to the content of the materials they are handling, emissions from those materials, and the equipment being used.

For purposes of this report, the term "**relative risk**" is used to denote a large-scale study with a viable, appropriate control group, conducted by an appropriate reputable organization. One country, Denmark, has reported results from in-depth, long-term, country-wide studies of solid waste workers, compared with data on the overall national labor force, that are could be considered statistically valid for determining "**relative risk**". The Danish studies covered the period of 1984 to 1992 and compared solid waste workers with the entire country work force. \74,75\

The Indian study of parasitic infection among solid waste workers was obtained from conducting stool samples from 1 500 workers from 33 Indian cities. The study was well conducted and involved a viable control group, and thus the term "**relative risk**" is used. \11\

The USA study on increased coronary disease events showed that solid waste workers had 2 times more risk than the country's general laborers, and thus represents a large scale comparative assessment of "**relative risk**". \17\

The Romanian study analyzed data from 168 Romanian cities, 65% of the country's urban centers, and compared the data on solid waste workers with appropriate control groups, thus being categorized as providing "**relative risk**" data. \22\

For other studies with good data, but without the same degree of statistical validity, this document provides only an indication of "**risk**" for the given area of the study and specific control population selected. See Box 1 for information on Denmark's "**relative risk**" reports, and the less controlled reports from specific case studies on "**risks**" in other countries. Throughout the text of this document, anecdotal data is reported, but without any such designation of "**risk**" versus "**relative risk**".

Because of inadequate understanding of the magnitude of the problem and poor financial resources, the risks are still largely unmanaged in most developing countries. To protect middle- and lower-income countries, characterized by inadequate waste collection, disposal that is still dominated by open dumping, laborers that are paid daily (so-called “casual” workers) without health benefits or job security, such costs may appear prohibitive unless supported by external financial assistance.

Box 1. Disease and Injury Risks for Solid Waste Workers versus Control Baseline Populations
(Based on data from various countries that is presented within this document)

- 6 times more **relative risk** of Infectious Disease (Denmark)\74\
- 2.6 times more **relative risk** for Allergic Pulmonary Disease and 1.4 for Non-Allergic Pulmonary Disease (Denmark)\74\
- 2.5 times fore **relative risk** for Chronic Bronchitis (Geneva in Switzerland)
- 1.2 increased risk of hepatitis (Genoa in Italy)\47\
- 3 times more **relative risk** for Parasites (India)\11\
- 10 times more **relative risk** for Acute Diarrhea (Romania)\21\
- 2 times more **relative risk** for Coronary Disease (USA)\17\
- 1.3 times more **relative risk** for Injury (Romania)\22\
- 5.6 times more **relative risk** for Accidents (Denmark)\74\
- 10 times more **relative risk** for Accidents (USA)\12,43,74\
- 1.9 times more **relative risk** for Musculoskeletal Problems (Denmark)\74\

Environmental Health Risks
People living and working in the vicinity of solid waste processing and disposal facilities also are exposed to environmental health and accident risks. These risks relate to the emissions from the solid wastes, the pollution control measures used to manage these emissions, and the overall safety of the facility. As with occupational risks, these risks are being substantially managed in high-income countries, but are still largely unmanaged in most developing countries. Pollution control costs money and adherence to safe design standards requires a commitment to construction and operation supervision. External financial assistance is needed to support poor countries in their environmental efforts, even though solid waste projects have proven to be more time-consuming to prepare and implement than most urban infrastructure improvements.

CONTEXT – SOLID WASTE SYSTEMS

The standards and norms for handling municipal solid wastes[2] in industrialized countries have reduced occupational health and environmental impacts substantially. About three decades ago, high-income countries required open dumps to be covered daily with soil to curtail vector access, and thus be upgraded to controlled landfills[3]. Since the early 1970's, when it became apparent that even controlled

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[2] Municipal solid waste includes nonhazardous wastes from households, commercial establishments, institutions, markets, and industries. Construction/demolition debris and yard wastes are not typically included in the estimated waste generation rate per capita of municipal solid waste, as they are highly variable and skew quantity assessments. Also, construction/demolition debris and yard waste do not require disposal standards, which are as stringent to meet as those for other solid wastes. In developing countries, while hazardous wastes, including infectious medical wastes, are not supposed to be within the general municipal solid waste, they typically can be found because no alternative collection and disposal system exists for these wastes and regulations regarding their management are not enforced.

[3] A controlled (or interim) landfill has daily soil cover and perimeter drainage to minimize leachate generation; but not the impermeable underlining and underdrainage, leachate treatment, and gas collection systems required of modern sanitary landfills /108/.

landfills may cause significant water pollution, sanitary landfill[4] technology was developed to provide barriers to pollutant migration (such as clay and plastic base liners), as well as to provide leachate and gas collection and treatment systems.

For the past two decades, occupational health and safety protection has become increasingly regulated to minimize work-related risks and labor unions have also successfully changed working conditions (Box 2). For example, most waste collection in high-income countries involves vehicles with low-loading heights and easy-to-lift plastic containers or bags, and workers are required to wear gloves when loading, as well as high-visibility vests in traffic. Waste sorting at materials recovery facilities involves dust suppression, conveyance enclosure, and ventilation-controlled work environments, and workers are required to wear personal respiratory protection if working spaces do not meet air standards set for occupational safety and health. Landfill equipment has roll bars and enclosed air-conditioned cabs, and workers are required where warranted to wear personal noise protection and receive formal training.

Box 2. Health Risk Factors for Solid Waste Workers

- Waste content
  - ⇒ fecal matter, blood, body fluids, animal flesh
  - ⇒ hazardous chemicals and heavy metals
  - ⇒ volatile organic and greenhouse gases
  - ⇒ pressurized gas containers, munitions
- Heavy loads, lifting exertion and vibration
- Landfill slides, fires and vehicle accidents
- Noise

Current Situation in Middle and Lower-income Countries

In developing countries, the health-related underpinnings of solid waste management still need to be addressed (Box 3). Even the minimal regulatory framework that exists in most of these countries for environmental protection and occupational health and safety is often not enforced. Large quantities of waste are uncollected; uncollected wastes clog drains and channels causing flooding, habitats for insect breeding and accumulate on open areas. Waste collection is by labor-intensive systems with little, if any, worker protection from direct contact and injury; waste disposal fills ravines and wetlands often near residential neighborhoods, and commonly is burned openly.

Box 3. Poorer Countries have Greater Worker Risks

- Collection is by labor-intensive systems
- Workers have less protection
- Most waste is not safely contained in readily liftable load sizes
- Recycling is conducted from mixed waste, rather than from segregated materials at source
- Many waste pickers are children or women of child-bearing age
- Disposal is by open dumping
- Disposal equipment operators are not in closed air conditioned cabs

In developing countries, solid waste collectors lift heavier loads; often to higher loading positions and in traffic conditions with significantly more dust and diesel exhaust pollution, than their high-income counterparts. Waste pickers[5] work informally at open dumps, typically living adjacent to the dumpsite in poor housing conditions, with minimal basic infrastructure for clean water and sanitation; and a significant portion of their number are children under 16 years old. Wastes sorting and recycling activities are typically conducted manually in micro and small-scale enterprises, with minimal washing and baling equipment and virtually no dust control or worker protection.

Solid Waste Generation

Municipal solid waste is produced as a result of economic productivity and consumption. Countries with higher incomes produce more waste per capita and per employee, and their wastes have higher portions of packaging materials and recyclable wastes. In low-income countries, there is less commercial and industrial activity, as well as less institutional activity, thus resulting in lower waste

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[4] Sanitary landfill is a disposal technology wherein solid wastes are placed on land (typically underlain by impermeable soils) that is naturally suited to protect the underground water. The site is prepared with drainage systems for contaminated seepage (i.e., leachate) from the solid waste and surface runoff, and constructed with gas collection and ventilation or flaring systems. Within the landfill, each day's solid waste is formed into a cell and covered with soil to minimize water infiltration, mitigate odors, and limit vector breeding. Leachate typically is treated to remove organic loadings and suspended solids.

[5] Waste pickers are commonly found at solid waste transfer depots and open dumps in developing countries. They pick through the waste, looking for recyclable materials and food waste for animal feeding. In large measure, they live in the immediate vicinity of the dump site where they work.

generation rates. In countries where personal incomes are low, there is, of necessity, extensive recycling at the source. Table 1 shows how waste generation rates vary by income level and city size.

Table 1. Global Perspective on Solid Waste Quantities

	LOW INCOME COUNTRY	MIDDLE INCOME COUNTRY	HIGH INCOME COUNTRY
MIXED URBAN WASTE – LARGE CITY (kg/capita/day)	0.50 to 0.75	0.55 to 1.1	0.75 to 2.2
MIXED URBAN WASTE – MEDIUM CITY (kg/capita/day)	0.35 to 0.65	0.45 to 0.75	0.65 to 1.5
RESIDENTIAL WASTE ONLY (Kg/capita/day)	0.25 to 0.45	0.35 to 0.65	0.55 to 1.0

Notes:

1. Country categorization by income is based on 1992 GNP data from the 1994 World Development Report published by the World Bank. Waste data based on a wet, "as received", condition (i.e., not oven dried).
2. For purposes of this table, a medium city has 100,000 to 500,000 residents, and a large city has above 500,000 residents.
3. Urban waste includes residential, commercial, industrial and institutional waste, as well as street sweepings and yard waste. Construction/demolition debris is not included.
4. Recycling rates can reduce by as much as 50% the amount of waste requiring disposal. In the USA in 1995, recycling recovered 27% of all wastes generated, with paper recycling reaching 41% and yard waste composting reaching 38%.

Source: Sandra Cointreau

Solid Waste Composition

Waste composition is largely affected by two factors: (1) income level of the country; and (2) extent of industrialization. Income level affects the main ingredients in solid waste, particularly the level of packaging (i.e., paper, plastic, carton, cans, and bottles). Income level also affects the extent of containment that is affordable at the household level (i.e., covered bins, plastic bags, cartons, open piles), which in turn affects the amount of soil and ash within the waste and the moisture content. Table 2 provides a view of how waste composition varies by income levels. Because there is less food material, yard wastes, and other putrescible organics in the solid waste of high-income countries, the resulting moisture content of the waste is low and the calorific value is relatively high. On the other hand, the wetter waste of developing countries does not have sufficient calorific value to self-sustain incineration, that is, it will not burn without the addition of fuel.

Historic data from 1960 in the USA shows that the amount of plastic and metal in mixed municipal solid wastes has dramatically changed over time (in percent by total weight). Nationwide, the quantity of metals comprised 12.3% in 1960, but only 7.7% in 1996; whereas plastics comprised only 0.4% in 1960, and increased to 9.4% in 1996. Furthermore, yard trimmings (garden wastes) decreased from 22.7% in 1960 to 13.4% in 1996 \16\. Developing countries are seeing comparable shifts in their waste compositions, with plastics content growing markedly in the last decade.

Hazardous Materials

In high-income countries, hazardous wastes are carefully regulated to be source segregated and separately managed in secured transport and disposal facilities, as well as tracked through cradle-to-grave manifest record-keeping systems. Despite the stringent laws and strong enforcement, not even the most sophisticated systems are foolproof. In 1997, when a private sector truck carrying municipal solid waste had an accident, the waste load that spilled into the street was heavily laden with syringes, IV bags, bloodied clothes, and other infectious medical wastes. Careful monitoring is essential, because private sector collection contractors can save money by illegally combining healthcare wastes with their nonhazardous municipal loads \50\.

Despite the lower level of commercial, industrial, and institutional activity in developing countries, their solid waste is not necessarily devoid of hazardous wastes[6] because the regulatory framework and enforcement system to segregate and separately collect such wastes are nearly non-existent or dysfunctional. Bloodied bandages, cotton swabs, and syringes from hospitals are commonly found within the mixed municipal solid waste collected in developing countries. Such wastes are often placed in piles within large bins or rooms, requiring manual emptying by workers with and shovels. Hazardous solvents, adhesives, plating materials, and pesticides from industries, as well as hazardous asbestos products from construction/demolition activity, are also common.

Table 2. Global Perspective on Urban Solid Waste Characteristics

COMPOSITIONOF RAW WASTE (by wet weight):	**LOW INCOME COUNTRY**	**MIDDLE INCOME COUNTRY**	**HIGH INCOME COUNTRY**
VEGETABLE/PUTRESCIBLE %	40 to 85	20 to 65	7 to 55
PAPER AND CARTON %	1 to 10	15 to 40	15 to 50
PLASTIC %	1 to 11	2 to 13	2 to 20
METAL %	1 to 5	1 to 5	3 to 13
GLASS %	1 to 10	1 to 10	4 to 10
RUBBER,MISC.%	1 to 3	1 to 5	2 to 12
FINES % (sand, ash, broken glass)	15 to 50	15 to 40	5 to 20
OTHER CHARACTERISTICS:			
MOISTURE %	40 to 80	40 to 60	20 to 35
DENSITY IN TRUCKS kg/m3	250 to 500	170 to 330	120 to 200
LOWER HEATING kcal/kg	800 to 1100	1000 to 1500	1500 to 2700

Table Notes:

1. Country categorization by income is based on 1992 GNP data from the 1994 World Development Report published by the World Bank. Waste data based on a wet, "as received", condition (i.e., not oven dried).
2. Compaction trucks achieve load densities of 400 to 500 kg/m3 in both developing and industrialized countries, based on their hydraulic mechanism designs. Higher densities, of up to 650 kg/m3, could result from high soil and water contents levels common in the wastes of some countries.
3. For self-sustained incineration, a year-round minimum greater than 1300 kcal/kg lower calorific value (that is, as received) is generally considered needed. For waste-to-energy plants, 2200 kcal/kg is the minimum calorific value desired.
4. Some Eastern European cities (such as Budapest, Hungary) within middle-income countries have marginally suitable levels calorific value for incineration of 1300 to 1600 kcal/kg. Singapore is above the margin, with about 1600 kcal/kg.

Source: Sandra Cointreau

In Europe, in 1998, industrial waste generation ranged from approximately 0.3 to 1.0 tonnes/person/year, with the highest levels in high-income industrialized countries like Germany and lower levels in poorer more agrarian countries like Portugal. From 1% to 3% of industrial wastes produced were considered hazardous. \108\

In 1993, industrial waste surveys conducted in 21 countries of Latin America showed, as expected, that the per person waste generation rate for industrial sludges and solids was a function of the country's level of industrialization. The highest rates (over 0.3 tonnes/person/year) occurred in upper-middle-income countries such as Mexico and Brazil, and the lowest rates (under 0.1 tonnes/person/year) in lower-middle-income countries such as Bolivia and Ecuador. \25\

In most of these countries, more than 30% of the industrial wastes were inappropriately discharged to open dumps and controlled landfills. Similarly, hazardous healthcare waste was being co-disposed with general municipal solid waste in open dumps and controlled landfills, seldom in sanitary landfills with adequate protective measures \25\.

[6] Hazardous wastes are defined as toxic, inflammatory, reactive, explosive, or infectious; and include such wastes as heavy metals in batteries, electroplating sludges, paint solvents, pesticides, and infectious healthcare wastes

Fecal Matter

Human fecal matter is common in solid waste. In high-income countries, human waste generated in cities is primarily handled in separate sewerage systems and only a limited portion gets into solid waste, largely through disposable babies' diapers (nappies). However, in developing countries, a significant portion of the human waste generated in a city ultimately reaches the solid waste system because of inadequate sanitation systems. In the poorest countries, because of a paucity of sanitation systems, people defecate along roadways and on open lots, night soil is deposited in open drains, and the resulting street and drain cleanings contain feces. Where buckets or bedpans are used, the human waste is often placed in a plastic bag or wrapped in newspaper before discarding it with the solid waste. In low-income countries that rely on latrines and toilets, it is not uncommon for people to throw the used toilet tissue in the solid waste dustbin rather than risk clogging discharge piping or overfilled cesspits. In upper-middle-income countries, it is common to see disposable diapers in the waste. In both low- and middle-income countries, septage from septic tanks and cesspits is commonly discharged at open dumps because there are no treatment facilities available for this material.

Waste Collection Systems

In high-income countries, most municipal solid wastes are collected. Due to the relatively high cost of labor and the strong regulatory framework for occupational health and safety, loading is commonly made as easy and mechanized as possible, thus minimizing occupational health and injury risk. All waste is required to be fully contained, either in a covered metal or plastic bin, or within a plastic bag. Occupational health and safety regulations limit the size and weight of each container or bag. Potentially infectious healthcare wastes are not normally discharged with municipal solid wastes in higher-income countries.

Most low-income countries experience low levels of collection service. Typically only 30% to 60% of the municipal solid wastes are collected. Service levels in middle income countries are slightly higher; typically 50% to 80% of the wastes are collected. Because the uncollected wastes accumulate near homes and work areas, city dwellers and their domestic animals have much more direct contact with wastes than city dwellers in high-income countries. Periodic clearing of the wastes accumulated in open piles is accomplished with wheeled loaders and open trucks, which raise significant dust and bioaerosol exposure levels.

Municipal solid waste in developing countries commonly is collected through labor-intensive systems, sometimes using hand or animal drawn carts. The waste discharged for collection seldom is stored in a plastic or metal container and covered with a lid. In few instances, unsuitably large oil drums are used. More typically, the waste is placed on the ground directly, thus requiring being shoveled by hand; or it is left in an open carton or basket to be picked up by hand. In either case, the waste awaiting collection is readily available to insect and rodent vectors[7] and scavenging animals. Collection workers in developing countries have significantly more direct contact with solid waste than their counterparts in high-income countries, who predominantly handle sealed plastic bags and covered dustbins. Because hazardous wastes are not separated at the source for separate collection and disposal, collection workers in most developing countries are more likely to encounter potentially toxic materials and gases, and infectious microorganisms.

[7] Flies, mosquitoes, and rats are among the better known vectors of disease, largely because of their contact with contaminated waste material or water.

Waste Disposal Systems

In high-income countries, essentially all collected wastes go to safe sanitary landfill, composting[8], and materials recovery[9] or incineration facilities that are designed and operated to meet high environmental protection standards. In these countries, hazardous wastes are handled separately from municipal solid waste, and subject to stringent rules. Landfill is still the primary method of disposal used by most high-income countries, because it is a relatively low cost compared to other disposal options. Because of a shortage of land licensed for land disposal in Europe, some European countries maximize the amount of waste recycling and composting possible, prior to landfilling of those materials that are unsuitable for resource recovery. In 1998, landfilling in the USA accounted for 55.4% of the nation's municipal solid waste disposal (down from 83.2% in 1986). Incineration and materials recovery, and to a lesser extent composting, shared the remaining 44.6%. \16\

In middle-income countries, probably less than 25% of collected wastes are deposited in controlled landfills, and probably less than 15% are deposited in modern sanitary landfills. The rest is discharged to open dumps, most of which burn openly and have hazardously steep side slopes. In low-income countries, nearly all of collected wastes are deposited within open dumps. The cost and resources required to implement waste technologies are often regarded as too prohibitively high to be sustained. In most developing countries, hazardous waste facilities have not yet been implemented and hazardous wastes are co-mingled for disposal with municipal solid wastes, despite laws to the contrary.

Solid Waste Management Costs

Table 3 shows how general cost ranges for solid waste collection, transport and sanitary landfill vary as a function of average GNP income. In developing countries, while the per capita quantities of wastes and labor costs are low, the costs of providing solid waste management (even at their current lower standard of operation) are not proportionately low. Equipment capital costs and fuel costs in low-income countries are comparable to those in high-income countries, and sometimes are higher because of importation costs and currency exchange variations. The result, as seen on Table 3, is that solid waste management cost is higher in low-income countries, when viewed as a percentage of personal income. Given the proportionately high cost of operating a full service in developing countries and competing urban infrastructure needs, the prevailing low levels of solid waste service are likely to continue for several more years.

[8] Composting is a solid waste disposal technology where the organic fraction of the waste is aerobically decomposed by the natural microorganisms within the waste and involves enhancing the conditions necessary for decomposition (e.g., nutrient, oxygen, and moisture levels).

[9] Materials recovery facilities provide conveyance, sorting, and processing facilities that enable the recovery of secondary materials such as paper, carton, metal, and glass from solid waste.

Table 3. Global Perspective on Costs for Proper Solid Waste Management Costs Versus Income

	LOW INCOME COUNTRY	MIDDLE INCOME COUNTRY	HIGH INCOME COUNTRY
Average WASTE GENERATION	0.2 t/capita/y	0.3 t/capita/y	0.6 t/capita/y
Average INCOME FROM GNP	370 $/capita/y	2,400 $/capita/y	22,000 $/capita/y
Collection Cost	10-30 $/t.	30-70 $/m.	70-120 $/t.
Transfer Cost	3-8 $/t.	5-15 $/t.	15-20 $/t.
Sanitary Landfill Cost	3-10 $/t.	8-15 $/t.	15-50 $/t.
TOTAL COST WITHOUT TRANSFER	13-40 $/m.t.	38-85 $/t.	90-170 $/t.
TOTAL COST WITH TRANSFER	16-48 $/t.	43-100 $/t.	105-190 $/t.
Total Cost per Capita	3-10 $/capita/y	12-30 $/capita/y	60-114 $/capita/y
COST AS % OF INCOME	0.7-2.6%	0.5-1.3%	0.2-0.5%

Table Notes:

1. Income based on 1992 Gross National Product data from the World Development Report 1994 published by the World Bank.
2. Costs are for owning, operation, maintenance, and debt service in 1995, assuming no equipment provision through grants. Appropriate (affordable) best practical standards of service and environmental protection for the skill and income level of the country are assumed.
3. If sanitary landfill can be located with an economic haul distance that allows direct haul in collection vehicles, the cost of transfer can be avoided. An economic haul time for a small truck carrying 2 to 6 tonnes commonly is within 30 minutes one-way from the collection area to the unloading point. Depending on traffic conditions, 30 minutes one-way would be 15 to 30 kilometers one-way. Larger trucks can readily haul for 30 to 50 kilometers one-way.
4. $/t means US Dollars per metric tonne, and $/capita/y means US Dollars per capita per year.

Source: Sandra Cointreau

In Table 3 it is assumed that sanitary landfill is the disposal method of choice, because it is usually the lowest cost of the operationally acceptable solutions. Sanitary landfill costs roughly 3-8 times more than open dumping with some grading to maintain truck access to the working face. Incineration, a capital and energy intensive option, is 5-10 times more costly than sanitary landfill for developing countries, and composting is 2-3 times more costly. Incineration and composting, like sanitary landfill, should be designed to comparable environmentally acceptable standards. Because they are substantially more costly than sanitary landfill, they are typically only considered when appropriate landfill is unavailable within a reasonable direct haul distance (Table 4). Additional transfer system costs for reaching more remote sites may outweigh the savings of choosing sanitary landfill, or when recovered energy or compost market demands could cover the cost differential.

Because of poverty and the paucity of environmental regulation and enforcement, disposal in many developing countries is still predominately by open dumping, often with associated open burning. When regulatory improvements and economic developments enable disposal to improved, sanitary landfill is the most economic and likely choice of disposal techniques. Typical costs for disposal options in countries of various income levels are outlined in the Table 4.

Table 4. Disposal Costs by Alternative Technologies for Large Cities

	LOW INCOME COUNTRY	MIDDLE INCOME COUNTRY	HIGH INCOME COUNTRY
Average GNP	370 $/capita/y	2,400 $/capita/y	22,000 $/capita/y
OPEN DUMPING	0.5-2 $/	1-3 $/t	5-10 $/t
SANITARY LANDFILL	3-10 $/t	8-15 $/t	15-50 $/t
TIDAL LAND RECLAMATION	3-20 $/t	10-40 $/t	30-100 $/t
COMPOSTING	5-20 $/t	10-40 $/t	20-60 $/t
INCINERATION	40-60 $/t	30-80 $/t	70-130 $/t

Table Notes:

1. The above sanitary landfill costs are for cities of over 500,000 people or over 250 tonnes/day, in order to capture economies-of-scale. For smaller cities, costs could be higher by a factor of 2 to 5. Bundling of disposal needs into inter-municipal regional sanitary landfills is recommended, with transfer stations implemented to enable economic long distance haul.
2. The higher range of costs for sanitary landfill is for systems with plastic membranes and full leachate collection and treatment systems; while the lower range of costs is for natural attenuation landfills where site conditions do not require leachate management. Careful site selection can substantially reduce landfill costs.
3. The higher range of costs for composting is for systems with mechanized classification, pulverization, and forced aeration; while the lower range of costs is for systems with hand sorting, trommel screening and simple open air windrows.
4. The higher range of costs for incineration is for systems with modern air pollution control; while the lower range of costs is for systems with minimal pollution control.

Source: Sandra Cointreau

HEALTH AND INJURY ISSUES

Population growth and economic development have brought increasing amounts of solid waste to urban areas. In most developing countries, the ever-increasing quantities have overwhelmed local governments' capabilities to cope efficiently. In many of these countries, infectious medical wastes and toxic industrial wastes are not segregated from domestic waste (with the probable exception of radioactive materials), exposing the waste collectors to a wide array of risks. Even when segregated from other wastes, they are often placed in large waste rooms that must be emptied manually by workers with picks and shovels.

In many developing countries, waste pickers find their livelihood through sorting and recycling of secondary materials. They have high occupational health risks, including risk from contact with human fecal matter, paper that may have become saturated with toxic materials, bottles with chemical residues, metal containers with residue pesticides and solvents, needles and bandages (containing pathogenic organisms) from hospitals, and batteries containing heavy metals. Exhaust fumes of waste collection trucks traveling to and from disposal sites, dust from disposal operations, and open burning of waste all contribute to occupational health problems.

This document focuses on the occupational health and injury risks associated with solid waste collection, processing, recycling, and disposal (Box 4). Environmental health and injury risks, such as downwind air pollution and downgradient water pollution from solid waste disposal facilities, are listed in Box 5.

Box 4. Occupational Health and Injury Issues
Some of the more commonly reported occupational health and injury issues in solid waste management:
- Back and joint injuries from lifting heavy waste-filled containers and driving heavy landfill and loading equipment;
- Respiratory illness from ingesting particulates, bio-aerosols, and volatile organics during waste collection, and from working in smoky and dusty conditions at open dumps;
- Infections from direct contact with contaminated material, dog and rodent bites, or eating of waste-fed animals;
- Puncture wounds leading to tetanus, hepatitis, and HIV infection;
- Injuries at dumps due to surface subsidence, underground fires, and slides;
- Headaches and nausea from anoxic conditions where disposal sites have high methane, carbon dioxide, and carbon monoxide concentrations; and
- Lead poisoning from burning of materials with lead-containing batteries, paints, and solders.

Box 5. Environmental Health and Injury Issues
Some of the more commonly reported environmental health and injury issues in solid waste management:
- Contaminated leachate and surface runoff from land disposal facilities affecting downgradient ground and surface water quality;
- Methane and carbon dioxide air emissions from land disposal facilities adding to global warming, and subsequently vector-borne disease abundance and pathogen survival;
- Volatile organic compounds in air emissions and inconclusive evidence on altered cancer incidence, birth defects, and infant mortality, as well as psychological stress for those living near solid waste incinerators or inadequately controlled land disposal facilities;
- Animals feeding on solid waste providing a food chain path for transmitting animal and human diseases;
- Uncollected wastes retaining water and clogged drains, thus leading to stagnant waters which encourage mosquito vector abundance;
- Uncollected wastes providing food and breeding sites for insect, bird and rodent disease vectors

From the information available, most occupational health and injury problems could be minimized by simple safety procedures that cost little; and most environmental impacts could be minimized by closing open dumps and implementing sanitary landfills. Most importantly, workers in developing countries need to wear protective gear, particularly gloves and face masks. Disposal sites need daily cover and proper control of contaminated leachate. Waste pickers need to be managed; children and domestic animals should not be working on disposal sites. By rearranging the disposal layout, implementing modest sorting facilities, and allowing only registered adults, the waste pickers could have improved access to recyclables and decreased health risk. Provision of water supply for washing, sanitation, and hygiene education are also highly recommended for waste pickers.

There appears to be a global relationship (not yet precisely quantified) between exposure to solid waste and increased health and injury risk. The risk is greatest in developing countries where the contact between the solid waste worker and waste is greatest and the level of protection is least.

To complicate the exposure risk to workers and pickers, their personal hygiene is often inadequate. Washing facilities are not typically provided for these people to use at the work place, in order to clean themselves before going home (often by public transportation). To some extent, this is due to inadequate education on hygiene and health relations. Study by US Agency for International Development indicates that cost-effective investment in sanitation requires hygiene promotion and education to achieve successful mortality and morbidity reductions. \104\

A side effect of solid waste handling is that the filthy nature of the work demotivates people about their hygiene. Dumpsite waste pickers in Katmandu[10], Nepal, revealed that 73% did not use soap to wash their hands; 88% did not use soap to wash their feet; and more than 65% did not change their clothing daily. About 18% regularly waited more than a week between baths and changing clothes\34\. In waste picking families in India, women reported preparing meals immediately after returning home from waste picking, without washing. Most women pickers bathed only once a week.

[10] This survey was conducted at the open dumps, prior to implementation of improved landfill conditions.

Since these women know they will become as dirty during the next day of work, they say they are not motivated to clean at the end of each day \42\.

AVAILABILITY AND QUALITY OF HEALTH AND INJURY DATA

Comparative hard data on health and accident consequences is inadequate in most high-income countries, and almost non-existent in developing countries, as discussed below. In some high-income countries, individual cities may have good data, but countrywide comparative data is rare. This document presents a review and assessment of the data that exists. The gaps in data are readily apparent and need to be addressed by routine record keeping of clinical analysis of solid waste workers and waste pickers, as well as greater support of epidemiological studies where serious health risks warrant.

One of the better overviews from high-income countries was conducted by the Danish National Institute of Occupational Health and provided a review of occupational health problems associated with collection of municipal solid waste. The study found that, in 1995, the overall **relative risk** (1.5) among Denmark's solid waste collection workers for occupational disease and injury was elevated when compared to Denmark's total work force \74\. The risk for solid waste workers and waste pickers in developing countries is undoubtedly much higher because of more manual systems that involve more direct contact with waste, less protective gear, and few well-designed technologies with pollution control systems.

Confounding Factors

In many developing countries, increased urbanization has led to an increase in certain communicable diseases related to hygiene and basic sanitation infrastructure. Public health laws and regulations, often quite old from previous, sometimes colonial administrations, commonly are not rigorously enforced and new regulatory frameworks may not exist. Increases in overall disease incidence in some developing countries create a confounding backdrop for analyzing disease relationships to solid waste. For example, country data from Ghana shows a dramatic increase in enteric fever, tuberculosis and malaria has occurred over the 1970 to 1995 period.

Epidemiological studies of solid waste workers and residents near waste sites are available only from high-income countries. While these studies indicate the risk level of disease, injury and death associated with solid waste handling and disposal, they commonly have either methodological problems or report finding confounding factors \21\. Such problems are due to confounding from other exposure sources, migration in and out of study areas, and birth deliveries and mortalities in and out of the study area. Odor perception and anxiety over living near a waste site may bias respondents to questionnaires and medical verification is inadequate. Socio-demographic differences of populations living near waste sites may also confound results. And finally, there are lag periods associated with some health effects, notably solid cancers that have a lag period of 6 years or more, and 5 years for most lymphatic and haematopoietic cancers (Ostrowski, 1999).

Anecdotal Information

Most of the developing country data discussed in this document have not been published, nor subjected to the rigors of academic or professional peer review. The data are from direct in-country observations and surveys, largely by local physicians, health workers and sociologists, and documented in modest reports to their respective local governments and health institutions. This is indicative of the hidden nature of the health risks suffered by solid waste workers and the shadow life of the informal sector waste pickers, as well as the lack of regulatory controls. Uncollected and accumulated solid waste piles are present in many residential areas and there are people living on the periphery of most dumpsites in developing countries, blurring the distinction between occupational and environmental health and safety effects.

In developing countries, there has been little study of the health and injury incidence of formal sector's solid waste workers, informal sector's waste pickers and recyclers, or people living in the vicinity of solid waste facilities. None of the studies appear to qualify as true epidemiological surveys and rarely do they relate the incidence of injury or disease observed to global country norms or control group observations. Most provide only anecdotal health data; but, based on the extensive field experience in developing countries by the author, are believed to be accurate descriptions of likely health conditions.

SOLID WASTE HANDLING AND GENERAL HEALTH RISKS

The Romanian Institute of Hygiene, Public Health, Health Services and Management Unit, compiled and statistically analyzed occupational health data on waste handlers and control groups. The study covered 168 Romanian cities, representing 65% of the country's urban centers. Researchers found that the incidence of acute diarrhea was consistently higher among waste handlers than for the general population, by a **relative risk** factor over 10 times in some areas. In Bucharest, the nation's capital, waste handlers were 25 times more likely to experience acute diarrhea than the general population. Waste handlers were had 1.7 times more **relative risk** to experience opthamological diseases and had 1.3 times more **relative risk** of physical injuries. There was no statistical difference in the dermatological disease incidence between waste handlers and control groups \22\.

For people working as dumpsite waste pickers in most developing countries, incomes are so low that many make insufficient money to meet daily subsistence needs—an issue which complicates the collection of occupation-related health data. Nevertheless, waste pickers surveyed in Katmandu reported that their income levels were better than they had been before they found work at the dumpsites. Despite the higher income, more of the waste pickers interviewed reported that they experienced higher disease levels since becoming waste pickers, than they had before \34\:

	Before	After
• Diarrhea	20%	32%
• Parasitic diseases	18%	45%
• Dysentery	11%	27%
• Stomach trouble	33%	68%
• Colds	48%	86%
• Eye trouble	6%	18%
• Headache	3%	23%

Health studies in developing countries indicate that waste picking is high-risk work. Some of the results are highlighted below.

- Tuberculosis, bronchitis, asthma, pneumonia, dysentery, parasites, and malnutrition are the most commonly experienced diseases among waste pickers based on health studies of waste pickers conducted in Bangalore, Manohar, and New Delhi in India. \42\
- At Metro Manila's main open dump, in 1981, 750 waste pickers studied revealed a 40% had shin disease and 70% had upper respiratory ailments. \1\
- About 180 waste pickers at the Calcutta, India open dumps were studied in 1995. During the course of one year, 40% had chronic cough, and 37% had jaundice. The average quarterly incidence of diarrhea was 85%, of fever was 72%, of coughs and colds was 63%. Eye soreness or redness occurred quarterly in 15% and skin ulcers in 29%., with nearly all rates higher at the largest dump site than these averages. \26\
- A comparative study of waste pickers working at Calcutta's Dhapa dump in the 1980's and nearby farmers who use organic solid waste as fertilizer, showed that pickers reported higher prevalence of respiratory diseases (pickers: 71% vs. farmers: 34%), diarrhea (pickers: 55% vs. farmers: 28%) and protozoal and helminthic infestation (32% vs. 12%). \69\

- At the Bombay, India open dumpsites, 95 solid waste workers were surveyed and examined. Of all landfill workers surveyed, 80% had eye problems, 73% had respiratory ailments, 51% had gastrointestinal ailments, 40% had skin infections or allergies, and 22% had orthopedic ailments. Based on clinical examination, 90% had decreased visual acuity. Most workers complained of eye burning, diminished vision, redness, itching, watering. Clinical examination showed 27% had skin lesions, of which 30% were determined to be directly occupation related. \55\

Data from Accra, Ghana (Box 6) provides an indication into the differences in worker health and safety in the solid waste sector, compared to a group of workers in construction \67\.

Box 6. Accra, Ghana, Occupational Health Data
Health data from 1994 was reviewed for the Accra Municipal Solid Waste Department and compared with a local construction company, providing a small sampling of no statistical validity, but some anecdotal interest. The solid waste workers experienced a higher incidence of sick days, work-related accidents, and mortality. The number of people reporting sick during the year was 47.6% of the total solid waste staff, versus only 33% of the total construction staff. Sick days consumed 0.7% of the total days among the solid waste staff, but only 0.5% among the construction staff. Death occurred for 3.6% of the solid waste staff, but only 0.6% of the construction staff. One death among the solid waste staff was directly work related. Lower incomes and higher ages among solid waste staff may explain some of this deviation, but not all \67\.

BIRTH DEFECTS AND INFANT MORTALITY

Birth defects or infant mortality may be caused by direct contact with pathogens or hazardous constituents in solid waste, inhaling of air contaminants, or drinking of contaminated water. This has not been substantiated conclusively. Most of the studies of birth defects do not provide any clarity on which of these pathways (i.e., contact, inhalation, or injection) may be primary exposure mechanisms. Nevertheless, it is relevant to see whether birth defects are higher or lower in the vicinity of solid waste facilities. In addition, some potentially hazardous gases that can be released from municipal solid waste facilities are noted in Box 7.

Box 7. Hazardous Gases in Trace Quantities at Municipal Solid Waste Facilities

- Landfills:
  - ⇒ benzene, toluene, ethylbenzene, methylene chloride, dichloro methane, carbon tetrachloride
  - ⇒ carbon monoxide
- Burning Open Dumps:
  - ⇒ volatilized heavy metals
- Incinerators:
  - ⇒ chlorinated and brominated dioxins and furans
  - ⇒ volatilized heavy metals

Municipal Solid Waste Landfills

A literature review in 1998 of various studies in the USA indicated that women living near municipal waste disposal sites showed increased risk of infants with birth defects such as eye/ear anomalies, chromosome anomalies, heart/circulatory defects, neural tube defects. Some of the disposal sites were implemented before the current stringent regulatory framework existed; and thus these sites may have received hazardous wastes mixed with the nonhazardous wastes. \21\ On the other hand, a study in the San Francisco Bay Area of California, USA was unable to identify elevated maternal risk for most types of birth defects around sites of environmental contamination. Only the **risks** of heart and circulation birth defects were found elevated near contaminated sites (Odds Ratio = 1.5) \91\.

No studies were found that analyzed the risk of maternal residence near disposal sites in developing countries. However, the following reported information lists documented problems that exist and have gone unstudied:

- In 1995-96 at the Payatas dumpsite in Metro Manila, Philippines, out of 600 families living within 0.5 km of the open dump, the missionary clinic reported there were 3 infants were born with imperforate anuses and 9-10 cases of children with cerebral palsy \14\.

- Morbidity data from dumpsite waste pickers in India suggest that waste picking children have 2.5 times more potential of morbidity that non-waste picking children from the same housing areas. \69\
- Based on studies of waste pickers conducted in Bangalore, Manohar, and New Delhi, India, 38% of women pickers have lost one child and 10% have lost 3 or more. According to these women, the main causes of their infant deaths were diarrhea, tetanus, smallpox, bronchitis and virus infections. \40\
- In 1981, the Cairo waste picking community had an infant mortality rate of about 240 deaths per 1000 live births (compared to only 98 per 1000 nationally). The major causes of infant death were: neo-natal tetanus, diarrhea, respiratory infection and measles; with tetanus causing roughly 50% of neo-natal deaths. In 1991, (after improving working conditions, basic sanitation, education, and birthing assistance) waste picker infant mortality reduced to 117 deaths per 1000 live births. In births involving instruction prior to birthing and attendance during, none of the infant mortalities were due to tetanus. \32\

Hazardous Waste Landfills

Significantly decreased birth weights for infants born near a hazardous waste landfill were reported by The New Jersey department of Health (Berry, 1997).

Medical data (from medical records, autopsy results and surgical reports) throughout California, USA was examined to determine the number of infants and fetuses with reported birth defects of the neural tube and heart from around 105 inactive Californian hazardous waste sites considered of national priority for remediation. The study included interviews with several thousand mothers, including those from control groups. The birth defect **risks** were found to be elevated for mothers living within 1 mile (1.6 km of the priority hazardous waste sites), and the results were determined to be not confounded by race/ethnicity, income and education. While elevated, it could not be said that the increase was statistically significant. The results were reported as follows \18\:

- Odds Ratio (OR) = 2.1, 95% Confidence Ratio (CI) = 0.6-7.6 for neural tube defects; and
- OR = 4.2, 95% CI = 0.7-26.5 for heart defects.

Data from several regional registers of congenital anomalies in five European countries (i.e., Belgium, Denmark, France, Italy, and the UK) were studied to determine whether birth defects correlated with proximity to hazardous waste landfills. More than 3400 cases were reviewed in the vicinity of 21 hazardous-waste landfills. The data showed that residence within 3 kilometers of such landfills was “associated with significantly raised **ris**k of congenital anomaly” (295 cases of defects compared to 511 controls living 0-3 km from sites, 794 cases/1855 controls living 3-7 km from sites). There was a “fairly consistent decrease in risk with distance away from the sites”. The identified defects with significantly raised odds ratio for residence within 3 km were: neural tube defects (odds ratio 1.86), malformations of the cardiac septa (1.49), anomalies of great arteries and veins (1.81), tracheo-oesophageal anomalies (2.25), hypospadlas (1.96), and gastroschisis (3.19) \27\. The results of this study have been strongly contested by other researchers and the waste industry. Additional studies are currently underway in Italy, UK and Poland.

Birth defects of the central nervous system and musculoskeletal were not increased amongst newborns relative to maternal residence within 1 mile (1.6 km) of hazardous waste sites in New York State \64\. No conclusions can be drawn at this time, on the significantly different risk levels found in these different studies.

AIR POLLUTION DISEASE LINKS

Over a study period of 1984-92, Danish solid waste collection workers experienced a **relative risk** of 2.6 for work-related allergic pulmonary diseases and 1.4 for work-related non-allergic pulmonary diseases compared to the entire work force. Waste collectors in Geneva had a 2.5 **relative risk** of acquiring chronic bronchitis, according to studies during the mid-1970's \75\.

In large measure, this increased risk is related to exposure to organic dusts. The major types of organic dusts are: Gram-negative bacteria, Gram-positive bacteria, actinomycetes (Gram-positive bacteria that possess mycelium), and fungi. Fungi create a major respiratory hazard because the filamentous fungi (i.e., moulds) are allergens. Mycotoxins are metabolites of filamentous fungi.

Mycotoxins appear to suppress the pulmonary defense system and thus increase the risk of respiratory cancer. Gram-negative bacteria are a serious threat because they produce endo-toxins on their outer membranes; and endotoxins are the main pulmonary immunotoxicants. \75\

Three German studies reported in 1994 measured airborne microorganisms at composting plants, materials recovery plants, incinerators, and landfills. The maximal levels reported at composting plants were generally higher than 10,000 cfu/m^3, which is a level usually found only in stables. At the composting plants, the highest concentrations of mesophilic actinomycetes were found during the dumping of the compost, at the end of the composting process. The highest concentrations of thermophilic actinomycetes were found in the compost plant delivery halls and the highest *Thermoactinomyces* occurred during screening of compost product. Median values for Gram-negative bacteria, *A. niger*, were more than 100 times higher than average background levels outside each plant area. The highest concentrations for total moulds were found in the shredding area of the composting plants. \75\

The following table (Table 5) is based on data from the above-mentioned German studies. The microorganisms measured at each type of facility showed that the highest levels of most bioaerosols were consistently found at composting plants. There are no internationally accepted standards for exposure to bioaerosols. Scandinavian studies suggest occupational exposure limits should be: 5-10 x 10^3 cfu/m^3 [11] for total microorganisms, 1 x 10^3 cfu/m^3 for Gram-negative bacteria and 1-2 x 10^2 ng/m^3 for endotoxin[12].

Table 5. Concentrations of Airborne Microorganisms

Microorganisms	Composting Plants (cfu/m^3)	Waste Sorting Plants (cfu/m^3)	Waste Incinerator (cfu/m^3)	Landfills (cfu/m^3)
A. fumigatus	$9x10^6$	$5x10^3$	$9x10^4$	$1x10^5$
A. niger	$3x10^6$	$6x10^3$	$1x10^4$	$1x10^4$
Mesophilic actinomycetes	$1x10^5$	$4x10^4$	$2x10^4$	$2x10^3$
Thermophilic actinomycetes	$5x10^4$	$2.7x10^4$	$8.1x10^3$	$6x10^3$
Thermoactinomyces	$2x10^5$	$7.4x10^2$	$1.2x10^3$	$4x10^2$
Total bacteria	$6x10^5$	$4x10^4$	$2x10^5$	$7x10^4$
Enterobacteria	$1x10^4$	$1x10^1$	$8x10^3$	$5x10^3$
E.coli	$3x10^2$	not detectable	$6x10^2$	$3x10^2$

[11] The term cfu/m3 refers to the bio-aerosol count in one cubic meter of air, or "colony forming units" of bacteria and/or fungi in air samples.
[12] Endotoxins are measured in terms of nanograms per cubic meter of air. One nanogram (ng) equals 15 endotoxin units (EU).

Similarity to Farmers Lung

A study in Norway showed that farmers were 2 to 3 times more at risk for chronic bronchitis – a condition so common among farmers that it called “Farmers Lung” \94\. Most at risk are farmers working in confined livestock outbuildings. Smoking was found to increase risk by a factor of 6. Another Norwegian study of farmers determined that when organic dust levels reach between 10^4 to 10^7 cfu/m^3 in the air-breathing zone, 40% to 50% of the particulates may penetrate the deeper reaches of the lungs and lead to inflammation of the lung lining \75\.

Like farmers, waste collectors and recyclers are exposed to organic dusts containing high concentrations of bacteria and fungi (Box 8), as well as related endotoxins. While crop and livestock farmers tend to be exposed largely to gram-negative bacteria, gram-positive bacteria, and thermophilic actinomycetes, studies indicate that waste collectors and recyclers are exposed most significantly to filamentous fungi \75\.

Confounding Factors

An elevated incidence of pulmonary diseases could be related to exposure to biologically active agents (e.g., microorganisms and their metabolites and toxins), volatile compounds, or mold spores. Sulfurous gases generated by anaerobic decomposition of organic wastes can be suddenly released when closed bags and containers are opened. Such gases will contribute to upper airway irritation, as well as nausea, both of which could exacerbate the exposure to bioaerosols. Non-allergenic agents (such as disinfectants) have been shown in UK studies to induce IgE sensitization to common aeroallergens and increase the risk of asthmatic symptoms. Diesel exhaust may play a potentiating role where waste collection is conducted in high traffic density, and most significantly in developing countries where vehicle emissions are not controlled. Also, waste collection is a physically strenuous effort resulting in significantly higher pulmonary ventilation and a greater tendency to breathe through the mouth instead of the nose. Smoking is potentially a significant confounder of studies of respiratory diseases and needs to be carefully considered during any epidemiological study of occupational risk from air emissions.

Box 8. Data on Elevated Bio-aerosol Exposure Levels for Solid Waste Workers

- 2-4 times higher than ambient at sanitary landfills (Italy)
- 2-10 times higher than ambient inside materials recovery plants (USA, Finland)
- 10-100 times higher than ambient at compost plants
- 10-100 times higher than ambient at collection truck hopper (Switzerland)
- 100-1000 times higher than ambient at the collection truck hopper (Denmark)

Allergic Pulmonary Diseases

Exposure to bio-aerosols is a contributing factor in allergic and asthmatic pulmonary diseases.

Allergenic Pulmonary Disease and Waste Collection

Study of solid waste collection in Norway found that 50% of occupational exposure during waste collection in the summer involved bioaerosol measurements over 10^6 cfu/m^3. Winter levels were lower by a factor of two. Measurements at compost plants were 60% higher than summer collection levels, and the endotoxin levels were also higher at compost plants \75\.

Study in Geneva found collection workers had a high exposure to bio-aerosols. Microorganism counts were between 10^4 and 10^5 cfu/m^3 in immediate proximity to the waste collection truck's loading hopper, and less than 10^3 cfu/m^3 at a distance of only 2 to 3 m away \74\.

A similar study in Denmark found bio-aerosols were as high as 10^6 and 10^7 cfu/m^3 at the loading hopper and that waste collectors carrying containers to the curb were exposed to only 25% of the bio-aerosol count confronting collectors emptying containers into the truck. When the trucks were equipped with a cover over the loading hopper and an exhaust to pull air under the cover, exposure levels dropped substantially to less than 2 x 10^4 cfu/m^3. The fraction of these bio-aerosols that were molds ranged from 77.5-98.5% \74\. Exposure to organic dusts was reduced in Denmark when the loading height of the truck was raised from 1 m to 4 m above ground and bins were mechanically raised to this higher elevation for emptying \75\.

Also in Denmark, waste collectors were monitored for their generation of immunoglobulins (i.e., antibodies that can indicate levels of immune response). Serum immunoglobulins (such as IgE, IgG, and IgA) increase production in response to allergens. In Danish studies, those exposed to high levels (up to 72 EU[13]/m^3) of endotoxins (pulmonary immuno-toxicants produced by Gram-negative bacteria) had significantly elevated concentrations of IgG and IgA. The researchers determined that monitoring for immunoglobulins could be used as an indicator of sub-clinical effects of relatively low exposure to organic dusts. \75\

In Polish studies, guinea pigs and rabbits exposed to aerosolized endotoxins had increased free lung cells, mostly lymphocytes. This led to increased immunological changes among the rats and increased interleukin I (IL-I). Prolonged exposure to endotoxins also inhibited leukocytes migration, production of precipitins and activated alveolar macrophages \68\.

Allergenic Pulmonary Disease at Compost and Materials Recovery Plants
Measurements at six materials recovery facilities in the USA showed that airborne bacteria and fungi (multicellular filamentous moulds commonly found in organic dusts, often leading to allergic response) concentrations measured inside the facilities were roughly one order of magnitude higher than the levels found outside the facility. A wide variety of pathogenic and nonpathogenic organisms were identified. \84\

At two materials recovery facilities in Finland, airborne bacteria and fungi concentrations were 2-10 times higher than background concentrations. These airborne microorganisms included no potent pathogens, only opportunistic pathogens that could cause infection if human resistance were below normal. \78\

At a paper and cardboard sorting plant in the UK, the maximum level of total bacteria at a sorting line was 10^5 to 10^6 cells/m^3. The highest levels were found in the receiving hall where the incoming waste paper was unloaded \75\.

Measurements of total airborne bacteria inside a composting plant and a materials sorting plant in Canada showed concentrations were significantly higher than the recommended maximum of 10,000 cfu/m^3. No work-stations exhibited excessive levels of gram-negative bacteria above suggested

[13] EU/m^3 means endotoxin units per cubic meter of air. 1 ng = 15.5 EU.

exposure levels. At all of the workstations, concentrations of *Aspergillus fumigatus*, a thermoresistant mold, were significantly higher than background outdoor air levels, as were total mold concentrations. Beyond 100 m, outdoor air levels of all microbial agents monitored appeared not to be affected by waste treatment operations. \75\

A UK study at composting plants measured various types of actinomycetes and determined that thermophilic actinomycetes grew extensively during the second stage of composting, when the temperatures reached up to 70°C. The compost substrate readily released airborne spores when disturbed during this stage of composting. These actinomycetes are known for being particularly important causes of allergic respiratory disease \75\. Fungi levels (measured as *Aspergilllus fumigatus*) at a composting plant did not decrease to ambient levels until after 500 m from the site \75\.

At operations for composting the putrescible organic fraction of municipal solid waste in Helsinki, Finland, fungi measurements were found to be significant, particularly during waste shredding and turning activities. The most common fungi identified were *Aspergillus* and *Penicillium*. Fungi levels sometimes exceeded recommended threshold levels, especially during waste shredding in summer. The numbers of fecal streptococci, fecal coliform bacteria, and *Clostridia* were significant. High counts of pathogenic bacteria in windrow piles during the initial weeks of composting. In time, as temperatures in the piles increased, sometimes exceeding 80^{o}C, pathogen counts decreased. Researchers recommended that compost workers wear respiratory masks during compost operations \98\.

Study of composting operations in Denmark found thermophilic actinomycetes (filamentous Gram-positive bacteria commonly found in dusts from plant origin) were the predominant source for airborne spores and that fungi were almost absent. Fungal spore levels were lower under conditions of higher humidity in the composting materials \75\.

The Helsinki study reported that significant levels of endotoxins were also reached at composting plants, ranging from 0.8 to 5.9 ng/m^3, with the higher levels evident during winter, when recommended occupational exposure limits were routinely exceeded \98\. Medical journals report that exposure to endotoxin from Gram-negative bacteria should be below 10 ng/m^3 to avoid a significant response, and below 100 ng/m^3 to avoid acute airway symptoms \75\.

A study of compost workers and a control group in the Netherlands assessed the relationship between bioaerosol exposure and airways inflammation. The results indicated that occupational exposure in compost workers caused acute and (sub-) chronic non-immune or type III allergic inflammation in the upper airways. The subjects studied were monitored for total cell counts, leukocytes and inflammatory mediators (MPO, ECP, IL8, NO, albumin, urea and uric acid) \75\.

A German study of microbial concentrations around a compost plant determined that there were no significant increases beyond typical ambient air levels at distances over 500 m. Only small endotoxin concentrations (200 times lower than a suggested threshold value of 50 ng/m^3) were detected just outside of the composting plant. The endotoxin levels measured 150 m downwind of the plant (0.24 ng/m^3) were 100 times lower than those found close to the rotating sieve inside the plant (20.7 ng/m^3) \75\.

An Austrian study of health risks among workers at materials recovery and composting plants and a control group indicated that work at waste treatment plants led to significantly elevated total serum IgE concentrations and increased blood sugar. However, there was no statistically significant impairment of lung function—as measured by spirometry \75\.

Within 18 months of opening a materials recovery plant in Denmark in 1986, there were eight cases of bronchial asthma and one of chronic bronchitis developed among 15 exposed workers. Study of the work environment indicated that these illnesses were probably related to high particulate levels, particularly bioaerosols. Subsequently encasing the conveyance system and installing vacuum air cleaning systems led to significant reductions in particulates, including airborne bacteria and endotoxins but not fungi \63,75\.

Allergic Pulmonary Disease and Landfills
The US Department of Health and Human Services' Agency for Toxic Substances and Disease Registry sent out questionnaires to 12,000 residents on Staten Island, where Fresh Kills Landfill is located. Out of 1279 responses received, 80% of residents living nearest the Fresh Kills Landfill, which served New York City from 1948 to 1999, reported having respiratory problems, and 60% were using medication for asthma or respiratory symptoms. Of the respondents, 151 people with asthma were included in a study to measure asthma-related landfill emissions daily (i.e., fine particulates, ozone and hydrogen sulfide), as well as natural stimulants of asthma (i.e., fungi and pollen) and correlate results with each participant's daily diary of respiratory symptoms, lung capacity, and odor recognition. The Agency's final report was not available for this review \38\.

The health of 100 landfill personnel was studied in Liguria, Italy, a region with eleven active sanitary landfills. There were five workers with respiratory allergy, one with skin allergy, and eleven with respiratory illness (seven of these with bronchitis) \49\. In 1991, the Institute of Hygiene and Preventative Medicine at University of Genoa, Italy studied airborne microbial agents: background levels around Genoa (67 to 269 UFC/m^3)[14] were below those at Genoa's landfills and solid waste street containers (150 to 889 UFC/m^3). Background fungi levels were 3-78 UFC/m^3, compared with 17-72 UFC/m^3 near solid waste facilities; and background staphylococcus spp. were 16-178 UFC/m^3 compared to 83-233 UFC/m^3 near solid waste facilities \48\.

Non-Allergic Pulmonary Diseases
Epidemiological studies have shown that there is an effect between higher pollutant concentrations and reduced pulmonary function. Comparative epidemiological study of preadolescent children in urban and rural areas of Iran, including pulmonary function tests, showed that exposure to urban air pollution had a clear and significant adverse effect on short-term lung function and/or lung growth and development. Physician diagnosis of bronchitis and asthma was higher among urban children \4\.

Non-Allergic Pulmonary Disease and Landfills
Dusts at open dumps and landfills, including hazardous dusts such as asbestos and silicotic particles (Box 9), may be injurious to the respiratory system of solid waste workers \109\. Solid waste workers and waste pickers at open dumps in developing countries suffer from dust created by traffic, as well as smoke derived from open burning and underground fires. In developing countries, waste collectors are exposed to higher levels of diesel exhaust fumes than their counterparts in high-income countries. Some studies suggest a relationship between diesel exhaust exposure, asthma, and decreasing lung function. Diesel exhaust may amplify the effect of normal allergens in susceptible individuals \74\.

Box 9. Data on Elevated Particulate Exposure Levels for Solid Waste Workers
- 3 times higher than the standard at materials recovery plants (Finland)
- 25 times higher than the standard at open dump (Philippines)
- 3 times higher than standard at open dump (Thailand)

Studies in several countries have postulated a relationship between working at open dumps and increased respiratory illness, as follows:

- Epidemiological survey's conducted on 400 waste pickers in Calcutta, India, and compared with a control group of 50, indicated that waste pickers at open dumps were particularly vulnerable to experiencing increased incidence of respiratory diseases. The waste pickers experienced a 71% incidence of respiratory disease, compared to only 34% in the control group \103\.
- At Bombay's open dumpsites, 25% of the waste workers examined had coughs and 26% experienced dyspnea. The majority (73%) complained of aggravated symptoms of cough and breathlessness during working hours. Abnormal pulmonary function tests were presented in 23% of the dumpsite workers, of which 26% had restrictive patterns. Chest X-rays showed 17.5% had non-specific shadows like post tuberculosis fibrosis, and about 11% presented reticulondular shadows \55\.
- Pulmonary function tests were conducted on dumpsite waste pickers and residents surrounding the dump in Bangkok, and 40% were below the normal range. Total suspended particulate levels at Bangkok's dump averaged 490 $\mu g/m^3$, exceeding average Bangkok residential levels of 260 $\mu g/m^3$ and the USA 24-hour standard of 150 $\mu g/m^3$. Methane levels of 20 mg/m^3 were measured

[14] UFC/m3 refers to the total number of airborne microorganisms counted in a cubic meter of air.

at the dumpsite, while nearby city background levels were about 0.3 mg/m^3. The presence of cigarette smoking in the household, though a common secondary factor for below normal lung function, performance did not appear to account for the increase in occupation related pulmonary dysfunction \56\.

- In 1991, 974 children were studied at Metro Manila's main open dump; of these, 194 were clinically examined. Chronic cough was present in about 23%, chronic phlegm production in 18%, wheezing in 25% and shortness of breath in 19%. Chest X-rays showed only 3% of these symptoms were attributable to residual or minimally active pulmonary tuberculosis. Pulmonary function tests showed 53% had decreased pulmonary function compared to country norms. Pulmonary function, as measured by spirometric examination, demonstrated that forced expiratory volume and forced vital capacity were reduced in a large portion of the children compared to predicted values. While causal factors are not known, total suspended particulate levels at the dumpsite were extremely high, 4,600 $\mu g/m^3$, 25 times the national standard in the Philippines \99\ .
- Questionnaires and clinical examinations were used in Calcutta to conduct an epidemiological survey of waste pickers and residents at the open dumps, as well as waste collectors and control groups. Of all of the groups studied, the dumpsite waste pickers had significantly higher disease incidences of cough and chest pain \103\.

Non-Allergic Pulmonary Disease and Materials Recovery

In Finland in 1989, researchers measured dust in the working air space of two materials recovery plants and one incinerator. Dust concentrations were highest at the sorting stations of the materials recovery plants: as high as 38 mg m^{-3} compared to an occupational health standard of 10 mg m^{-3} for 15 minutes of exposure; and the median level of 4.6 mg m^{-3} was close to the occupational health standard of 5 mg m^{-3} for 8 hours of exposure. Median and peak dust levels within the incinerator were lower than the occupational health standard. \78\. More recently, in 1992-93, dust levels were measured at six newly built materials recovery facilities in the USA. Total and respirable dust concentrations generally were found to be at least one order of magnitude lower than worker protection standards \84\.

Infectious Pulmonary Disease and Medical Waste Treatment

At a privately owned medical waste treatment plant in Morton, Washington, USA, three workers contracted tuberculosis and 13 others show evidence of being exposed to tuberculosis but were not symptomatic. At other USA plants, namely those where sealed containers of medical wastes are processed directly without opening and/or recycling the containers, tuberculosis has not been reported \106\.

Elevated Heavy Metals

Studies by Canadian and Norwegian scientists have demonstrated that the Arctic has become a deposit for atmospheric contaminants, and that some of these contaminants are present in steadily increasing levels in the flesh of polar bears and the breast milk of Inuit indigenous people. Mercury is the scientists' greatest concern, as the levels in the Arctic have been rising steadily, by as much as 1 to 2% a year. As one of the most volatile of heavy metals, it can travel quite far. It is also known for leading to birth directs and brain damage in relatively small doses. Its main sources are "coal burning fires, garbage incinerators, and gold mining" \71\. See Box 10.

Box 10. Data on Elevated Heavy Metals in Blood from Solid Waste Work

- 2.5 times higher than controls among children pickers (Philippines)
- 1.5-3 times higher than controls among solid waste incineration workers (USA)
- elevated cadmium and mercury among paper sorters (Denmark)

Heavy Metals and Paper Sorting

Significantly elevated levels of cadmium in blood were found in paper sorters and solid waste handlers. Mercury was elevated in blood only among paper sorters. While elevated, all levels measured were within acceptable ranges for long-term health \75\.

Blood Lead and Landfills

High blood lead levels (mean of 28μg/dl) are reported for child waste pickers in Metro Manila. More than 70% of children working at Metro Manila's largest dumpsite had blood lead levels that exceeded the WHO[15] guideline of 20 μg/dl. The average blood lead levels of children in a Metro Manila slum removed from the zone of influence of the dumpsite were significantly lower, at 11 μg/dl \99\. Water supplies tested to be within acceptable limits for lead \99\. Thus for blood lead to be at the reported levels, air contamination is the most probable explanation. This is likely due to open burning of solid wastes that typically contain lead in batteries, paints, soldered cans, ceramics, glass, and consumer electronics \81\. For comparative purposes, it is worthwhile to note that blood lead levels were examined in 104 urban children in Mexico City between 1987 and 1993 and that the overall geometric mean blood lead level was 9.6, despite the City's well known urban air pollution problems \83\.

Blood Lead and Incineration

Incinerators discharge heavy metals (mercury, lead, cadmium, arsenic) in various forms, volatilized in the stack gas, solidified in fly ash, and solidified in bottom ash or slag. Incinerator workers are required to clean particulates bi-monthly from the electrostatic precipitator system for control of stack emissions. In 1992, 56 workers at three incinerators in New York were studied for exposure to lead, and compared to a control group of 15 workers at heating plants. The workers were exposed to air lead concentrations as high as 2500 $\mu g/m^3$, compared to the WHO standard of $1 \mu g/m^3$. Blood samples taken showed those incinerator workers had a mean blood lead level of 11.0 μg/dl compared to the heating plant control group of 7.4 μg/dl. Blood levels were higher (16 μg/dl) in workers who had most often cleaned the precipitators, and the highest level (28.7 μg/dl) was found in a worker who did not regularly wear his protective device. Significantly lower blood lead levels were found in workers reporting that they consistently wore respiratory protection during cleaning of the precipitators. While blood lead levels were higher for incinerator workers than for heating plant workers, the levels for both groups were below the USA OSHA health safety action limit considered (in 1989) to be unacceptable in the workplace of 40 μg/dl \62\.

The leachability of heavy metals from ashes of incinerated hazardous waste have been shown to be highly dependent on the combustion temperatures achieved, with almost no leaching from ashes following incinerator temperatures above 1500^oC. Headaches and Mood Disorders (Ramesh, 2001)

Landfill gas[16], also called biogas, includes the greenhouse gases methane, and carbon dioxide. Mean levels of greenhouse gases emitted from solid wastes deposited in landfills have been estimated for high-income countries to be 0.085 tonnes of methane per tonne of solid waste and 0.193 tonnes of carbon dioxide per tonne of solid waste \2\.

Landfills, one of the four most significant contributors to atmospheric methane, are estimated to account for 6-18% of the total methane emissions globally \66,41\. Methane, at the current atmospheric level that is more than double its pre-industrial level, is believed to be second only to carbon dioxide in its global contribution to the greenhouse effect…even though it is significantly lower concentrations than carbon dioxide \66,45\. One tonne of methane is equivalent to 21 tonnes of carbon dioxide in terms of greenhouse effects \59\.

Methane is colorless, odorless and lighter than air. Methane has a slightly narcotic effect, but is only noticeably anesthetic at concentrations of over 50% volume in air. If the gas is allowed to accumulate to concentrations of 5-15% by volume of air, rather than disperse in air (such as in monitoring wells, shafts, trenches, buildings), sparks can lead to combustion or explosion \109\.

Accumulated hydrogen sulfide, as might be encountered in gas monitoring wells when uncapped for measurements, is an asphyxiant gas. At high levels it can cause permanent neurological impairment and cardiopulmonary arrest (Fuller, 2000).

Carbon dioxide is also colorless and has a slight acidic taste and smell. It is 1.5 times heavier than air, and can thus concentrate in a landfill valley. Air containing 4-5% carbon dioxide can induce unconsciousness and a concentration over 9% can cause death \1093\.

[15] World Health Organization guideline value.

[16] Landfill gas, also called biogas, is the decomposition by-product of microbial metabolism of organic waste material under the prevailing anaerobic conditions which exist within soil-covered waste cells in a sanitary landfill.

Headaches and Landfill

By reducing the oxygen content of air from the normal of 21% to below 17%, asphyxiation can occur. Such low oxygen levels are possible if landfill gas accumulates to a ratio of 1:4 in air \109\. A critical review of the North American literature indicated that headaches, wheezing, sleepiness, narcotic symptoms and mood disorders occur among residents living proximal to a landfill.\21\

At many dumpsites in developing countries, waste pickers report having headaches, including 23% of the pickers in Katmandu and 36% of waste pickers and surrounding dumpsite residents in Bangkok \34,56\. While the causal agents are not known, low oxygen levels could be one cause. Carbon monoxide levels at the largest open dump in Metro Manila averaged 55 mg/m^3, five times higher than the WHO 10-hour standard. These waste picker exposure levels were even higher than those of open taxi ("jeepney") drivers in central city traffic in Metro Manila \99\.

Cancer

Cancer risk could be caused a wide range of constituents being released from solid waste: either into the air, water; or food chain. Volatile organics, heavy metals, and certain inorganic gases each have the potential to induce cancer, if dose levels are high enough over a period of time that is long enough.

Because of their high vapor pressures and low solubilities, volatile organic compounds are observed in solid waste decomposition gases. One study identified 92 different volatile organic compounds in the headspace loading area of solid waste collection trucks, including alcohols, aldehydes, ketones, carboxylic acids, and esters. Total volatile organic concentration varied from 0.9 to 8.1 mg/m^3 in the loading area headspace. Furthermore, sudden peaks in exposure are likely to occur when the lids of waste containers are opened \74\.

Landfill gas has a number of trace volatile organic compounds, some of which are potentially toxic (dichloromethane), carcinogenic (benzene and vinyl chloride), as well as potentially affecting the incidence of kidney disease (toluene) and leukemia (benzene) \81,23\. The USA government estimated its municipal solid waste landfills released approximately 200,000 tonnes/year of volatile organic compounds, excluding methane \81\. These trace constituents are normally at non-toxic concentrations, unless there are significant quantities of industrial and household hazardous wastes present (solvents, paints, pesticides, adhesives) and landfill gases are inadequately ventilated \109\. Elevated levels of volatile organics were measured at one of Bangkok's open dumps, higher by more than an order of magnitude compared with nearby city background levels, notably for toluene (700 $\mu g/m^3$), ethylbenzene (120 $\mu g/m^3$), m&p-xylene (330 $\mu g/m^3$), and o-xylene (110 $\mu g/m^3$). Significant levels of benzene, methylene chloride and methyl chloroform were also recovered. While elevated, these levels were still below workplace standards promulgated by the USA OSHA[17] \56\.

The United Nations Environmental Program (UNEP) is working on the development of global treaty to reduce and/or eliminate 12 specific persistent organic pollutants that can accumulate and magnify in the food chain and ultimately damage ecosystems and human health. UNEP's 12 priority persistent organic pollutants are: the pesticides aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, mirez, and toxaphene; the industrial chemicals polychlorinated biphenyls (PCB's) and hexachlorobenzene; and the combustion byproducts dioxins and furans. Municipal solid waste incineration is a leading source for dioxins and furans in countries where incinerators are not operated at sufficiently high temperatures over sufficiently long retention periods. Aside from dioxins and furans, pollutants emitted by municipal solid waste incinerators include particulates, heavy metals (lead, cadmium, mercury, nickel, chromium), volatile organic compounds (in addition to polychlorinated dibenzodioxins and dibenzofurans, there are polycyclic aromatic hydrocarbons), and inorganic gases (hydrogen chloride, hydrogen fluoride, sulfur dioxide) \30,15\.

Cancer and Landfill

One of the largest municipal solid waste landfills in North America, located in Quebec Province, Canada, was studied for cancer incidence of residents living near the site. At the time of the study, 1991, the site had been operated for more than 20 years and had received over 30 million tonnes of solid waste, including industrial waste. Landfill gas composition was analyzed and shown to contain 35 volatile organic compounds, including suspected carcinogens: benzene, vinyl chloride, methylene

[17] Occupational Health and Safety Administration of the US government.

chloride, chloroform, 1,2-dichlorethane, bromodichloromethane, tetrachloroethylene, 1,4-dichlorobenzene, 1,2-dibromoethane, and carbon tetrachloride. Cancer incidence over the 1981 to 1988 period was determined from hospital medical records. Observed versus expected rates were determined for all types of cancers and modest **relative risk** differences appeared to exist. In women, rates of stomach and cervix uteri cancer were in excess. In men, rates of stomach, liver, trachea, bronchus, lung, and prostrate cancer were increased. There was also a stronger association for cancer of the liver and intrahepatic bile ducts than for the other cancers, with **relative risk** elevated by nearly 80% in the closest proximity (less than 4 km) and downwind. The **relative risk** increases for other cancers were less than 30% elevated above normal. In addition to the above cancer-risk data, other studies determined that there was a 20% increase in the frequency of low birth weight children born to women living proximal to the site \37\.

A comprehensive review of the published literature from North America indicates that residence near municipal solid waste landfills involved an increased incidence of cancer. Cancers occurring at higher than expected levels included: lung, bladder, liver, stomach, breast, cervix and prostate cancers \21\. A study that was completed in 1998 by the New York Department of Health examined cancer rates from 1980 to 1989 within a radius of under 0.5 km around 38 closed landfills. A four-fold increase in **relative risk** was found for bladder cancer and leukemia among females living near some of these landfills \106\. Length of residence near the landfill was not considered and this raised questions regarding where these females may have been exposed elsewhere to a cancer inducing agent \106\. It is worth noting that studies of cancer rates are typically dealing with landfills that were open in the 1960's and 1970's and thus were not meeting modern sanitary landfill standards or more effective gate-control for receipt of hazardous wastes. Nevertheless, a four-fold increase was significantly high enough to warrant concern and further study.

At New York City's largest municipal solid waste landfill there were more than 500 people working on site and 75,000 residents within 1 mile of the site (1.6 km). The New York Department of Health reported in 1996 that the overall cancer incidence of residents within 1 mile of the landfill was not elevated, but that there was a slight-to-moderate increase in lung cancer within the whole of Staten Island and, to a lesser extent, an increase in incidence of cancers of the colon, bladder, pharynx, and larynx. In 1997, air quality data was submitted from the New York Department of Environmental Conservation for evaluation by the US Department of Health and Human Services' Agency for Toxic Substances and Disease Registry. The Agency found no landfill-related air contaminants of public health concern within the available data \38\.

Solid waste disposal sites in developing countries typically receive both general municipal waste and hazardous industrial and medical wastes. No data could be found on whether there is any increased cancer incidence associated with these sites. Data from hazardous waste sites in the USA indicates that there was at least 30 priority pollutants that were present at a significant number of hazardous wastes sites and that had completed exposure pathways from the source of contamination to a receptor population. Of these priority pollutants, eighteen were determined to be carcinogenic, namely: arsenic, benzene, chromium, vinyl chloride, benzo(a) pyrene, beryllium, cadmium, carbon tetrachloride, chloroform, 1,2-dichloroethane, 1,1-dichloroethene, di(2-ehylhexyl)phthalate, methylene chloride, nickel, polyaromatic hydrocarbons, polychlorinated biphenyls, tetrachloroethylene, trichloroethylene. Epidemiological studies in New Jersey and Massachusetts found higher incidences of urinary bladder and gastrointestinal tract cancers and leukemia in areas with hazardous waste sites \47\.

Cancer and Incineration

Particulate emissions from incinerators in high-income countries need to be carefully controlled through air pollution equipment such as electrostatic precipitators. Because many heavy metals are associated with incineration's bottom ash and fly ash, particulate control limits these constituents from creating air pollution with carcinogenic risk. Most (if not all) incinerators in developing countries are built only with short stacks and no particulate control.

Some of the volatile organic compounds (polychlorinated dibenzodioxins and dibenzofurans, and polycyclic aromatic hydrocarbons) emitted by municipal solid waste incinerators are believed to be potentially carcinogenic but the concentrations at which this may occur are not certain. Even in high-income countries where there are good pollution controls now in place, airborne concentrations of these compounds may be up to four times higher than background within 1-2 km of an incinerator \30\. The epidemiological significance of this is not known.

Based on average municipal solid waste compositions in Germany, polychlorinated dibenzo-p-dioxins and furans average 50 µg I-TEQ/tonne (wet, and assuming a moisture content of 35%). A pollution control modeling effort determined that these dioxins and furans in the air emissions of modern incinerators would be 0.1-1 Ng I-TEQ/Nm^3 of flue gas (assuming gas generation is 5140 Nm^3/tonne of solid waste). With very high temperature combustion and secondary burning, the lower level of emissions is routinely possible. In the solid residues, these dioxins and furans were estimated as 0.2 ug I-TEQ/kg (dry) in bottom ash, 0.05 in boiler ash, and 0.3 in fly ash (assuming solid residue generation is 300, 5, and 32 kg/tonne of solid waste, respectively) \29\.

Stack emissions were analyzed in 1987 from a continuously operating modern incinerator and at a discontinuous batch-type incinerator in Japan. Significant mutagenicity was found in the stack gas, by using the Ames Salmonella/microsomal mutagenicity bioassay test, and thirteen polynuclear aromatic hydrocarbon compounds were identified \107\.

In 1990, study in the USA examined mutagencity for a solid waste incinerator and two medical waste incinerators. The results for the solid waste incinerator closely matched the Japanese results for solid waste incinerators. The results indicate that the completeness of combustion and the effectiveness of pollution control equipment more significantly affect mutagenic potency, than by the nature of the material being burned. The mutagenicity data from solid waste incinerators and healthcare waste incinerators were comparable to industrial and utility boilers burning coal, wood and oil \107\.

Three batch-operated municipal waste incinerators in Norway were studied in 1985 for emission of organic micropollutants such as polycyclic aromatic hydrocarbons, polychlorinated dibenzo-p-dioxines and dibenzofurans. The start-up concentrations of polycyclic aromatic hydrocarbons were over ten times higher than at the end of the batch combustion cycle, but still below levels measured from traditional wood stoves. This pattern of decreasing concentrations as combustion occurs was not observed for emissions of polychlorinated dibenzo-p-dioxins and dibenzofurans, which suggested that incineration conditions in the combustion chamber are not the determining factor for the formation of these compounds. Mutagenicity was assessed, and a correlation was found only between the content of polycyclic aromatic hydrocarbons and mutagenicity \7\.

A national commission in Germany from 1985-90 measured dioxin and furan concentrations under various operating conditions in fifteen incineration units, with the finding that these emissions could be limited by continuously controlling and adjusting operating conditions, but still would always require flue gas pollution control to reach acceptable emission standards \46\.

Lag periods of ten years are generally assumed for solid cancers to develop as a result of cancer-inducing agent exposure, and five years for lymphatic and haematopoietic cancers \30\. Cancer incidence of over fourteen million people living within 7.5 km of 72 solid waste incinerators in Great Britain was examined over a period of over ten years, starting in 1974. Observed and baseline expected numbers of cases were determined for each 1 km band from each incinerator. While the **relative risk** differences were not high, the study determined that there was a decline in **relative risk** with distance from incinerators for all solid cancers combined (stomach, colorectal, liver, and lung cancers). The reasons for the decline could not be determined and confounding could not be ruled out. There was a stronger **relative risk** association for liver cancer than for the other cancers (37% higher incidence than expected under normal conditions), even after adjusting the data to consider deprivation and ethnicity factors related to the populations nearest incinerators. The study found no evidence of increased risk for lymphatic and haematopoietic cancers, including non-Hodgkin lymphomas and soft-tissue sarcomas \30\.

DIRECT CONTACT DISEASE LINKS

Solid waste collection workers in high-income countries routinely wear gloves to handle the dirty containers where solid wastes are stored, and are seldom directly in contact with waste itself. Conversely, in developing countries, solid waste workers and waste pickers routinely touch the waste they collect and/or sort through; and, because they typically are wearing only sandals, are stepping on waste. Parasitic and enteric infections are common, and, to a lesser extent, viral infections such as hepatitis and HIV infection occur. While solid waste collectors in Denmark had a relatively high risk of occupational disease and injury (1.5) when compared to Denmark's total work force, the highest **relative risk** was found for infectious disease (6.0) \72\. Comparable information is not available from developing countries, but the substantially greater contact between the solid waste worker and the waste in developing countries should create an even higher **relative risk**.

A study in Denmark also suggested that high levels of airborne pathogens correlates with increased diarrhea. \73\ As discussed earlier, collection activities result in significant levels of airborne particulates near the hopper of the collection vehicle, and upon opening the collection container. Also, waste piling in composting and waste spreading in landfilling generate particulate emissions, including airborne pathogens. One recent phenomenon in sanitary landfill operation is the recirculation of leachate (which contains micro-organisms assimilated to the waste within that landfill). This practice can significantly improve the rate of biodegradation within the refuse mass, but care is needed to minimize creation of aerosols and to protect workers from aerosol ingestion. Drip irrigation of the leachate should be considered in preference over spray irrigation.

Parasitic Infections

In the early 1970's, about 1500 solid waste samples were analyzed from 33 Indian cities. *Trichuris trichiura* (a human whipworm) and *Ascaris lumbricoides* (a human roundworm) were commonly present. More samples were found to contain these parasites during monsoon season, than during summer or winter season. Stool samples collected from solid waste collectors and a control group of similar socio-economic background revealed 98% of the solid waste collectors were positive for parasites, while only 33% of the control group was positive \11\. Similarly, stool specimens collected from children working at or whose family members worked at the dumpsite in Bangkok showed that 65% were infected by one or more parasites. Hookworm (*Ancyclostoma duodenal* or *Necatoramericanus*) was the most prevalent (14%) of the helminthic infections and *Giardia lamblia* (a flagellate protozoon) was the most prevalent (44%) protozoan infection \56\. See Box 11.

Box 11. Elevated Levels of Parasitic Infection among Waste Pickers at Open Dumps

- 98% among children pickers in Manila, Philippines \99\
- 97% among all pickers in Olinda, Brazil \24\
- 92% among all pickers in Calcutta, India \26\
- 65% among all pickers in Bangkok, Thailand \56\

In stool samples from children waste pickers at Metro Manila's largest dumpsite, nearly 98% had *Trichuris trichiura, Ascaris lumbricoides*, or both parasites \99\. Survey of 180 waste pickers at Calcutta's open dumps revealed a history of worm expulsion reported by 24%. Stool examination showed a high rate of *Ascaris lumbricoides* (50%) and *Trichuris trichiura* (58%) infection, as well as moderately high *Giardia lamblia* (17%) infection—92% had pus cells and 100% has mucous in the stool \26\.

In Olinda, Brazil, squatters on a site previously used as a dump showed that 263 out of 270 respondents had intestinal parasites; 150 had three different types of parasites and 93 had two types. The most common infestation was with *Ascaris lumbricoides* \24\.

Blood tests of waste pickers in Delhi, India showed that eosinophils were elevated in 59% of children, 42% of women, and 61% of men. Elevated eosinophil levels indicate parasitic infection, and may also indicate allergic diseases. \113\

HIV and Hepatitis Infection

In high-income countries, the main concern with infectious healthcare wastes is the transmission of HIV, which causes AIDS, or hepatitis A and B, through injuries caused by syringe needles (and other shares) contaminated with blood and other body fluids. Those most at risk are health care workers. The USA reported 31 health care workers who were infected with HIV by contaminated puncture wounds, but none in housekeeping workers. The risk of HIV infection after puncture has been estimated to be about 0.3%. However, the risk of hepatitis B virus infection from a comparable injury was estimated to be at least 10 times higher, or 3% or more. Solid waste workers in the USA are currently estimated to have a risk of contaminated puncture that is roughly 1/1000th of the risk level of hospital nurses \77\.

In 1990, Institute of Hygiene and Preventative Medicine at University of Genoa, Italy studied infectious disease of solid waste workers. Clinical examinations were conducted on 1396 solid waste employees of Genoa for hepatitis B and D virus markers. Though no tests for significance were conducted, higher prevalence of HBsAG carriers (2.9%) compared to general population (2.0%) was reported. Higher prevalence of anti-HBs and anti-HBc positive subjects was 13.8% against general population (11.8%). Data indicated that probability of hepatitis B virus contact increases with years worked \48\. This suggests an increase in chronic active hepatitis with only marginal differences in convalescent hepatitis in the two populations.

Infectious healthcare wastes used to be routinely collected and disposed of together with general municipal solid waste until roughly 20 years ago in high-income countries, before source segregation of healthcare waste became common practice. In fact, in the early 1970's in New York City, there were between 50-100 puncture wounds per year from medical wastes (as well as needles discarded by drug users) reported among all city solid waste collectors. However, there was no correlation found between such injuries and disease incidence \17\.

In most developing countries, infectious wastes are still mixed with general solid waste for collection. Waste pickers, many of whom are children, at the dumpsites commonly segregate and recycle the disposable syringes and cotton bandages, despite the obvious contamination from the blood and other body fluids visible on these wastes. When queried, they are commonly unaware of the health risks associated with these materials. Male dumpsite waste pickers in Bangkok were tested for HIV and hepatitis B antibody. Results showed 5% were positive for HIV antibodies and 24% were positive for hepatitis B antibodies \56\. Whatever the cause, these are extremely high incidences.

WATER CONTAMINATION DISEASE LINKS

Rainfall that runs over solid waste or infiltrates through solid waste extracts dissolved and suspended constituents and thus becomes a contaminated liquid called leachate. As the waste decomposes through aerobic and anaerobic microbial action, waste-derived constituents increasingly become available to form leachate of greater concentration. Leachate from sanitary landfills can reach high organic concentrations well in excess of 20,000 mg/l of COD (chemical oxygen demand) and 10,000 mg/l of BOD_5 (five-day biological oxygen demand) in the first several years after land disposal. It can also have high concentrations of total dissolved solids, ammonia, nitrate, phosphate, chloride, calcium, potassium, sulfate, and iron, as well as numerous heavy metals (commonly including lead, zinc, cadmium, and nickel) and organic trace constituents (commonly including byproducts of decomposing solvents, pesticides, and polychlorinated biphenyls) \105,106,85\. In addition, high numbers of fecal bacteria are typical, while viruses seldom survive in leachate because of their sensitivity to the low pH values common to leachate \10\.

In high-income countries, the quantity of leachate generated is carefully minimized through sanitary landfill practices; and, once generated, this leachate is collected and treated to meet local environmental standards for wastewaters. Few developing countries have leachate management as part of their land disposal practices. However, because of the minimal compaction and containment of the deposited wastes, leachate is significantly diluted. Also, open burning removes much of the organic fraction of the wastes and may lead to a leachate that is relatively low in organic concentration. Leachates from open dumps in developing countries typically have COD's below 5000 mg/l.

Once in the ground, leachate moves as a contaminated plume or slug, with dispersion only at the edges; and it becomes diluted only when it reaches an open area enabling mixing, such as a stream or well. The movement of this contaminated plume or slug is slow, typically at a rate of only 10 to 100 meters/year. In may take years, even decades, before contamination reaches a downgradient well or surface water.

Groundwater samples collected from hazardous waste sites throughout the USA showed that 50% were contaminated with high levels of trichlorethylene, with average concentrations of about 2000 μg/l (compared to a drinking water standard of 5 μg/l \59\. Even though most developing countries have limited industrial development, complex organic hydrocarbons, including chlorinated hydrocarbons, are consistently present in leachate because general municipal waste is co-disposed with hazardous industrial waste. Data from sites in Mexico and Indonesia include significant levels of tetrachloroethane, xylene, toluene, and N,N-dimethyl formamide \53\. These contaminants are known to be potential carcinogens.

Downgradient users of leachate-contaminated groundwaters can potentially be exposed to significant dissolved contaminant levels; but seldom do disease microorganisms migrate far in most soils (except sand) due to ion exchange and adsorption attenuative mechanisms. \105\ In the case of direct discharge of leachate to surface water from a land disposal site, downgradient users may be exposed to disease organisms in their bathing, food irrigation, and drinking water supply, as well as through eating contaminated aquatic organisms. Solid waste workers and waste pickers at disposal sites in developing countries are seldom provided with safe drinking and washing water. While the health impacts of unsafe water downstream of open dumps are not documented in the literature, risks are expected to exist at most disposal sites in every developing country. Diarrheal diseases are the most often encountered health consequence of contaminated water supplies. Diarrhea is still one of the leading causes of death among children under five in developing countries, despite dramatic improvements in water supply and sanitation over the past two decades. Recent outbreaks of cholera during the early 1990's in Conakry, Guinea occurred largely in settlements within the immediate vicinity of the city's solid waste open dump and were believed associated with fecal contamination in the leachate from the dump.

As disposal sites in developing countries are converted from open dumps to sanitary landfills, leachates will become more concentrated in organics, and resulting biological oxygen demand (BOD). High BOD levels enable leachate to remove dissolved oxygen from any receiving groundwaters, which have only about 10 mg/l of dissolved oxygen in uncontaminated conditions. If groundwaters become anoxic, soil attenuation mechanisms that precipitate various heavy metals will be diminished. \59\

VECTOR DISEASE LINKS

Ice core records reveal that pre-1750 (pre-industrial age) global atmospheric concentrations of carbon dioxide were 280 ppm by volume. These increased to 355 ppm by volume in 1992. To stabilize carbon dioxide concentrations at present levels will require a 60% reduction in global carbon dioxide emissions. Similarly, to stabilize methane levels will require a nearly 20% reduction in methane emissions \13\. If climatic changes toward warmer temperatures continue unchecked, there will be an increase in various vector-borne diseases, such as dengue fever, and increased pathogen survival, as in the case of cholera \66\. See Box 12.

Box 12. Diseases from Vectors in Contact with Solid Waste

- Hanta Virus, Plague, Leptospirosis increase with exposure to rat droppings and urine
- Dengue Fever increases where uncollected solid waste (i.e., tires, cans) holding water providing mosquito breeding sites
- bacterial infections spread by houseflies that have come in contact with fecal matter in solid waste

Dengue Fever

Vector-related diseases remain an important public health threat throughout developing countries. The organic materials in waste provide breeding sites for insects and rodents of varied species. The dengue vector mosquito (*Aedes aegypti*) that favors small, clean water pools for breeding spreads dengue fever, including containers, tires, and tin cans found in waste piles \61\. Dengue reportedly arrived in the Americas, specifically in the USA, in 1985 with a shipment of used tires from Asia \66\. Recently, dengue fever has been declared an epidemic in Latin America. In 1993, it accounted for 23,000 deaths globally; and up to 2.5 billion people in tropical and sub-tropical countries are considered at risk. There are tens of millions of cases per year; about 95% of cases are children, and attack rates can be as high as 6400 per 100,000 \110\.

In 31 towns of Venezuela, 100 dwellings in residential neighborhoods were studied for the variables affecting the prevalence of *Aedes aegypti*. Deficiencies in water supply, solid waste collection, and human waste disposal were included. The only variable with a clear correlation to prevalence of the dengue vector mosquito was water supply service deficiencies, because frequent water interruptions of long duration lead households to provide their own on-site water collection and storage tanks. The principal type of receptacle found to contain the *Aedes aegypti* larvae or pupae were household water storage containers. There was also a high correlation for households with animal drinking pans. In towns with poor solid waste collection service, there was a high correlation at households with disposable containers and tires littering open lands, as these containers held rainwater and provided breeding sites \6\.

Leptospirosis and Hanta Virus

Rodents breed and feed in uncollected solid waste and at open dumps \61\. Their numbers are related to the available food supply, as well as the extent of pest control supported in city budgets, as evidenced by a huge increase in the rat population of New York City following significant budget cuts in the pest control program \65\. Furthermore, their numbers are known to fluctuate in response to environmental changes, with global warming and, in some localities, forest clearance anticipated to increase rodent populations \66\. Leptospirosis is spread by exposure to urine from rats and other rodents. Also rat-related, more than 2000 cases of bubonic plague were reported in 1993 and 1994, the highest total since global data were first compiled in 1954, and a four-fold increase over 1990 \111\. In El Bolson, an Argentine resort town, an outbreak of hanta virus, a disease spread by contact with rodent droppings or inhaling dust contaminated with rodent urine, killed 10 people in 1996 and devastated the economy for the town's population of 18,000 \93\.

Cholera

Cholera is also on the increase. Nearly 385,000 cases were reported in 1994 \111\. Cholera is considered a disease of deficient sanitation and poverty. It is now known that it can live in small water fleas (copepods) and can be transported farther and live longer when passed on primarily in drinking water and through poor hygiene habits \40\.

Enteric Bacteria

In Tamwe, Mynamar (Burma) in 1989, houseflies were captured in different parts of the city and during different seasons. The captured flies were homogenized and cultured to isolate bacterial pathogens. Enteric bacteria were isolated more frequently in flies from refuse dumps, latrines and animal pens. The rates of isolation of pathogens and the fecal coliform counts were highest in the hot/wet season. Citywide, fly-pools of 10 flies each averaged the following results: Escherichia *coli* in 76%, *Vibrio cholerae non-01* in 46%, *Salmonella* in 12%, and *Shigella* in 5% of all fly-pools \51\.

ANIMAL FEEDING DISEASE LINKS

Excreta contain significant numbers of the pathogenic organisms and can serve as a pathway for infection. When human feces are available for ingestion, animals can be infected and become a reservoir for later infection of humans. In high-income countries, a large amount of human feces arrives at disposal sites due to the prevailing use of disposable diapers. However, in such countries, wastes are usually covered with soil daily and domestic animals are prohibited from feeding on the waste. Due to inadequate sanitation systems in most developing countries, human fecal matter is always present in the solid waste. Also, many open dumps in developing countries allow the open discharge of pumped septage from cesspits and septic tanks.

Domestic animals (e.g., cows, goats, pigs, chickens, and horses) are present at most open dumps in these countries and animal infection is likely. Wastes from slaughterhouses are often indiscriminately discharged to the same open dumps as municipal solid wastes, raising concern about diseases (such as Bovine Spongiform Encephalophy, 'mad cow disease', which necessitated the selective slaughter of hundreds of thousands of cattle in 1996) being spread when animals eat the infected flesh of other animals \20\. In 1998, beef cattle on one of the Galapagos Islands experienced an epidemic of foot and mouth disease that was believed to be directly related to grazing at the open dump for municipal waste. Immediate actions were taken to close the dumpsite and implement a new controlled landfill with restrictions on cattle access.

Waste pickers at open dumps in developing countries are particularly at risk from diseases from infected animals, because they commonly collect food wastes to feed the animals they raise for their own consumption. In some developing countries, a major source of income of waste pickers is collection of food waste for animal husbandry. Adequate cooking of meat is an important control measure; but during food preparation, handling of contaminated meat can contaminate areas and equipment where other foods are prepared (see Box 13).

Box 13. Diseases from Eating Undercooked Meat of Animals in Contact with Solid Waste

- Trichinosis increases where pigs and bears feed on solid waste with uncooked meat containing whipworm
- Taeniasis increase where pigs, beef and dogs feed on solid waste with human and animal fecal matter containing tapeworm

Trichuriasis

Trichuriasis is caused when infective larvae of the *Trichuris trichiura* (human whipworm) are ingested, typically from eating raw or undercooked meat from natural hosts such as domestic pig, bear or boar. Prevalence in natural hosts (e.g., pigs, bear, and monkeys) increases when they feed on solid waste that contains raw or undercooked meat from infected animals or their excrement. *Trichuris trichiura* can survive within the infective stage outside of its host for up to 9 months \33\. To control the spread of trichinosis, the practice of feeding garbage to pigs which prevails in most developing countries should be eliminated. \58\ As noted above, under the section on Parasitic Infections, a majority of solid waste collectors in Indian cities, waste pickers in Calcutta, and waste pickers in Manila had stool samples revealing *Trichuris trichiura* infection. The causal factor is not known, i.e., whether eating contaminated and undercooked meat fed with contaminated solid waste caused the infection, or whether ingesting the parasite directly through poor hygiene caused it.

Trichinella Spiralis

Trichinosis in humans is contracted from animals that are natural to *Trichinella spiralis* hosts (e.g., pig, bear, boar, and badger) only when fed with raw or undercooked meat from infected animals. \19\ In the late 1940's in the USA, the average number of cases per year was about 400 with 10-15 deaths per year. With improved control over animal feed, trichinosis incidence decreased by the early 1980's; the average number of cases per year decreased to 57 and only 3 deaths per year \91\. *Trichinella spiralis* in humans increased in some Central and eastern European countries including Latvia, Belorussia, and Georgia, from the late 1970's through the 1980's, mainly through increased consumption of bear, boar, and badger, as well as increased access of these animals to raw meat in municipal solid waste at open dumps \10\.

Recent studies from 31 farms in Oahu, Hawaii showed that pigs testing positive for *Trichinella spiralis* were found only on farms feeding food wastes to pigs \28\. More than 400 rats at one pig farm in the USA were examined for *Trichinella spiralis* between 1983 and 1985; and 42% were found infected with *Trichinella spiralis*. After meat scraps and dead animals were controlled so that the rats had no access to uncooked pork, infection levels were maintained, probably through cannibalism within the rat population. The study concluded that rat populations need to be controlled to minimize transmission between rats and swine \60\.

It is unfortunately a common site on open dumps in developing countries to see pigs. Also, most of the waste pickers surveyed are recovering food wastes to bring home to their pigs. Even if the meat is well cooked, the home slaughter of these animals and the subsequent contamination of kitchens with potentially contaminated raw meat, could facilitate disease transmission. Prior to the implementation of sanitary landfills in Peru, pigs were raised in large corrals at the open dumps, and pig owners competed for whole truckloads to be dumped in their corral, by paying the truck drivers. In Metro Manila, thousands of waste pickers at the open dump in Payatas gather food wastes to sell to large pig farms.

An epidemiological study conducted nationwide in Romania showed high incidences of trichinosis within the general population during 1992 and 1993. These high disease levels reflected outbreaks that occurred in several cities during each of these years. Nationwide, the registered cases were 1421 in 1992 and 2402 in 1993. The study could not determine the causes of these outbreaks, but poor storage and disposal of wastes was considered one possible factor \22\. Shortly after the dissolution of the former Soviet Union and the changes in the Warsaw Pact bloc of countries, hygienic control over pig rearing might have eased and led to the poor sanitation conditions typically considered contributory to this disease.[18]

Taeniasis

Taeniasis is an infection caused by the adult stage of tapeworm *Taenia saginata* (beef tapeworm) and *Taenia solium* (pork or dog tapeworm). Cysticercosis is an infection caused by the larvae stage of tapeworm *Taenia solium* from pigs. Humans are infected either through direct ingestion of undercooked meat from infected animals or through fecal contamination from infected animals or humans. Animals that are natural hosts (e.g., pig, dog, ape) become infected by ingestion of tapeworm eggs expelled in human feces \58\. Therefore, the prevailing practice of grazing domestic animals on open dumps in developing countries that contain human feces will enable the host (humans) to carrier (animals) and back to host life cycle to be completed. *Taenia saginata* and *Taenia solium* may also survive outside of its host for nearly a year \33\.

Open dumps in developing countries typically contain exposed waste from slaughterhouses, and support significant populations of dogs. Researchers determined that canine tapeworm infects 76% of dogs living near animal slaughter places in Bangladesh, because they feed on discarded raw meat or organs \95\. In Katmandu, Nepal, there are 32,000 dogs for a human population of 700,000, and canine tapeworm has become a recognized health concern. More than 25% of households surveyed in Katmandu replied that they fed their dogs raw meat or organs; and more than 33% said their dogs defecated within the house \91\.

Mad Cow Disease (bovine spongiform encephalopathy, BSE)

It has been traditional to bury animal and poultry wastes from slaughtering, butchering, kitchens, and livestock holding or rearing, or put them into municipal disposal sites. Also, “downers”, or animals that were unable to stand and considered not fit for human consumption, were regularly killed and then buried or disposed at municipal disposal sites. Since the outbreak of Mad Cow Disease in 1996, concerns have been raised about burial, landfill, or windrow-pile composting, as well as spreading of compost onto grazing lands. Compost, unless it occurs under high temperature in-vessel systems, does not reach temperatures high enough to destroy the prions that cause Mad Cow Disease. In-furnace incineration is the preferred method of disposal for waste that is suspected of contamination with Mad Cow Disease prions.

Highly Pathogenic Avian Influenza (H5N1)

The H5N1 type of avian influenza is highly contagious among birds. Some birds are infected, but live as reservoirs; while others become diseased and die. The virus is excreted in manure and remains highly virulent for days, sometimes weeks in the manure. The virus contaminates the flesh and eggs of infected birds, and slaughter wastes discharged to disposal sites is able to infect animals and birds. H5N1 has infected and killed tigers and leopards fed raw poultry from infected birds. More than 115 human deaths have occurred, mostly among people raising, marketing or slaughtering infected birds. Some wild crow have been found dead from H5N1 and it raises the issue of birds that are known scavengers of discarded meat. \114,115\

There are concerns of manure and slaughter waste disposal from any birds, because it is not possible to detect which birds are infected but not diseased. There is potential of direct contact of people working at disposal sites (particularly open dumps that have no daily soil cover), contaminated dusts from vehicle unloading, and dusts from compost turning. Because most open dumps have foraging cows, pigs, goats, dogs, cats, and birds, the concern about open dumpsites as links in the spread of this disease need priority attention.

INJURIES

Collection Injuries

In 1995, the **relative risk** for an occupational accident among Denmark’s waste collectors was about 5.6, compared to Denmark's total work force. From 1989 to 1992, the number of occupational accidents in the Danish waste collection activity was 95 per 1000 workers per year, compared to only

[18] During 1993, there was also an outbreak of Leptospirosis among the general population in one small city in Romania, where the number of cases went from 0 in 1992 to 108 in 1993. \21\

17 per 1000 nationally for all workers. The most commonly reported accidents for Danish waste collectors were fractures, sprains, wounds, soft tissue accidents, and chemical burns \74\.

In 1998, the U.S. Department of Labor reported that solid waste collectors had the seventh most dangerous job in the USA. They reported that the **relative risk** of waste collectors being killed was 10 times greater than other workers' risk, and that 81% of mortalities resulted from vehicular accidents. Waste collectors had a fatality rate of 48.8 per 100,000, based on 1996 nationwide statistics. Between 1992 and 1996, 111 waste collectors were killed in the USA

The U.S. National Traumatic Occupational Fatalities Surveillance System indicated that 36% of fatalities between 1980 and 1992 occurred when the collection worker slipped or fell from a refuse collection vehicle or was run over by the refuse collection vehicle; and 18% of these occurred when the collection vehicle was backing up.\76\ The USA fatality rate was 48.8 per 100,000 workers in 1996. There were 111 fatalities among garbage collectors between 1992 and 1996, of which vehicular accidents accounted for 79%. While the private sector had only 34% of the worker population, 59% of the fatalities occurred in the private sector \106\.

While this risk factor is disturbing, there has been a steady improvement in job safety and resulting accident rates within the USA. Over two decades ago, study in New York City showed that solid waste workers experienced 20 times more injuries than that of all USA workers (148 injuries per 1 million man-hours of solid waste work, compared to 7.35 for all USA industries in 1975, and 29.42 for USA underground mining). Most injuries among New York solid waste workers were experienced during waste loading (60%) and driving (30%), with over 60% of all injuries occurring during the later part of the work shift suggesting a fatigue factor. Injury reports indicated that nearly 50% of the New York collectors were either standing or bending when they were hurt. In 1975, the risk among New York collectors of suffering a fracture or dislocation was estimated to be about 0.7 during a 20-year work period \17\. The USA average for solid waste related injuries was lower at that time, but still showed that the accident frequency rate for solid waste workers was higher than any other industry, i.e., the **relative risk** for accident was 10 times that for all industry (104.53 injuries per 1 million solid waste workers compared to 10.55 for all industry in 1973) \44\.

Detailed records maintained in Sacramento, California, USA indicate that most collection work related injuries occur in the lower back, then the legs, followed by the arms and shoulders. Improper lifting and falls were the greatest causes of incidents. \101\ Improved safety training and conversion to more automated waste collection vehicles has lead to a reduction in Sacramento's lost work days, as a percentage of total available work days, from 2.84% in 1991 to 0.58% in 1997. While the number of incidents, as a percentage of the work force experiencing accidents, has not changed significantly, there has been a dramatic reduction in the number of lost days per incident \101\. See Box 14.

Box 14. What is in a Health and Safety Campaign

Educate Everyone:

- Explain the health and injury risks to workers.
- Educate their families, to create a positive support system for the workers.
- Show which protective gear and measures to minimize risks.
- State the requirements for use of protective gear and measures.

Establish Record-Keeping:

- Show you mean business by keeping track of health and safety performance.

Create a Team Spirit:

- Mottoes, jingles, artwork, and other creative encouragement for good health and safety.
- Use organizational development techniques to encourage people to look out for each other's health and safety.

Provide Incentives:

- Recognition for good health and safety records.
- Let the public know your progress (signs, press releases, photos of the best of your workers).
- Monetary rewards for good health and safety records.

Provide Disincentives:

- Penalties for poor health and safety records.

Due to poor working conditions and lack of worker protection gear in developing countries, accident rates among solid waste workers are generally higher. A Brazilian study reported accident levels of about 700 per 1000 waste collectors per year. Brazilian waste collectors averaged 9.5 lost working days per year because of occupational accidents. In Brazil, most accidents occurred on Mondays and 91% occurred among workers employed on a task or piece rate basis \74\. The Brazilian study found that the legs were the most injured part of the body during waste collection, followed by the arms \75\. In Cairo, Egypt in 1991 a one-month health survey was conducted with 1530 waste collectors/recyclers from 199 families. During that month, 2% of the Caireen waste collector/recyclers were injured \32\.

Poor vehicle maintenance, brake failure, or driver failure is sometimes the cause of serious vehicle accidents. For example, in Utah, USA in 1999, a solid waste collection vehicle was involved in an accident that injured four people and left the driver of the truck in a coma \106\. In Quito, Ecuador in 1998, a solid waste collection truck entering the weighing station of the landfill was unable to stop and the driver was killed.

After complaints by shareholders, one of the world's largest private solid waste service companies dramatically reduced their accidents and related costs. In 1996 the company started a major safety campaign for its 30,000 employees. In less than a year, injuries and related insurance claims decreased. The private waste company had 18 to 19 injuries for every 100 employees; by December 1997, that number dropped to below 10. The savings on claims were reported to have more than covered the costs of the safety initiatives \96\.

Disposal Injuries

Data from the USA indicates that the injury and illness rate for collection workers was higher than for disposal workers at landfills and incinerators. In 1996, the overall injury and illness rate for all workers (including collection workers) in sanitation services was 13.0 lost workdays per 100 full-time workers, while it was only 6.4 for incineration workers. At incinerators, accidents involving equipment and vehicles were the biggest problem, while at landfills both vehicle accidents and landfill gas explosions are the major risks \104\. The scrap metal industry also has high worker injury and illness rates—11.1 lost workdays per 100 full-time workers in 1996, with conveyor belts being one of the main sources of injuries \104\.

Data reported earlier, for 1989 in the UK, indicated there was a **relative risk** that 80 out of 100,000 landfill site workers would experience either injury or death. While elevated, this reported **relative risk** factor was significantly lower than the risk of UK construction workers (237 out of 100,000) and miners (161 out of 100,000) \78\.

Survey of disposal sites throughout the UK determined there were only 4 incidents of biogas explosions at disposal sites from 1963 to 1976, a period when most sites were open dumps or interim landfills. Survey results for the period of 1976 to 1981 showed 47 incidents of biogas explosion. This significant increase in explosions coincides well with the transition from open dumps to sanitary landfills, wherein compaction and soil cover led to more anaerobic conditions within the deposited mass of waste and thus greater generation and containment of methane. Also, as open dumping conditions were curtailed, open burning was eliminated and more organic material was available to generate methane. By 1989, a total of 2 deaths and 9 injuries were directly attributable to inadequate control over landfill gases \86\.

In Liguria, Italy, a region with 11 active landfills for municipal solid waste, records of 100 sanitary landfill workers were studied. There were 10 occupational injuries in 1994, namely: 4 to lower limbs, 3 to upper limbs, 1 to pelvis, and 2 to head \49\. For the 180 waste pickers at Calcutta's main open dump, in 1995 the quarterly figures for cut injuries was 69%, pinprick was 33%, and eye injury was 16%. Also, 49% reported they had received dog bites and 16% had received rat bites at the dump \24\. The most common injury experienced by dumpsite waste pickers and waste recyclers is puncture wound. In Bangkok, 88% of waste pickers reported being injured by glass, 73% by needles, 30% by bamboo, and 25% by metal \56\. Roughly 82% of the dumpsite waste pickers surveyed in Katmandu, Nepal stated they had received wounds to the leg, and 70% had received wounds to the hand \34\. In Metro Manila's largest dumpsite, 17% of the children waste pickers had lacerations/wounds during the one-time clinical examination in 1991 \97\.

Many of the largest dumpsites in developing countries have more than one recycling group. These groups compete with each other over access rights to the waste, usually bidding against each other to have truck drivers dump in their area of the disposal site. Rivalries between waste pickers sometimes lead to injury and even death. During the late 1970's more than 20 waste pickers killed each other in a large fight over recyclables in the main open dump of Metro Manila. Two men were found dead in a Venezuela landfill in 1994, with reports that their deaths resulted from rivalism between recycling groups. Field interviews at this landfill indicated that knife and firearm injuries from rivalism ranged from 20 to 30 incidents annually \43\.

Accidents with disposal site equipment and trucks are probably the greatest cause of fatalities at most dumps in developing countries. Waste pickers crushed together to reach incoming recyclables may be run over as trucks back up to unload. During the night, sleeping waste pickers may be run over because few dumpsites have area lights. Others fall under the wheels of the truck as they run to jump on or off of the riding steps. At the main disposal site in Trinidad, officials estimate that, on average, one waste picker dies each year in this manner. Study at the Venezuela's Bonanza Landfill indicated there were an average of 4 runovers annually, with most occurring at night. At the same landfill, an estimated 7 nonfatal injuries occurred each year from waste pickers jumping on and off of the trucks' riding steps \43\.

Individual accidents occur when the surface of the dump site collapses into a cavity caused by underground fires and there are accidents with the landfill equipment, including: one child in North Sumatra, Indonesia, 1996; one child in Casablanca, Morocco, 1995; five child deaths in Metro Manila, Philippines, 1990; one child death in San Salvador, El Salvador, 1998; two severely burned adults and one mortally burned victim in Almaty, Kazakhstan, 1999 \55,97\. While statistical information is virtually nonexistent, workers at open dumps typically mention that waste pickers commonly get burned. The dumpsite managers sometimes set fires intentionally, to minimize the nuisance of flies, odors, and rodents. Other times, the waste pickers deliberately burn piles of waste with cans, in order to remove their coatings or paper wrappers; and these fires can easily get out of control and spread.

Even proper landfills in high-income countries are sometimes subject to fires. For example, just in 1999, there was a reported fire at a construction debris landfill in North Carolina, USA that spread throughout the entire landfill of about four hectares and took 6 weeks of using bulldozers and excavators to put out. \104\. There was also a fire in 1999 at an Oklahoma, USA sanitary landfill that "produced 15-foot (5 m) flames and thick smoke", partially fueled by shredded tires in the landfill. The blaze could not be extinguished and, ultimately, could only be contained by digging trenches around it \104\.

Dumpsite Slides

Slides occur when side slopes at landfill are too steep and unstable. Even a slope of 3 to 1 has been known to experience a slide under certain conditions, such as vibration or high moisture saturation, which both affect the contact adhesion of particles in the disposed mass. In seismic areas, landfill slopes need to be lessened in accordance with site-specific geotechnical calculations, and 5 to 1 slopes or lower could be necessary to avoid a slide. A man was killed and 250 residents evacuated in O Portino, Spain in 1994 when 100,000 tonnes of solid waste slid toward a coastal village. Inadequate drainage and steep slopes were reputedly the cause \5\. A large slide of solid waste buried 2 children at an open dump in Calcutta, India, in July 1992; and a similar accident occurred in Tangra, India 5 years earlier \12\. A huge slide of about a million tonnes of solid waste occurred from the sanitary landfill in Bogota, Colombia in 1997, but no deaths or injuries were reported. \31\.

Until 1993, the 20 year-old open dump, Umraniye-Hekimbasi in Istanbul, operated without compaction of the waste after deposition. The side slopes of the waste were steep (3 vertical to 1 horizontal, as opposed to the typically recommended landfill side slope of 1 vertical to 3 horizontal). Underground fires were common and created underground cavities. Fires at the site were believed fueled by continuous generation of methane gases from waste biodegradation. In 1993, a large displacement of the waste mass occurred (about 1.2 million cubic meters) and slid, engulfing eleven homes and killing 39 people. It is likely that an accumulation of methane exploded and triggered the landslide \54\.

In July 2000, the largest open dump in Metro Manila, known as Payatas, suffered a deadly landslide. This dump was the home and livelihood for more than 20,000 families, mostly squatters which had been relocated here from other areas of Metro Manila where they had illegally settled. Heavy rains from a typhoon saturated the steeply sloped dump and caused a landslide that buried homes. More than 50 people were killed. Like the dump in Istanbul that failed, this site was subject to continuous underground fires fueled by methane from decomposing waste materials. The combination of burned out cavities in the refuse, unstable steep slopes, fine-ground and uncohesive ash residue from burning, and enough water to saturate and liquefy the mass triggered a disaster waiting to happen. Inadequate government concern and resolve allowed homes to be built directly on the slopes of the landfill.

Lifting-Induced Musculoskeletal Injuries

Based on annual nationwide surveys of about 250,000 private establishments in all types of occupations, the U.S. Bureau of Labor Statistics reports that musculoskeletal disorders make up about one-third of the overall total of occupational injuries and illnesses. Out of 705,800 musculoskeletal disorders caused nationwide by work in 1994, 367,424 were due to overexertion in lifting. Of these, 65% affected the back. Review of the global literature provided strong evidence that low-back disorders are associated with work-related lifting and forceful movements. Among the studies using objective measures, there were high Odds ratios ranging from 2.2 to 11 \8\.

Records from the USA revealed that musculoskeletal restrictions due to arthritis were 4 times as common for waste collectors than for general laborers. Waste collection work is characterized by heavy lifting. Loading weights in some developing countries are higher (where oil drums are used as solid waste containers) and loading heights are higher (where open tipping trucks are used as collection vehicles), making the potential for injury greater. There is substantial risk for low back pain and musculoskeletal disorders of the neck, shoulders and arms \72\. One USA private sector collection contractor implemented exercise programs to minimize back injuries and strains, including hiring professional exercise trainers. Within one service area, injuries were more than halved \96\.

From 1984 to 1992, the **relative risk** for musculoskeletal problems among Danish waste collectors was 1.9. Several studies on waste collection movements have demonstrated that mechanical loads on the skeleton frequently exceeded maximum acceptance limits recommended; throwing waste bags results in high shear forces on the spine, and carrying loads results in excessive torque to the shoulder \74\.

Several laboratory studies have shown that relative energetic loads, expressed as oxygen consumption, are significantly higher for waste collectors than recommended limits. In keeping with such findings, coronary related disease events were two times as common among USA waste collectors than for general laborers \17\.

Waste pickers in Bangalore, India complained of musculoskeletal pain if they were engaged in sorting wastes in a sitting position and of backaches if they were carrying heavy loads of waste \100\. About 180 waste pickers at the Calcutta main dumpsite were studied in 1995. During one year, 70% reported chronic backache \26\. At Bombay's open dump sites, 95 solid waste workers reported experiencing continuous backache, neck ache, and wrist/knee/ankle joint pain \55\.

Vibration-Induced Musculoskeletal Injuries

Based on the global literature wherein quantitative exposure assessments were conducted, there was positive associations between back disorder outcomes and work-place vibration exposures, with Odds ratios from 1.4 to 39.5 \8\.

German studies found that the effect of vibration on drivers of landfill equipment is significant. Spinal injuries experienced by landfill equipment operators develop from higher than average degeneration of the vertebrae and intense vibration of hands and arms from operating the equipment levels \107\. A study of landfill personnel in Liguria, Italy, found that eighteen workers had lumbago (low back pain and ischialgia) \49\. In most developing countries, the bulldozers commonly used are open, with narrow steel seats, and have more vibration potential than those found in high income countries. Bombay's dumpsite equipment operators reported that the high vibration levels even made them feel they were vibrating during off-work hours \55\.

Noise-Induced Injuries.
It is well documented that excessive noise levels can affect hearing loss. But, recent research indicates that occupational noise exposure can also affect blood pressure. In a study at two plants (one with high noise (over 89 dBA) and another with less high noise (below 83 dBA)), involving over 300 male workers at each, clinical examinations and questionnaires that cumulative noise exposure was a significant predictor of diastolic blood pressure in high-noise conditions \95\.

Noise levels in materials recovery facilities in the USA often exceeded OSHA action levels for worker protection. Truck unloading, trommels, glass crushers, can compactors, paper choppers, grinders, aluminum can vacuum, tub grinder, and other processing equipment contributed to the noise levels, and operators at these equipment stations are required to wear hearing protection \83\. Noise levels from modern heavy equipment at landfills can range from 70 to 80 decibels at 10 meters \85\. It is less common for equipment in developing countries to be required to address noise safety standards and operations could reach higher noise levels. Noise control is not routinely specified in equipment tenders and when noise levels are higher, an accompanying hearing loss as a common risk.

RECOMMENDATIONS

Near-Term
The preceding discussion of health and injury impacts shows that it is difficult to distinguish between occupational and environmental risks in developing countries (especially lower-income countries and middle-income states experiencing major economic difficulties), because many people who are not solid waste personnel live and work in the immediate proximity of large piles of solid waste, whether uncollected accumulations, clandestine dumps, or official land disposal sites. Clearly, improved solid waste collection in developing countries would decrease the population exposed to risk.

Every developing country needs to adopt a plan to upgrade open dumps to controlled landfills and and transition to sanitary landfills with landfill gas collection (with either flaring or recovery for energy generation.\88\. To enable gases to be adequately controlled, for purposes of both health protection and control of green house gases, landfills should be at least 300 tonnes/day. This enables economies-of-scale in the basic landfill operation and also enables adequate depth of landfill (at least 10m) so that gases can be extracted at high enough methane concentrations to enable burning.

Emergency measures to curtail underground fires by placing soil daily on waste are necessary to curtail surface collapse and resulting injuries. Emergency measures are also needed to lessen the side slopes of uncompacted solid waste at disposal sites, to be no greater than 3 horizontal to 1 vertical [19] so that fatal slides and subsidence does not occur.

Airborne contamination (such as biodegradation gases, particulates and bioaerosols) is one the greatest threats to solid waste workers and waste pickers. Air monitoring needs to be regularly conducted, particularly at processing, transfer and disposal facilities. Direct-reading instruments that measure methane and oxygen deficiency are of primary importance; these include combustible gas indicators, flame ionization detectors, and oxygen meters \69\. At disposal facilities, volatile organics should also be analyzed in the biodegradation gases being collected and/or vented. In waste handling, sorting, and composting facilities, monitoring for organic dust is needed \74\.

Every city needs to implement record keeping on the health of its solid waste workers, including the informal waste pickers/recyclers. Rather than having open access of waste pickers to solid waste

[19] In seismically active areas, side slopes of solid waste may need to be even lower, such as 5 horizontal to 1 vertical.

disposal sites, they should be registered, carry photo identification at all times, and participate in a regular vaccination and health examination program. Local medical schools and occupational health institutes need to be encouraged to study the health of solid waste workers in comparison with appropriate baseline control populations, since true epidemiological data is lacking for this sector. Cities that use private companies to collect, process or disposal of their solid wastes need to include special clauses in each contract, requiring worker health and safety protective measures, including annual medical check-ups and vaccinations. Payment to these private companies and contract renewal shall consider whether these requirements are met.

International development agencies that provide solid waste equipment and facilities need to specify health and safety conditions for municipalities to meet in the use of these units, including improved record-keeping on incidents of disease, injury and death. Health and safety conditions from international development agencies would encourage cities to give more attention to this issue.

For those who make their livelihood from collecting, sorting, or otherwise handling waste, measures to improve their work conditions are needed. Various guidance documents in the published literature provide a base for developing country-specific recommendations \75,81,71,96\. Most disease risks can be reduced by interrupting or containing pathways of exposure to contaminants, and minimizing the concentrations of contaminants. Simple measures include: wearing protective clothing, goggles, and respiratory equipment; providing proper air filtration, conditioning and ventilation; controlling emissions; and practicing good hygiene. As a starting point, the people involved in solid waste management in all middle and lower-income countries would benefit significantly if a few modest measures were taken to protect their health:

Training and General Work Arrangements:

- Provide solid waste workers and waste pickers with clean drinking water and sanitation facilities.
- Vaccinate solid waste workers for hepatitis A and B, tetanus, diphtheria, polio, typhoid, and in endemic areas against encephalitis. For workers at open dumps and landfills, consider rabies vaccination.
- Develop medical surveillance standards and protocols, including baseline and follow-up medical examinations (e.g., overall fitness and strength, heart condition, pulmonary function, allergies/asthma, vision, auditory acuity, hepatic and renal function, standard clinical laboratory tests (e.g., CBC, SMA-22 biochem profile),vaccination and disease history, surgical history, musculoskeletal condition, sensitivity to heights or claustrophobia, vertigo/dizziness, incidence of seizures, etc.), routine survey of workers about job tasks performed and their physiological responses to their job tasks.
- Provide solid waste workers and waste pickers with protective clothing, shoes/boots and gloves. Solid waste workers should wear highly visible colors to help collection vehicle and other equipment drivers visually locate workers' positions during reversing, loading and unloading.
- Provide solid waste workers and waste pickers with a place to wash with soap before eating, smoking, or going home at the end of the workday. Provide training on the value of good hygiene in disease prevention, including clean bandaging over any skin discontinuities during work. Ideally, all workers and pickers should also change their clothing before leaving the site and taking public transport.
- Develop training materials on occupational and environmental health and injury issues relating to solid waste management for staff at all levels.

- Provide health and safety plans for all staff at all levels, including operational procedures for safe waste handling, accident response procedures, emergency call numbers, fire control, gas release response, hazardous materials release response, munitions response, first aid and emergency evacuation procedures.

Special Precautions for Collection Workers:

- Train workers on work practices during waste collection and compaction that minimize contact with hazardous substances (such as acids and solvents) and limit exposure to flying debris or splattering liquid from breakable items (such as glass from florescent light bulbs, bleach from plastic jugs, pesticide from aerosol cans).
- Provide collection workers with slip-resistance shoes and prohibit all jumping on and jumping off of the riding step unless the vehicle is at a full stop.\81,3\.
- Riding steps on solid waste collection vehicles should be self-cleaning and slip-resistant. Design riding steps to withstand the impact of sudden and repeated 200-kilogram loads, and grab handles should be capable of withstanding 200-kilogram pulls. Riding steps should be used only for distances within the collection zone that are less than 0.3 kilometers and speeds are under 15 kilometers per hour. For travel to and from the collection zone, the collection vehicle shall be large enough to safety seat all collection workers within the cab \81,3\.
- Drivers need to be trained to wait for the collectors to signal before moving and to avoid sudden stops when the collectors are on the riding steps. They should stop immediately during backing when visual contact is lost with any workers on foot, and use a coworker as a spotter. Agreed upon hand signals need to be included in training of all drivers and workers \81,3\.
- Provide all refuse collection vehicles and landfill equipment with audible reversing alarms and visible reversing lights.
- Provide good air pollution controls on all collection and transfer vehicles. Minimize diesel-powered vehicles and use unleaded gasoline (petrol).
- Collection vehicles should not have exhaust pipes discharging into the breathing zone of workers on the riding steps, as overexposure to exhaust fumes can cause dizziness and confusion, and lead to falls or slips.
- Provide two-hand constant-pressure controls for collection vehicles with compaction mechanisms \81,3\.
- Design collection routes to minimize, or possibly eliminate, crossing traffic that is going in the opposite direction.

Special Precautions for Disposal Workers:

- Register adult waste pickers, provide vaccination for hepatitis A and B, tetanus, polio and typhoid, and provide annual medical examinations.
- Prohibit children from waste picking and prohibit domestic animals from being fed with food waste that has been mixed with other municipal wastes or fed with any waste from slaughtering.
- Provide education on the safe care/feeding of domestic livestock and pets to waste pickers and animal raisers in the vicinity of solid waste disposal sites.
- Conduct gate inspection and control at all disposal sites. Spot for waste loads that are burning and divert them to a safe unloading area where firefighting equipment is available. Spot for hazardous wastes and send these to secured disposal sites or specially prepared cells.
- Restrict access to disposal sites such that only safety-trained personnel with protective gear are permitted to high-risk areas. All workers should wear hard-soled safety shoes to avoid puncture wounds to the feet.
- Provide solid waste workers operating or working in the vicinity of heavy equipment with protection from excessive noise levels.
- Provide air filtered and air conditioned cabs for all heavy mobile equipment used at landfills.
- Provide roll bars on heavy mobile equipment used at landfills.
- Clean and wash with disinfectant the cabins of heavy mobile equipment used at regular intervals.
- Minimize the working face of the landfill and cover each daily receipt, so that potential bioaerosols and contaminated particulates are minimized.
- Collect landfill gases through active pumping systems and either flare or recover for energy use so that it is fully combusted, thus destroying anoxic gases, methane and volatile organics.

Special Precautions for Workers using Processing Equipment:

- Provide solid waste workers operating waste processing equipment with protective eyeglasses.

- Require solid waste workers and waste pickers who are working in areas where there are waste shredders, composting piles, vibrating or rotating screens, leachate recirculation spray nozzles, or burning wastes to wear respiratory protection such as facemasks. Conduct regular medical check-ups of these workers with special emphasis on lung function, immunoglobulin concentrations (particularly total IgG and IgE), and blood sugar \74\.
- Minimize sorting from the ground by providing conveyor belts and/or tables that facilitate sorting.
- Improve the storage of solid wastes at the source so that the loads to be collected are well contained and not too heavy.
- Establish engineering and materials norms for special facility and stationary equipment design requirements that minimize exposure to hazards (e.g., ventilation, air conditioning, enclosed conveyor belts, low loading and sorting heights, non-skid flooring, safety rails on stairs and walkways, spill protection and containment, drainage and leachate interception and treatment, noise control, dust suppression, dust filtration, gas alarm systems, fire alarm systems, fire sprinkler and other fire control systems, and evacuation facilities,).
- Provide air filtered and air conditioned cabs, back-up lights and chimes, and roll-over protection, for all heavy mobile equipment used at transfer stations and processing plants.
- Conduct gate inspection and control at all treatment and transfer sites. Spot for waste loads that are burning and divert them to a safe unloading area where firefighting equipment is available. Spot for hazardous wastes and send these to secured disposal sites or specially prepared cells.
- Restrict access to treatment and transfer sites such that only safety-trained personnel with protective gear are permitted to high-risk areas.
- Within all enclosed tipping areas, such as those routinely found at transfer and processing sites, fresh air ventilation is needed to avoid excessive levels of carbon monoxide, and air filters are need to minimize dust and particulate levels. Provide carbon monoxide detectors with visible and audible alarms. Routinely change or wash the air filters.
- Clean and wash with disinfectant the cabins of heavy mobile equipment.
- Cleaning of materials recovery facilities and transfer stations should be done with vacuum cleaners, rather than sweepers. Washing down needs to be avoided, so as not to create growth conditions for bioaerosols and pathogenic microorganisms. With less washing, there are also likely to be fewer pools of stagnant water that could serve as breeding sites for mosquitoes \36\.
- Waste stored at any incinerator, transfer station, or materials recovery plant should be in a deep concrete-lined pit, to minimize access by rodents and prevent their escape should they fall in.
- Shredder should be located in sealed rooms or chambers to contain any explosion that might occur. Provide adequate sprinkler systems and firefighting equipment \36\.

Source Segregation Procedures:

- At households, commercial establishments and institutional buildings, implement source segregation of non-hazardous recyclable wastes, so that the economic incentive for waste picking at disposal sites is reduced.
- At hospitals and industries, implement waste segregation and separate collection of hazardous and healthcare wastes from general wastes \89\.
- Control the importation, through false labeling and other corrupt practices, of hazardous wastes for recycling and/or disposal.

Long-Term Overview

A reduction the quantity of solid wastes being generated is a primary way of reducing environmental and occupational health effects of waste management. Education is needed to promote manufacturing technologies and consumer practices that generate less waste.

Source segregation of recyclables leads to the highest recovery of clean and high-grade materials. However, it comes with a relatively high educational requirement to change the public's behavior at the source, as well as with additional collection costs. At the source, some injuries occur, during the efforts to remove the tops and bottoms of cans, as well as wash them. For the collector, collection of recyclables from each household could be made safer if the bins were well designed to ease sorting, or the bags were transparent to enable viewing of sharp metal and glass objects \35\. If appreciable quantities of recyclable materials remain in solid waste when it reaches a transfer station or disposal site, safe sorting could be conducted using conveyor belts, vacuum ventilation over sorting stations, air filtration systems, and worker face masks and gloves.

From a health and injury perspective, waste picking should be prevented within sanitary landfills. Until new modern landfills can be implemented and existing open dumps closed, existing communities of waste pickers need assistance to make their recycling efforts safer, increase their sorting and waste processing productivity, and network with potential buyers of secondary materials. Technical assistance needs to be provided to help waste pickers transition from independent informal sector workers to organized enterprises, cooperatives, or economic groups. Access to credit needs to be arranged in a special revolving fund for micro and small-scale enterprises of pickers[20], including provisions to minimize or eliminate the need for collateral. Some pickers will be too young, old, or handicapped to be included in any program to transition them into more structured employment; and special welfare and support programs are needed to provide them with a safety net when access to waste picking is curtailed.

For the organic fraction of solid waste, composting is popularly considered a disposal solution that results in minimal health risk, assuming that waste that is appropriate for composting should be free of hazardous materials. Bioaerosols and airborne particulates present some risk during shredding and pile-turning operations if respiratory protection is not worn \96\. If the quality of the incoming waste is not carefully controlled at the source to be free of hazardous wastes, the resulting compost may have heavy metal and organic chemical components which are injurious to soil structure, toxic to plants, and potentially carcinogenic if bioaccumulated through the food chain. To avoid potential toxicity, compost product needs to be analyzed prior to distribution, to be sure that recommended limits for selected constituents are not exceeded. \52\.

Pathogens survive in solid waste according to their natural tendency, overall moisture content and temperature of the waste deposit. Some pathogens (such as *Trichuris trichiura*, *Taenia saginata*, and *Ascaris lumbricoides*) can survive at infective stages of their life cycles outside their host for months, even in a land disposal site unless there is open burning or underground fires \52,103\. Composting is one way to destroy pathogens, depending on the temperatures achieved and maintained within the composting piles. Ascaris eggs are considered the hardiest survivors and are useful for monitoring compost quality. Pathogen larvae tend to move to the cooler parts of the compost pile. Depending on the temperatures achieved and maintained, most insect eggs and larvae are destroyed. Fly larvae cannot survive temperatures above 50^{o}C. For complete pathogen destruction, all parts of a compost waste pile would need to spend several hours at temperatures above 60^{o}C, or between 50^{o}C and 60^{o}C for at least 7 days \33,103\.

All land disposal sites that are open dumps or controlled landfills should eventually be closed, and new sanitary landfills implemented (unless there is a market for compost to absorb the incrementally higher cost of composting). It takes a minimum of four years to site, design and implement properly a new sanitary landfill including efforts to involve the public through local consultations. Costs for new landfill facilities typically will increase overall solid waste management costs by 15% to 30%, given that most developing countries currently have no disposal cost because of their open dumping practices.

[20] The Consultative Group to Assist the Poorest (CGAP), is a multi-donor effort with the World Bank entrusted to manage a donor-fund to assist micro and small scale enterprises. World Bank criteria to define micro and small scale vary by country and income level.

Incineration is not generally considered economically viable for developing countries, because their wastes are too wet and too low in combustibles to burn without supplementary fuel. Where incineration is implemented in a developing country, air pollution control measures that address standards comparable to those required in high-income countries should be implemented. For adequate health protection, the cost of such air pollution control commonly increases the basic cost of incineration by at least 25%. Such protection would include specifying high temperatures be achieved in a secondary combustion chamber, oxygen contents during combustion, minimum combustion residence times, electrostatic precipitators, use of auxiliary burners, stack gas scrubbing systems, and criteria for calculating stack heights \110\. Municipal waste incineration's total cost per tonne is higher by a factor of 5 to 10; and incineration investment costs are higher than sanitary landfill's costs by a factor of 10 to 20.

Special wastes, such as infectious healthcare wastes and hazardous industrial wastes, are best handled in systems separate from municipal solid waste collection and disposal. The infectious wastes should be segregated at the source and placed in sealed disposable containers; and the containers should remain sealed until treated or incinerated within a closed system. Systems for incinerating healthcare wastes use significantly higher temperatures than municipal waste incinerators; and healthcare waste incineration's total cost per tonne is higher by a factor of 10 to 20.

Ultimately, full cost accounting is needed to make strategic planning decisions among various solid waste technical options, taking investment, operating, environmental and social costs fully into account. Some of the economic costs to consider include: loss of property value and related property taxes near poorly managed waste handling facilities, lost productivity when collection vehicles make longer trips to disposal, transfer costs to more distant disposal sites, loss of habitat and wildlife, loss of water supply sources, build-up of phyto-toxic contaminants in soil from poor quality compost application, loss of worker productivity and educational outcome due to illness or injury, as well as disposal site remediation and long-term monitoring costs.

New information on the costs for hazardous waste site remediation provides some insight on the need for full cost accounting among disposal options. Although land disposal with minimal containment and emission control may have once seemed inexpensive, when remediation costs are added they present a far different perspective. In the USA, more than 430,000 sites were listed as requiring remediation, of which over 17,000 were at military installations and involved highly complex mixtures of radioactive and chemical wastes. The cumulative cost estimate for the clean up of all these sites will be approximately $750 billion. Not included in this high cost to society are the non-site-specific costs of long-term monitoring and administration of these sites following clean up, nor the cost of adverse non-reversible health and environmental impacts \47\.

NEXT STEPS

This document is an initial step toward improving occupational and environmental health and safety in solid waste systems. It provides a broad view of the issues—enough to make it clear that the health and safety risks are compellingly significant. International solid waste management, health, and development agencies are recommended to take immediate and serious action. Most importantly, they need to:

- Support studies that would provide more insight on the magnitude of the health and safety problems in developing countries and their causes;

- Ensure that private sector participation through contractual or licensing arrangements in developing countries requires private operators to provide health and safety protection for their workers;
- Establish mechanisms of financial and technical support for municipalities to provide health and safety protection for their workers and encourage national governments to develop a policy framework;
- Finance improved disposal systems, closure of open dumps, provision of health and safety gear, and education on health and safety.

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