5

Health Aspects of Excreta and Night Soil Systems

IN THIS AND THE NEXT CHAPTER, the health implications of the principal varieties of excreta collection and treatment systems are discussed. These are separated into night soil (or "dry") and sewage (or "wet") systems. (The health implications of reuse and effluent-discharge practices are considered in chapter 7.) Little attention is paid here to the technical details of the systems examined, except to those bearing on specific health problems. The reader wishing more information on technical aspects should consult the second volume of this series (Kalbermatten and others 1982), the related document published by the International Development Research Centre (Rybczynski, Polprasert, and McGarry 1978), and standard sanitary engineering texts. In this chapter, three excreta collection systems—the pit latrine and its various modifications, the composting latrine, and cartage systems—are described, and the discussion concludes with an examination of the health implications of dry treatment of night soil by trenching and composting. Excreta collection and treatment by wet systems are examined in chapter 6.

Pit Latrines

Pit latrines are the simplest of all on-site disposal systems. Excreta fall into a hole in the ground, and a new pit is dug when the hole is about two-thirds full (see figure 5-1). A ventilated improved pit (VIP) latrine, and a modified pit latrine called a ROEC (Reed Odorless Earth Closet), are shown in figures 5-2 and 5-3, respectively. Pits are covered by sqatting slabs, seats, or pour-flush bowls.

Cleanliness

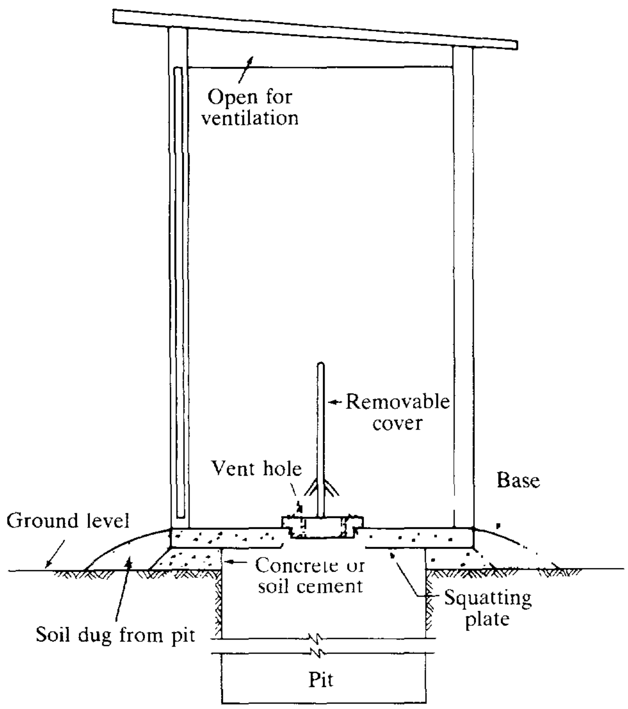
In all latrines cleanliness is of the utmost importance. Squatting slabs easily become fouled and pour-flush bowls may block up. Fouled and unhygienic pit latrines are found all over the world, often because they have been constructed in communities previously accustomed to defecation on the open ground who have also had inadequate community involvement or health education. Fouled pit latrines become a focus of disease transmission and may make health matters worse than before the sanitation intervention.

Odor

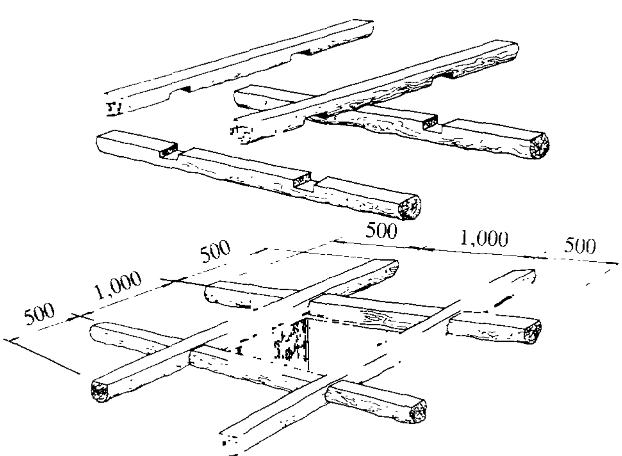
Pit latrines with squatting slabs often are malodorous. If they are, they may not be used and thus cannot yield any potential benefits in improved health. Odors can virtually be eliminated by fitting a vent pipe to the pit. This pipe should be at least 100 millimeters in diameter, painted black, and fitted on the sunny side of the latrine so that it can heat up, the heat creating an updraught. [See note on page 82.]

Insect breeding

Pit latrines with squatting slabs will usually become breeding sites for flies. Flies that visit a pit latrine to breed or feed may carry pathogens when they leave and thus promote disease transmission. If the pits are wet, they may also become *Culex pipiens* breeding sites. Well constructed pits with pour-flush bowls will not allow such insect breeding. If squatting slabs are used, a vertical vent pipe—100–200 millimeters in diameter, covered by a fly screen, and combined with a dark interior to the superstructure—will greatly reduce both the amount of fly breeding and the escape of any flies that do breed. Flies breeding in the pit will be attracted by the light coming down the vent pipe and will attempt to escape by this route, only to be prevented by the fly screen. The effect of vent pipes on mosquito breeding in wet pits remains uncertain and the latest findings are reviewed in chapter 36.



Side view



Alternative base using hewn logs

Figure 5-1. *Conventional unimproved pit latrine* (dimensions in millimeters). In termite-infested areas, use treated wood or termite barrier. From Kalbermatten and others (1982); adapted from Wagner and Lanoix (1958)

Pathogen survival in the pit

Most pit latrines are filled in when two-thirds to three-quarters full and are either never dug up again or only dug up after many years. In either case pathogen survival is of no concern because all pathogenic organisms will be dead. In some areas, however, two alternating pit sites are used, a pit is dug out a year or two after closing, and the contents are used as fertilizer. This system resembles the double-vault composting toilet (see below) except that it operates on a longer cycle. If the pit has been left for a minimum of one year, there will be no viable pathogens (except, possibly, a few *Ascaris* eggs). The chances of viable *Ascaris* eggs being present are greater if the pit is wet and partly below the water table. The risk involved in reusing material that has been buried for at least 12 months is small, however, and the pit contents may immediately be used on the fields with confidence. [See note on page 82.]

Groundwater pollution

Pollution of this kind is a genuine hazard in areas where pit latrines are widely used and where the groundwater is high and is used as a water source. The subject is discussed in detail in chapter 7.[1]

Composting Toilets

Developed countries have shown a growing interest in composting toilets because these sewerless facilities circumvent financial and ecological problems attendant on the waterborne disposal of human wastes.[2] Financial considerations and the lack of municipal effort required to maintain composting toilets make their use attractive in some developing countries, for which agricultural reuse of the composted product is an additional benefit. The precautions necessitated by the problem of pathogen survival in this product, however, must be noted.[3]

Technical description

There are two basic kinds of composting toilets, continuous and batch. Both require the addition of a carbon source, such as garbage, vegetable leaves, or sawdust. The continuous composting toilets are based on the Swedish "multrum" toilets, and an example of such a design is shown in figure 5-4. They have been under trial in Tanzania and Botswana since 1977 but have had no wide application in developing countries.

1. See the subsection "Effluent Discharge. To groundwater."
2. See chapter 1, "Characteristics of Sullage."
3. See chapter 3, "Limitations in Assessing Health Benefits" and table 3-2; see also chapter 4, "Objectives of Night Soil and Sewage Treatments. Excreta and night soil treatment."

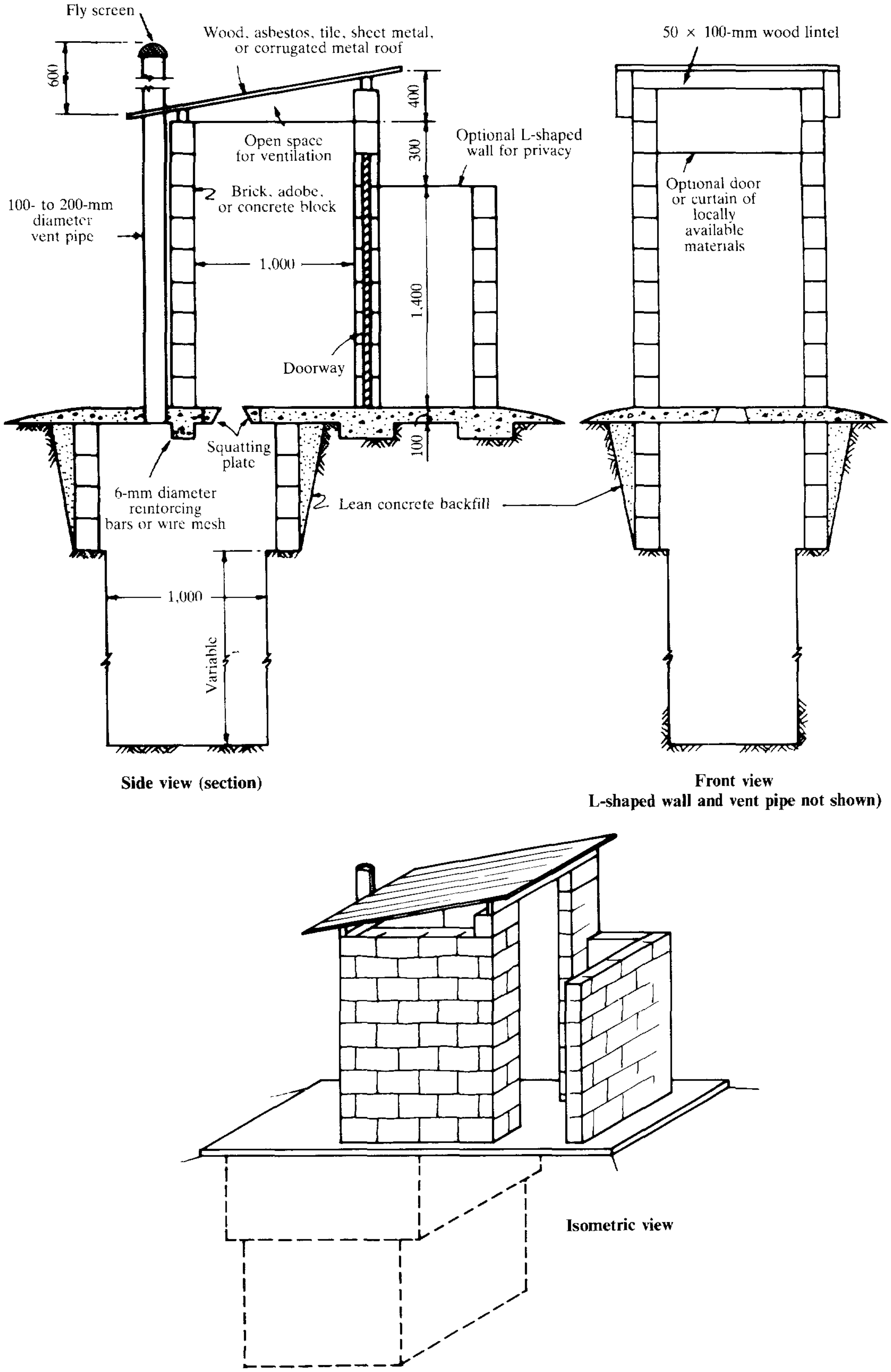


Figure 5-2. *Ventilated improved pit* (*VIP*) *latrine* (dimensions in millimeters). In the side view, a pedestal seat or bench may be substituted for the squatting plate. An opening for desludging may be provided next to the vent pipe. Dimensions of the bricks or concrete blocks may vary according to local practice. Wooden beams, flooring, and siding may be substituted for concrete block walls and substructure. From Kalbermatten and others (1982)

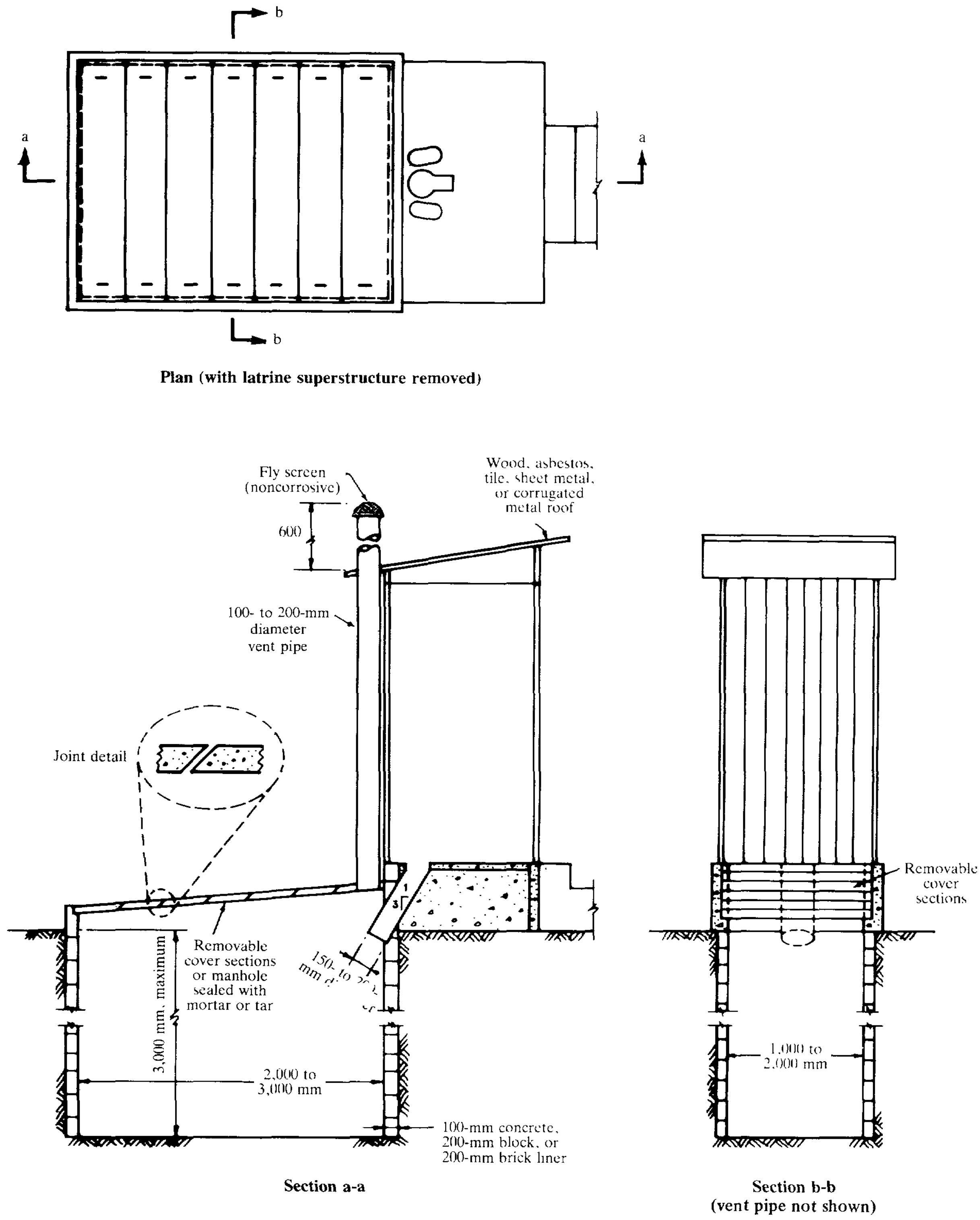


Figure 5-3. *Reed Odorless Earth Closet* (ROEC) (dimensions in millimeters). Pedestal seat with curved chute may be substituted for squatting plate. Construction materials and dimensions for the superstructure may vary according to local practice. From Kalbermatten and others (1982)

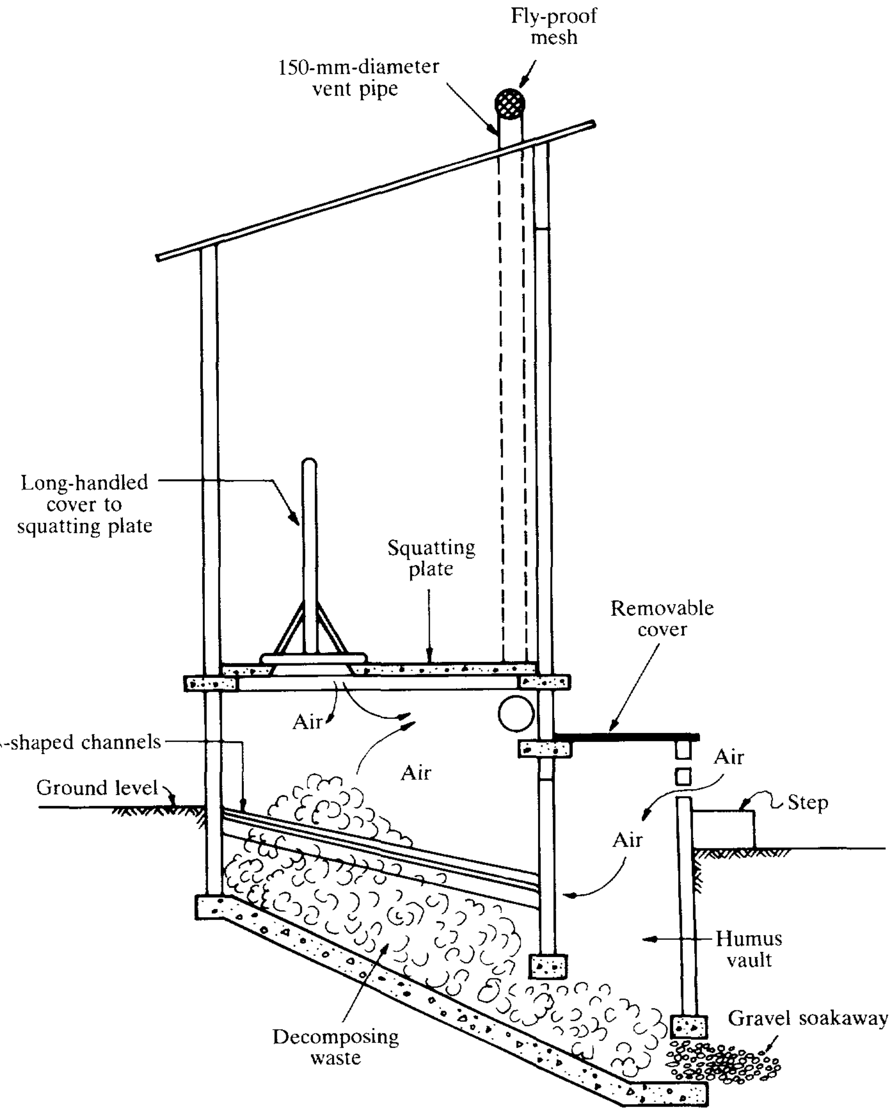


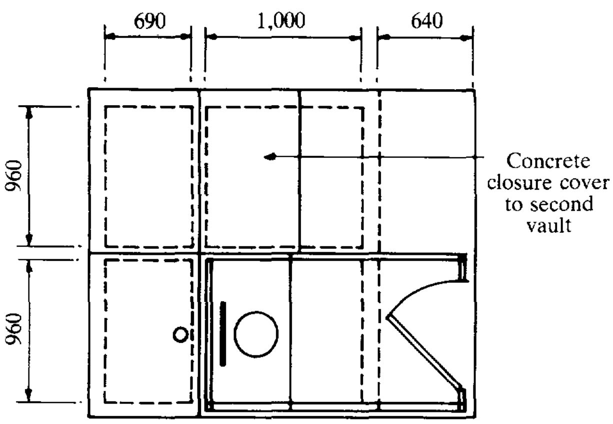
Figure 5-4. "*Multrum*" *continuous-composting toilet.* From Kalbermatten and others (1982); adapted from a drawing by U. Winblad

Only limited and inadequate microbiological data exist on continuous composters (Gurak 1978; reviewed by Feachem, Mara and Iwugo 1980). The batch composter is common in China and Vietnam, and the most usual design is the double vault (see figure 5-5). Again, no appreciable microbiological data on these toilets have been located, although such data may exist in China and Vietnam.

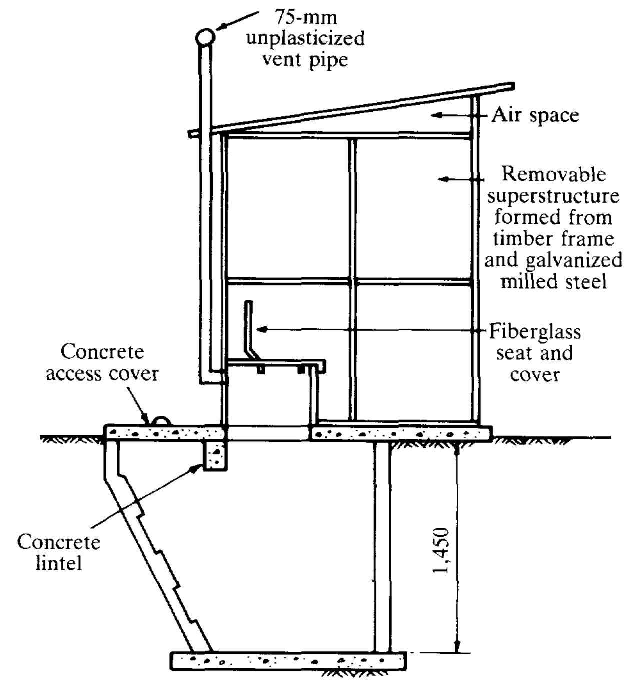
Pathogen survival in product

In both kinds of composting toilet, the composted product is used as an agricultural fertilizer and soil conditioner. It is important, therefore, that pathogen destruction should be as complete as possible. The two main factors affecting the survival of excreted pathogens are time and temperature. Temperature in the composting pit or vault depends on the air supply, the C:N ratio, and the moisture content. If the digestion is anaerobic, the temperature may remain ambient or it may rise at most to around 35°C. If it is aerobic, the temperature will rise to the 50–70°C range if the C:N ratio and moisture content are correctly regulated. These conditions may be difficult to achieve, especially in arid developing countries where little organic material (needed as a source of carbon) is available for adding to the wastes.

It is certain that double-vault composters will be anaerobic, and it is probable that multrums will be also. Anaerobicity and ambient temperature certainly

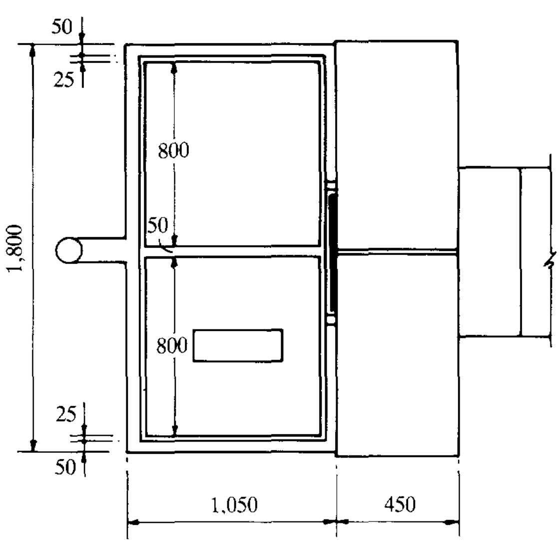


Plan



Section

Model used in Botswana



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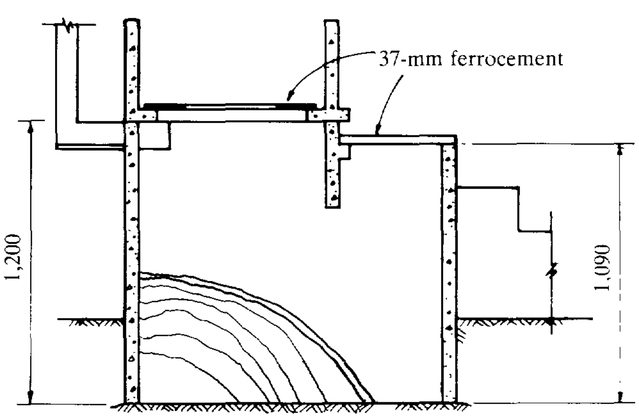
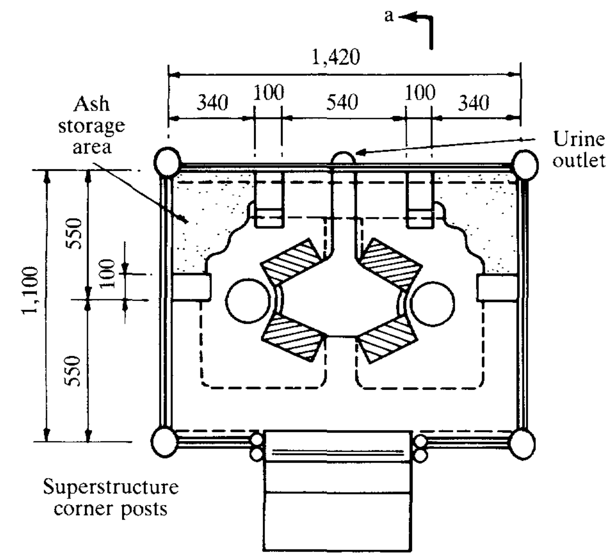


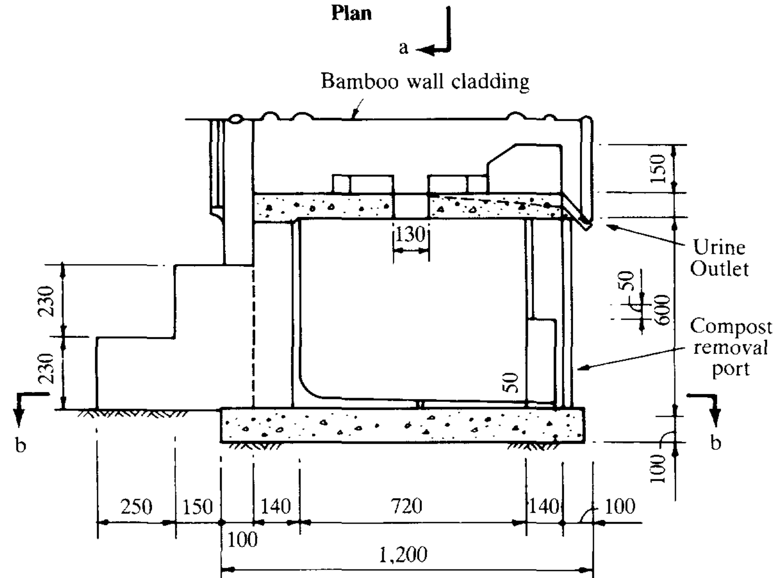
Section

Model used in Tanzania

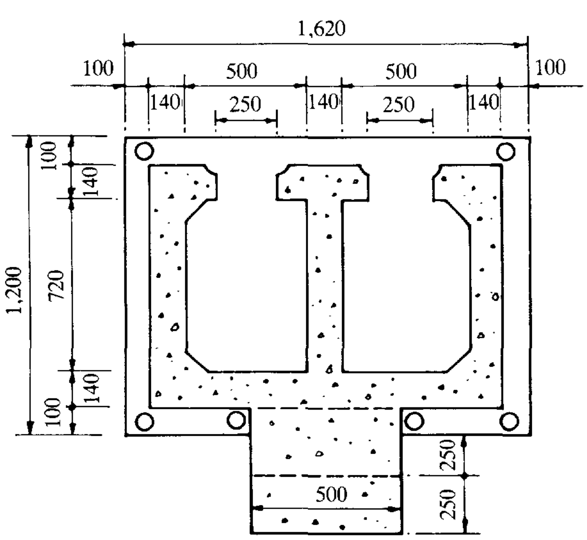
Figure 5-5. *Double-vault composting* (DVC) *toilet* (dimensions in millimeters). From Kalbermatten and others (1982); top, adapted from a drawing by R. A. Boydell



Plan



Section a-a



Section b-b

Figure 5-5 (*continued*)

Model used in Vietnam

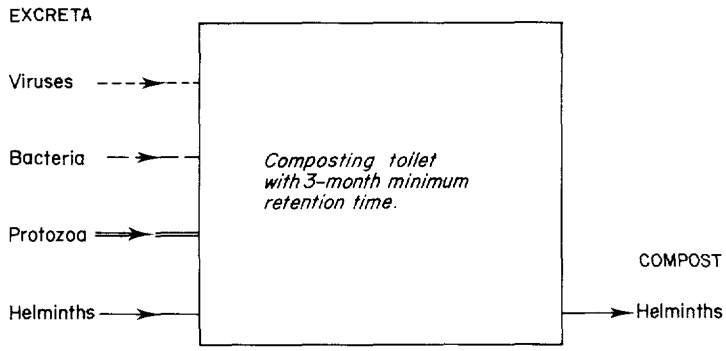


Figure 5-6. *Pathogen flow through a batch composting toilet (double-vault)*

are the correct, conservative assumptions to make where pathogen removal is the concern. Pathogen removal then depends on the retention time in the unit. There appears to be a wide variation in retention time used in both the multrum (continuous) and double-vault (batch) systems, and the pathogen removal efficiency of any given design can be estimated by consulting table 5-1. It is clear from the table that a minimum retention time of 3 months will yield a product free of all pathogens except the more persistent helminth eggs, as visualized in figure 5-6. Three possible pathogen control strategies can be adopted for compost:

- To use the compost as produced and accept the level of risk involved. This risk could be reduced to sufficiently low levels by using the compost only to prepare ground prior to planting or by not applying compost within 2 months of harvesting.
- To apply the compost only to industrial or fodder crops.
- To provide further treatment for the compost through heating it (probably impracticable) or through mixing it with an ovicide (also often impracticable).

The first of these strategies is probably the most realistic, and the quality of the product will become better as the retention time is increased beyond 3 months.

Cartage Systems

Cartage systems include a variety of technologies by which night soil is periodically removed from containers in or near the house. One of the oldest—and, generally, least hygienic—systems is the bucket latrine. A squatting slab or seat is placed immediately above a bucket which is filled within a few days by the excreta of an average family (see figure 5-7). The bucket is positioned adjacent to an outside wall and is accessible from the street or back lane. A night soil collector ("scavenger" or "sweeper") will call regularly—preferably every day, but more typically once or twice a week—to empty the bucket.

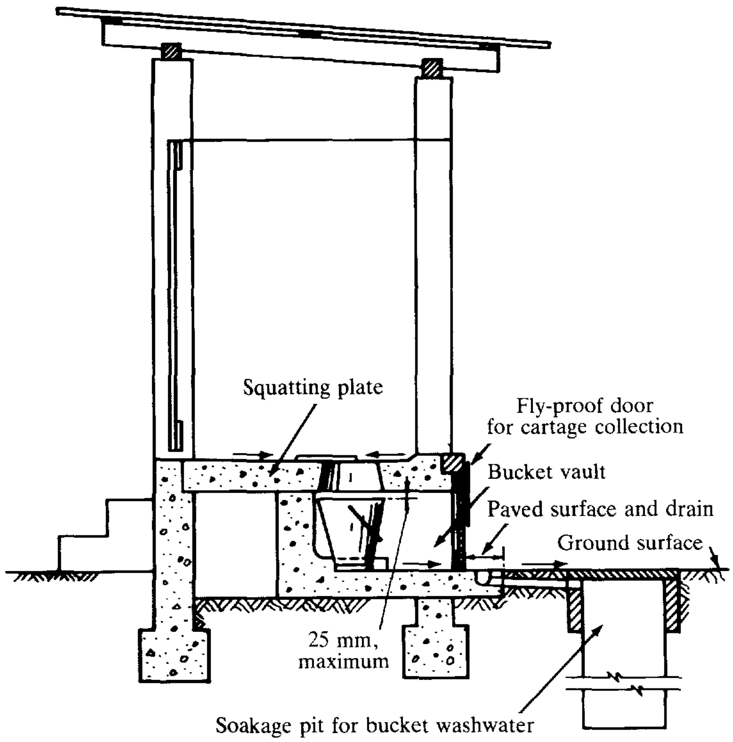
Table 5-1. *Probable pathogen content in final product of anaerobic composting toilets operating at ambient temperatures in warm climates*

Pathogen	*Retention time* (months)						
	1	2	3	4	6	8	10
Viruses							
Enteroviruses[a]	+	+	0	0	0	0	0
Bacteria							
Fecal coliforms	+	+	0	0	0	0	0
Leptospira spp.	0	0	0	0	0	0	0
Salmonella spp.	+	+	0	0	0	0	0
Shigella spp.	+	0	0	0	0	0	0
Vibrio cholerae	+	0	0	0	0	0	0
Protozoa							
Balantidium coli	+	0	0	0	0	0	0
Entamoeba histolytica	+	0	0	0	0	0	0
Giardia lamblia	+	0	0	0	0	0	0
Helminth eggs							
Ascaris lumbricoides	++	++	++	++	+	+	+
Hookworms[b]	+	+	0	0	0	0	0
Schistosoma spp.	0	0	0	0	0	0	0
Taenia spp.	++	++	++	++	+	+	+
Trichuris trichiura	++	++	+	+	+	+	0

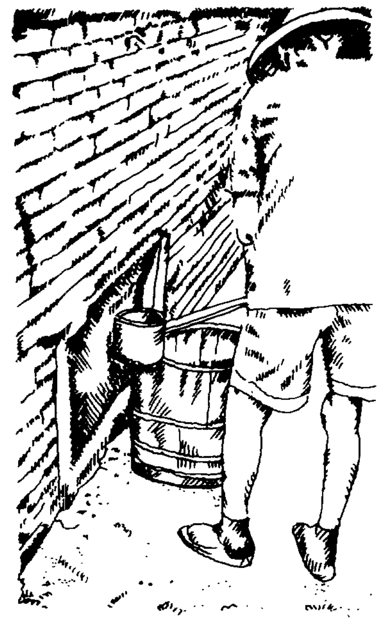
0 Complete elimination; + low concentration; ++ high concentration.

a. Includes polio-, echo-, and coxsackieviruses.

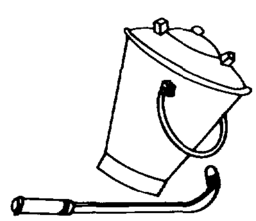
b. *Ancylostoma duodenale* and *Necator americanus*.



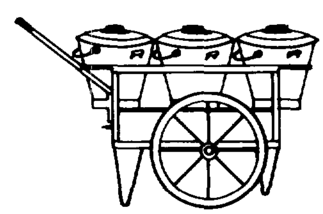
Bucket latrine



Night-soil collection by dipper and bucket (here a vault rather than a bucket is located in house)



Night-soil bucket and scraper



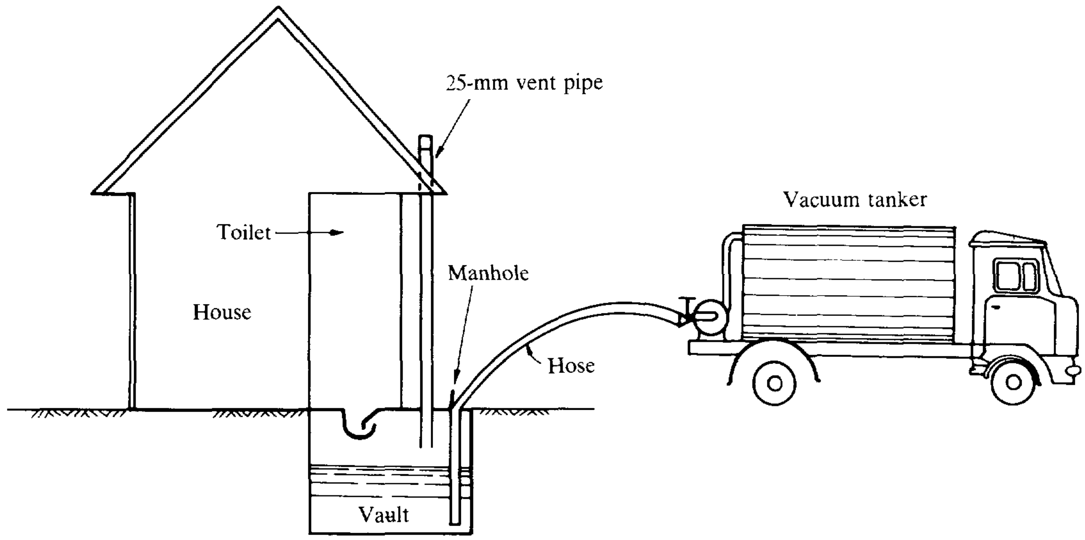
Cartage wheelbarrow for three or six buckets

Figure 5-7. *Bucket latrine and cartage.* Fly-proof doors and paved surfaces and drains are commonly missing in most existing bucket latrines. From Kalbermatten and others (1982); top left, adapted from Wagner and Lanoix (1958); top right, from a photograph courtesy of Michael G. McGarry; bottom, Department of Social Welfare, Ahmedabad, India

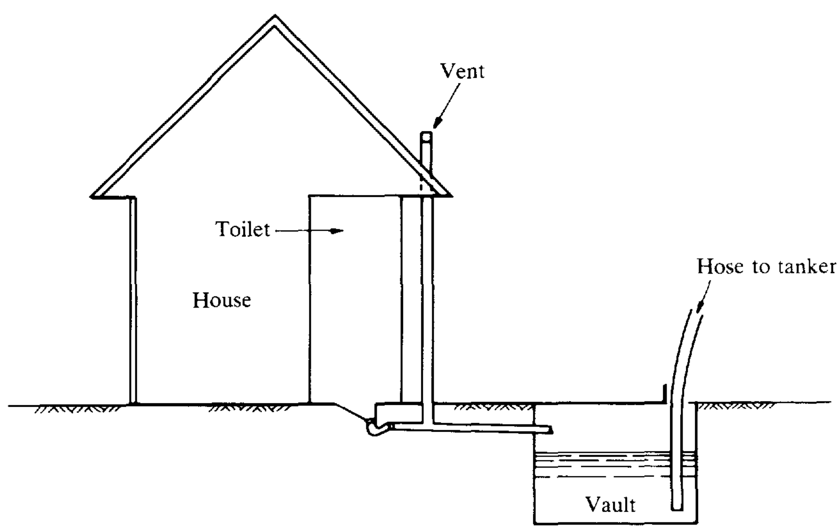
Many households in East Asia, and elsewhere, store their excreta (plus the small amounts of water used for pour flushing and anal cleansing) in sealed vaults under or beside the house (see figure 5-8) that are emptied by a vacuum truck about once every 2 weeks. This system has relatively high operating costs but may have relatively low initial costs. It is suitable for high-density urban areas where access by truck is possible and truck maintenance facilities exist. The health dimensions of a cartage system depend on the manner in which the night soil is deposited, collected, transported, treated, and reused. Each of these will be considered in turn.

Night soil deposition

The two normal methods of deposit are into the bucket or vault. Both these depositories can be satisfactory if they are hygienically maintained. The bucket, a smaller vessel than the vault, is more likely to



Vault below squatting plate



Offset vault

Figure 5-8. *Alternative designs for vault toilets.* From Kalbermatten and others (1982)

overflow and to contaminate its surroundings. The bucket latrine is also almost certain to be malodorous, and this will discourage use. In contrast, the vault can be ventilated, making a hygienic and pleasant latrine.

The possibility of fly breeding depends on the frequency with which the depositories are emptied. Houseflies and blowflies require a minimum of 1 week to develop from egg to adult, and so a bucket emptied every 5 days will not permit fly breeding, provided it is well cleaned each time it is emptied. Vaults, however, are emptied less frequently, and fly breeding is a danger. Breeding can be reduced by installing a pour-flush water seal to prevent access of adult flies or by installing a vent pipe with a fly screen similar to the one recommended above for pit latrines. A pour-flush water seal is probably the only reliable method of preventing fly breeding in vault latrines.

Night soil collection

Collection of night soil from vaults by vacuum trucks can be hygienic and risk free—provided that the outlet pipe from the vault is in good repair and that all fittings on the truck and suction hose are well maintained. A little spillage is probably inevitable, but it can be reduced to an acceptable minimum by good equipment and well-trained operating personnel.

By contrast, collection from bucket latrines is always messy. The worst method is to empty the buckets and immediately return them, which causes the latrine area to become progressively more fouled (with consequent risk of infection to the household, the sweeper, and passersby). Emptying the bucket, rinsing it out, and returning it is also undesirable and will probably result in the washwaters being deposited in the street. The best arrangement is to replace the bucket by another cleaned and disinfected one, with dirty buckets being returned to a central depot for cleaning and disinfection. Operation of this system is facilitated by use of a color code in which all buckets collected on Monday, for example, are red and the replacement buckets green. Such a bucket-replacement system is often not feasible on a large scale because of the difficulty of transporting large numbers of buckets. It can, however, work well in army camps, prisons, disaster relief camps, and other institutions of limited size.

It is clear that the risks from a cartage system depend greatly on the quality and regularity of the service provided. The system is sensitive to a few days' interruption in collections, whether from mechanical breakdown or absence of the sweeper.[4]

Night soil transport

The differences in health risks between the alternative bucket and vault-and-truck systems become obvious at the transport stage. The worst system is the one in which buckets are emptied by hand into open carts or into larger buckets, which are then carried by hand or on yokes. Under these arrangements there will always be spillage. People who come into contact with this fresh night soil risk infection from any of the nonlatent pathogens (categories I and II in table 2-2). This risk is not simply to the sweepers themselves, but also to anyone who lives on or walks, plays, or works in the streets or back lanes where the night soil has been spilled. The risk to children is obviously great because they commonly play in back lanes and alleys. The latent pathogens that develop on soil (category III—hookworms, *Ascaris*, and *Trichuris*) may well develop into their infective stages where they have been spilled in fresh night soil, and there is evidence that the cartage of night soil is partly responsible for the high levels of *Ascaris* egg contamination found in the soil of some cities. Vacuum trucks, by contrast, can transport night soil through the streets with minimal risk of spillage.

Night soil treatment

Night soil treatment is also discussed in conjunction with wet systems in the next chapter. Night soil can be digested and dewatered (as is sludge), it can be mixed with sewage and treated in conventional plants, or it can be sluiced into waste stabilization ponds (see chapter 6 for descriptions of these treatments). Night soil can also be treated by dry systems, such as trenching or, preferably, composting. Following adequate treatment, night soil can be used in agriculture, aquaculture or gas production (see chapter 7).

Where trenching is used, the health implications can be serious. A badly managed and inadequately controlled trenching ground will be a major health hazard to all who work on it or to those—children, for example—who may gain access. The families and close contacts of these people are also at risk. The proper management of a trenching ground is largely common sense: trenches should be at least 0.6 meters deep and should be filled with night soil to a depth of not more than 0.3 meters; they should then be rapidly covered with tamped earth, to make a small mound of earth over the trench, after which they are left for at least 2 years. Yet, however well managed the surface of a trenching ground is, the risk of groundwater pollution may always be present. This risk is minimized by careful location of the trenching ground following a hydrogeological survey. Given these limitations, in many situations the most appropriate and attractive method of night soil treatment is by mixing it with refuse and composting (see below).

Night soil reuse

Reuse is described in detail in chapter 7. The reuse of untreated night soil in agriculture is a widespread

4. See chapter 8, the sections "Influence of Social Structure and Organization" and "Social and Organizational Aspects of Excreta Cartage Systems."

practice, but one that is to be strongly condemned for its health hazards. There is much evidence that the use of untreated night soil on crops contributes to the transmission of infection to those working in the fields and, to a lesser (but still significant) degree, to those handling or consuming the crops. Treatment or storage of night soil should therefore always be provided prior to its reuse.

Composting

Again it must be stressed that temperature and time are the two most important factors in the achievement of low pathogen survival in waste treatment processes. In the treatment of night soil or sludge for reuse, an almost pathogen-free product is required. This is only achieved by processes incorporating long retention times (such as ponds or protracted digestion and drying; see the next chapter), heat (such as thermophilic digestion; see the next chapter), or thermophilic composting (discussed here). The attraction of thermophilic composting is that it can yield a safe product for reuse in a relatively short time (<2 months) and that it does not require an external source of energy for heat. In addition, composting technologies are available that are relatively low cost and labor intensive. The compost produced is a useful soil conditioner and source of plant nutrients that may increasingly be in demand among poor farmers as the cost of industrially produced fertilizers rises (Food and Agriculture Organization 1975).

Composting has been thoroughly reviewed by Gotaas (1956), and more recent accounts are provided by Haug (1979); Polprasert, Wangsuphachart, and Muttamara (1980); and Shuval, Gunnerson, and Julius (1981). A wide range of fecal composting technologies are available. They all incorporate the mixing of night soil or sludge with a carbon source (such as refuse or sawdust) to achieve a C:N ratio of approximately 20–30. Moisture content (20–60 percent) must also be regulated for optimal performance, with wetting or turning (for drying) at appropriate intervals.

The most important feature of composting, from the health viewpoint, is the temperature achieved—and this depends on the oxygen content of the pile, C:N ratio, moisture content, particle size, and pH. If the process is anaerobic, temperatures will remain at (or only a little above) ambient temperature, and mesophilic microorganisms will predominate. Foul-smelling gases are usually produced, and the process of degradation proceeds slowly. If the process is aerobic, substantial heat is generated by the proliferation of thermophilic microorganisms, and degradation is more rapid and usually free of odor.

A newly erected compost pile will contain entrapped oxygen and, if the other factors mentioned above are correctly regulated, thermophilic aerobic processes will be established and the temperature at the center of the pile will rapidly rise to 55°C or above. As the available oxygen is used up, however, the process will become progressively more anaerobic and temperatures will fall. There are three methods commonly used to sustain the supply of oxygen and therefore maintain thermophilic temperatures: the pile is regularly turned, or ventilation tubes are arranged in the pile, or forced aeration is provided by blowers or suckers. In the last two cases, the pile is usually lagged to prevent heat loss. Temperatures can rise to 80°C in these well-managed, thermophilic, aerated composting systems, and it is possible to ensure that all parts of the pile spend several hours at temperatures above 60°C—of the utmost importance in curtailing pathogen survival.

Pathogen survival

Pathogen survival in compost systems depends upon the time-temperature characteristics of various parts of the pile. The death curves derived for some pathogens, discussed further in Part Two, are plotted in figure 5-9. Time-temperature points above the curve for each pathogen represent certain, total destruction. It is clear that enteroviruses and *Ascaris* eggs are the most hardy, but the time-temperature combinations given in the note to figure 5-9 will ensure their destruction. If all parts of a compost pile can be brought to a time-temperature state within the "safety zone" in figure 5-9, complete pathogen destruction should be guaranteed (see figure 5-10). There are two possible exceptions. First, spore-forming bacteria—such as *Clostridium perfringens*, discussed in chapter 4—are more resistant but present little risk. Second, hepatitis A virus appears to resist rapid heating, and its ability to survive temperatures around 60°C for several hours is unknown.

Much of the literature on pathogen survival in compost, which has previously been reviewed by others (for intance, Kawata, Cramer, and Burge 1977; Krige 1964; Nell and Wiechers 1978; Reeves 1959; Shuval, Gunnerson and Julius 1981; Wiley 1962; Wiley and Westerberg 1969; WHO International Reference Centre for Wastes Disposal 1978) is reported in Part Two. This literature indicates that a well-designed system under good management produces a pathogen-free, or almost pathogen-free, compost if all sections of the pile reach the required temperature for the required

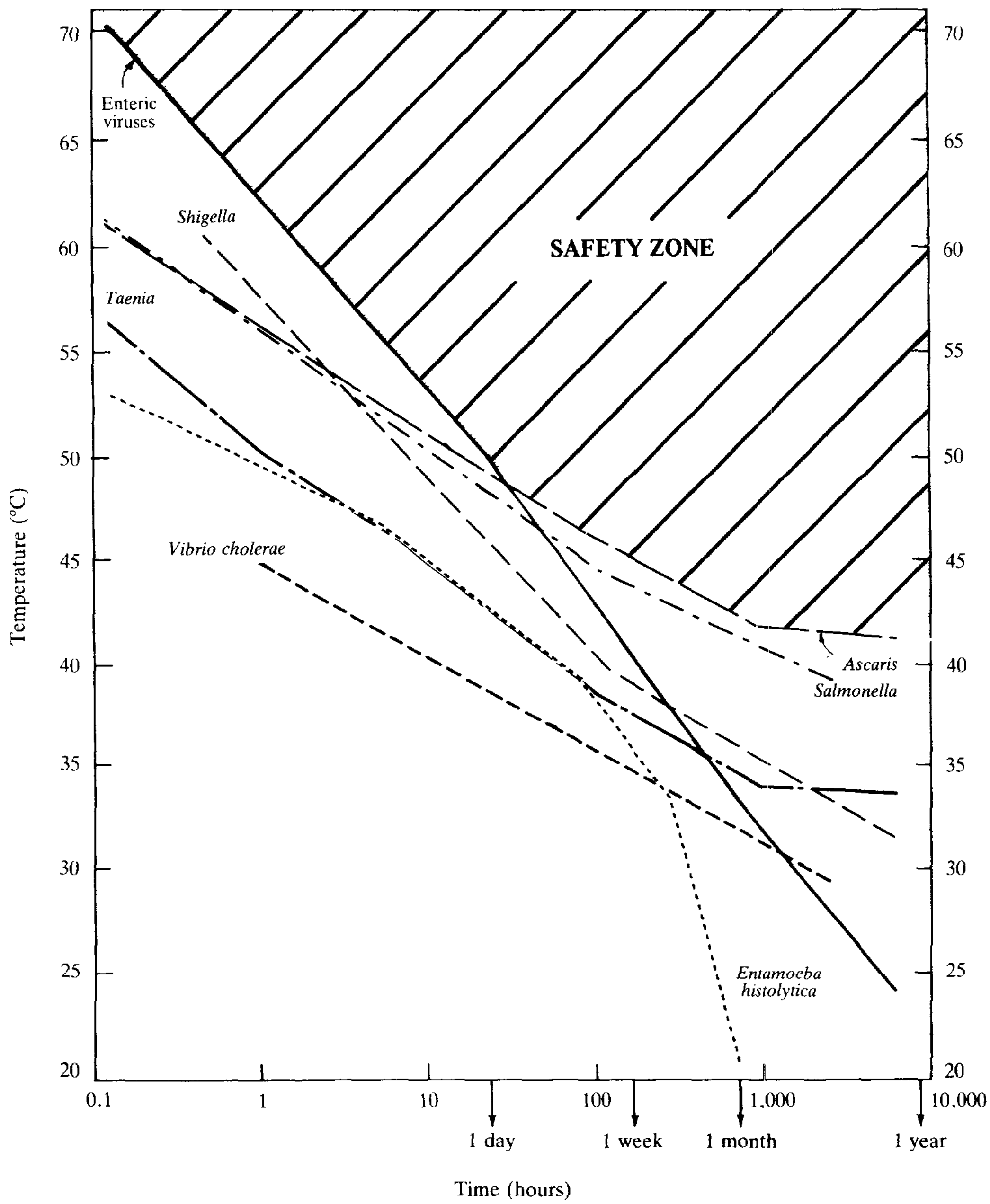


Figure 5-9. *Influence of time and temperature on selected pathogens in night soil and sludge.* The lines represent conservative upper boundaries for pathogen death—that is, estimates of the time-temperature combinations required for pathogen inactivation. A treatment process with time-temperature effects falling within the "safety zone" should be lethal to all excreted pathogens (with the possible exception of hepatitis A virus at short retention times). Indicated time temperature requirements are at least: 1 hour at ≥62°C, 1 day at ≥50°C, and 1 week at ≥46°C. For more detail on the time-temperature combinations lethal to these and other pathogens, see the graphs in chapters 9, 15–17, 20, 22, 23, 32, and 34 of Part Two (from which this composite was made)

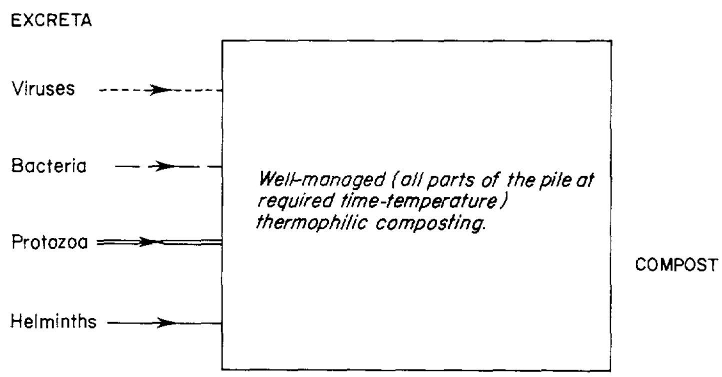


Figure 5-10. *Pathogen flow through a well-managed thermophilic composting process*

time. The organism most likely to survive this treatment is *Ascaris*, and *Ascaris* eggs may therefore be used as the indicator of successful composting.

Fly breeding

One of the major problems in managing composting operations is fly control. All raw materials used for composting attract flies and are good media for fly breeding. Flies can lay eggs in the material at the place of collection or during the handling of the material at the compost site. Different species predominate under different conditions, but good control measures should affect them all. Fly larvae cannot survive temperatures above 50°C, and so, as for other pathogens, the achievement of high temperatures in all parts of the pile is the essential requirement for control. Fly larvae may, however, migrate along temperature gradients to seek the cooler parts of the pile (such as the edges or the areas near ventilation shafts). These larvae may be destroyed by effective and well-controlled turning or by lagging unturned piles. The use of insecticides in compost piles is not desirable unless it has been demonstrated that these chemicals will not affect the composting process or the acceptability of the product to farmers.

Fly breeding may pose a general problem in all composting systems. The level of fly breeding provides some gauge of how successfully the pile is managed and whether it is being thoroughly heated, with minimum fly breeding an explicit goal for the management of all composting plants. It is possible to monitor the level of fly breeding by positioning flytraps at appropriate sites around the plant and recording the daily catch. This provides a continuous and immediate check of management and temperature control that is most useful to the staff in charge. Fly breeding will, of course, fluctuate markedly with the seasons, irrespective of the condition of the compost pile.

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Note added in proof

Since this chapter was written, there have been a number of developments in the design of ventilated improved pit latrines, especially with regard to ventilation mechanisms (wind shear across the top of the vent pipe is now known to be more important than absorption of solar radiation) and the use of twin pit VIP latrines (which are permanent structures requiring each pit to be emptied in alternate years). There have also been significant developments in superstructure design, notably the spiral shape used in Zimbabwe which obviates the need for a door, while still ensuring privacy and good fly control. In rural Zimbabwe spiral latrines have been built almost entirely out of local materials and at a financial cost to the householder of only US$10. These and other developments are described in a series of working papers and technical notes prepared by the Technology Advisory Group established by the World Bank as executing agency for the United Nations Development Programme Interregional Project INT/81/047 "Development and Implementation of Low-cost Sanitation Investment Projects", they may be obtained by writing to The Project Manager, UNDP INT/81/047, Transportation and Water Department, World Bank, 1818 H St NW, Washington DC 20433, USA.