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**Guidelines for the Safe Use of
Urine and Faeces
in Ecological Sanitation Systems**

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Contents

Introduction – use of excreta	1
Disease-causing microorganisms in excreta	2
Pathogens in urine	3
Risk of disease transmission through urine.	4
Pathogens in faeces	4
Environmental transmission routes	7
Barriers to decrease/minimize exposure	9
Regulations and guidelines in relation to the risks	11
Treatments to sanitize excreta	12
Factors that influence pathogen die-off	12
Treatment of urine	13
Storage	13
Other possible treatments	16
Treatment of faeces	17
Storage	17
Heat treatment	21
Composting	22
Alkaline treatments	23
Addition of ash and lime	23
Addition of urea	26
Incineration	26
Conclusion	27
The possible use of a treatment indicator	28
Practical recommendations in relation to agricultural use	29
Urine	29
Faeces	29
Alternative use of urine	30
Alternative use of faeces	30
Aquaculture	31
Identified needs for further investigations – Knowledge gaps	31
Identified needs to adapt guidelines to local conditions	32
Concluding recommendations	33
Ecological sanitation toilets – general	33
Urine – treatment and use	33
Faeces – treatment and use	34
Practical aspects	35
References	36

Introduction – use of excreta

Use of wastewater is presently practised in many areas of the world. There are several driving forces. Water scarcity and the continuous population growth, especially in urban areas, have forced a development towards over utilization of scarce water and crop fertilization resources. A future higher use of excreta is driven by the realization of its content of valuable plant nutrients. Human excreta may also contain pathogenic microorganisms, that directly or diluted in the wastewater constitute a threat to human health. Diarrhoeal and parasitic diseases are major contributors to the Global Burden of Disease (GBD), where environmental transmission through contaminated water, food crops or through direct contact to faecal contaminated sources are major contributors.

Direct use of excreta, human faeces and urine, results in the beneficial use of plant nutrients to agricultural land. These products usually do not contain industrial chemical contaminants that may hamper the reuse of municipal wastewater, but should be treated to reduce the levels of human pathogens to a safe level. Human metabolites such as hormones may occur, but the reuse on agricultural lands will lessen their negative impact on water sources. From a hygienic perspective, both use of wastewater and of excreta may reduce the risks of pathogen exposure, if treatment and other barriers against exposure are accounted for. In contrast, the risks may be enhanced, due to improper practices in the handling chain of excreta, and due to both improper treatment and use of wastewater, as well as diffuse exposure.

A framework for microbial exposure control and management in relation to the use of wastewater and excreta was developed and published by WHO in the 1980s (WHO, 1989). These guidelines are currently under revision, and new guidelines are anticipated during 2005, separately accounting for the use of wastewater and excreta. Within this current EcoSanRes report, the focus is on treatment and handling of faeces and urine, accounting for current information of risk management and circumscribing to a source-separation strategy.

In many parts of the world it is a tradition to keep the urine and faeces apart. The old Japanese practice of nightsoil recovery from urban areas separated urine and faeces, with the urine regarded as a valuable fertilizer (Matsui, 1997). In Sweden, urine was historically often collected separately. Mainly due to practical reasons, it was poured into the drain to avoid smells and to prevent the latrine from filling too quickly (Sondén, 1889). There are some benefits of keeping the fractions separated that are still valid and can be refined in today's ecological sanitation systems. These include:

- **Less volume** – the collection system will fill up much slower if the urine is diverted and the volume of faecal material will be kept small. Further reduction of the volume and weight of faeces through dehydration/decomposition is possible.
- **Less smell** – the smell will be less when keeping the urine and faeces apart and will result in both more convenient and acceptable use of the toilet and handling of the excreta.
- **Prevention of dispersal of pathogen-containing material** – a drier faecal fraction will cause less risk for leaching and transport of pathogens through fluids to the groundwater and to the surrounding environment.
- **Safer and easier handling and use of excreta** – the faeces will be drier, which may be beneficial for pathogen reduction. In addition, drying will facilitate further reduction of pathogens by various other treatment means and will also make it easier to handle and to use the separated urine and faecal fractions.

These practical and hygienic benefits of keeping urine and faeces apart have led to the conclusion that we should aim for urine diversion in all dry sanitation systems. It may also be beneficial to supplement waterborne sanitation systems with urine diversion to allow the use of urine as a fertilizer and to decrease the environmental effects from nutrients in toilet waste, i.e. eutrophication. Source-separating (diverting) systems have therefore been identified as part of sustainable development and substantial research is currently carried out in several countries, of which Sweden has been one of the first.

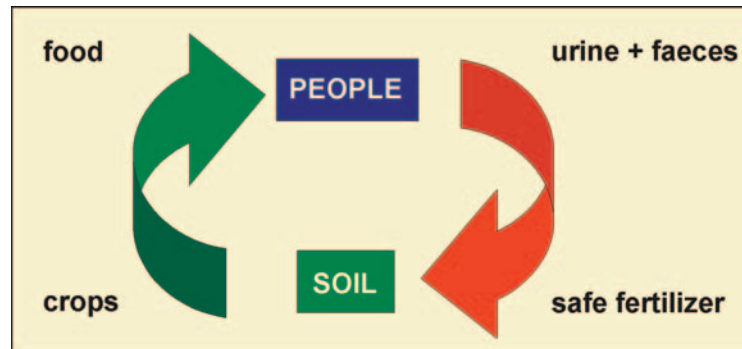


Figure 1. The concept of ecological sanitation – by obtaining safe fertilizer products from urine and excreta, it is possible to close the nutrient loop.

A main aspect is that the use of excreta should not result in enhanced disease transmission and an increased number of infections in human populations. The current EcoSanRes Guidelines for the handling and use of collected urine and faeces therefore aims to minimize the risk for transmission of infectious diseases that potentially can occur through urine and/or faeces.

Disease-causing microorganisms in excreta

Occurrence of disease-causing organisms in human excreta is the result of infection in individuals. Such infections do not necessarily manifest with clinical symptoms, but will lead to an excretion of the pathogens in question. For organisms infecting the gastrointestinal track, this excretion is mainly through faeces.

The prevalence of infections mirrors the hygienic situation in a society. Infections are always an exception and not a general situation for an individual. Infections of individuals may, in rare cases, be chronic, for bacterial and viral diseases. The individuals are then called “carriers”. Parasitic worms (helminths) may establish themselves for long periods in the human body and have a high prevalence rate in societies with unsanitary conditions.

An individual will normally excrete large amounts of microorganisms in faecal material. The numbers are in the range of 10^{11} - 10^{13} /g. These saprophytic organisms are normally of no health concern. Urine is normally sterile in the urine bladder, but “pick up” organisms that occur in the lower parts of the urinary tract. Thus, a content of 10^3 organisms/ml of urine is not indicative of an infection. These saprophytic organisms are also generally harmless.

If a disease-causing organism infects a person, the clinical manifestations are governed by factors related to the organism in question and by factors related to the infected individual. Most of the disease-causing organisms of concern are excreted, in variable numbers, in faeces, but a few also through the urine. The likelihood of them resulting in new infections in other

susceptible individuals is a function of contact and exposure. This in turn is governed by factors such as the excreted amounts and the infective dose (number of organisms that need to be taken in orally to cause an infection), which varies between different organisms and even between strains. A few types of organisms may also infect through the skin. The likelihood of contact and exposure is further governed by the ability of different species and strains to withstand adverse environmental conditions outside the human body and persist in a stage where they can infect a new individual upon exposure.

These factors are further dealt with in this text, starting with a summary of the disease-causing organisms that may occur in urine and faeces. Since the prevalence of this occurrence will vary due to the prevailing sanitary conditions in different regions of the world, they are presented here in general terms. This is also justified by the fact that the prevalence and subsequent risks may vary within wide ranges, between the normal background situation, the endemic situation for an organism, and the high-risk situation during epidemics.

PATHOGENS IN URINE

Several types of bacteria may cause urinary tract infections. The environmental transmission of these are normally of low importance. *E. coli* is the most common cause of urinary tract infections, where certain clones may also be associated with gastrointestinal infections.

The pathogens traditionally known to be excreted in urine are *Leptospira interrogans*, *Salmonella typhi*, *Salmonella paratyphi* and *Schistosoma haematobium* (Feachem *et al.*, 1983). There is a range of other pathogens that have been detected in urine but their presence may not be considered significant for the risk of environmental transmission of disease (Table 1).

Leptospirosis is a bacterial infection causing influenza-like symptoms with 5-10% mortality. It is generally transmitted by urine from infected animals (Feachem *et al.*, 1983; CDC, 2003a) and is considered an occupational hazard for sewage workers and farm workers in developing (tropical) countries. Human urine is not considered to be an important source for transmission due to low prevalence (Feachem *et al.*, 1983; CDC, 2003a).

S. typhi and *S. paratyphi* are only excreted in urine during the phase of typhoid and paratyphoid fevers when the bacteria are disseminated in the blood stream. These organisms are now rare in developed countries. Even though the infection is endemic in several developing countries with an estimated 12.5 million cases per year, urine-oral transmission is probably unusual compared to faecal-oral transmission (Feachem *et al.*, 1983; CDC, 2003b). For diverted urine, the risk for further transmission of *Salmonella* will be low, even with short storage times, due to the rapid inactivation of Gram-negative faecal bacteria (Table 5; Höglund, 2001). Die-off rates of *Salmonella spp* are similar to the ones for *E. coli* in collected urine.

Schistosomiasis, or bilharziasis, is one of the major human parasitic infections mainly occurring in Africa. One of the types of *Schistosoma* is mainly excreted by the urine, while the other types are excreted with faeces. When infected with urinary schistosomiasis, caused by *Schistosoma haematobium*, the eggs are excreted in urine, sometimes during the whole life of the host. The eggs hatch in the aquatic environment and the larvae infect specific aquatic snail species, living in freshwater. If the eggs do not reach the snail host within days, the infectious cycle is broken. After a series of developmental stages, aquatic larvae emerge from the snail, ready to infect humans through penetration of the skin. If the urine is stored for days and is used on arable land, the use diminishes the risk of transmission of schistosomiasis. If

fresh urine is used, this should not be done close to surface water sources in endemic areas. *S. haematobium* is found in 53 countries in the Middle East and Africa, including the islands of Madagascar and Mauritius. There is also an ill-defined focus of *S. haematobium* in India (WHO, 2003).

Table 1. Pathogens that may be excreted in urine and the importance of urine as a transmission route

Pathogen	Urine as a transmission route	Importance
<i>Leptospira interrogans</i>	Usually through animal urine	Probably low
<i>Salmonella typhi</i> and <i>Salmonella paratyphi</i>	Probably unusual, excreted in urine in systemic infection	Low compared to other transmission routes
<i>Schistosoma haematobium</i> (eggs excreted)	Not directly but indirectly, larvae infect humans via freshwater	Need to be considered in endemic areas where freshwater is available
Mycobacteria	Unusual, usually airborne	Low
Viruses: CMV, JCV, BKV, adeno, hepatitis and others	Not normally recognized other than single cases of hepatitis A and suggested for hepatitis B. More information needed	Probably low
Microsporidia	Suggested, but not recognized	Low
Venereal disease causing	No, do not survive for significant periods outside the body	-
Urinary tract infections	No, no direct environmental transmission	Low

The main risks in the use of excreta are related to the faecal fraction and not the urine fraction. Therefore, it is of major importance to avoid or diminish faecal cross-contamination to the urine fraction. Even though some pathogens may be excreted in urine, the faecal cross-contamination that may occur by misplacement of faeces in the urine-diverting toilet (Schönning *et al.*, 2002), is related to the most significant health risk (Höglund *et al.*, 2002).

Risk of disease transmission through urine.

The main risks of disease transmission from handling and using human urine are related to faecal cross-contamination of urine and not from the urine itself.

PATHOGENS IN FAECES

Enteric infections can be transmitted by pathogenic species of bacteria, viruses, parasitic protozoa and helminths. From a risk perspective, the exposure to untreated faeces is always considered unsafe, due to the potential presence of pathogens. There are many different types of organisms causing enteric, parasitic or other types of infections which may occur, and their prevalence in a given society is often unknown.

In surveillance systems, bacteria have traditionally been considered the leading group of organisms causing gastrointestinal illness. This is partly the case in developing countries, where outbreaks of cholera, typhoid and shigellosis are of major concern and seem to become more frequent in urban and peri-urban areas (S. Brian, WHO, *pers. comm.*, 2003). Enteric



Figure 2. Faecal cross-contamination to the urine constitutes the major health risk in the subsequent handling of this fraction. It is necessary for the toilets to be adapted to the user and the system. A toilet pedestal may be more risky if squatting is generally practised. The seat should further be adapted for the user. In schools, a large front collection for urine will result in problems with displacement.

viruses are also of general importance and are now further considered to cause the majority of gastrointestinal infections in industrialized regions (Svensson, 2000).

More than 120 different types of viruses may be excreted in faeces, with the most common from the enteroviruses, rotavirus, enteric adenoviruses and human caliciviruses (noroviruses) groups (Tauxe & Cohen, 1995). Hepatitis A is also recognized as a pathogenic virus of major concern when applying wastes to land and is considered a risk for water- and food-borne outbreaks, especially where the sanitary standards are low. The importance of Hepatitis E is emerging.

Among bacteria, at least *Salmonella*, *Campylobacter* and enterohaemorrhagic *E. coli* (EHEC) are generally of importance, in both industrialized and developing countries, when evaluating microbial risks from various fertilizer products including faeces, sewage sludge and animal manure. They are also important as zoonotic agents (transmission between humans and animals, as well as their faeces/manure). In areas with insufficient sanitation, typhoid fever (*Salmonella typhi*) and cholera (*Vibrio cholera*) constitute major risks in relation to improper sanitation and contamination of water. *Shigella* is also a common cause of diarrhoea in developing countries, especially in settings where hygiene and sanitation is poor.

The parasitic protozoa, *Cryptosporidium parvum* and *Giardia lamblia/intestinalis* have been studied intensively during the last decade, partly due to their high environmental resistance and low infectious doses, and for *Cryptosporidium* its association with several large waterborne outbreaks and for *Giardia* its high prevalence as enteric pathogen. *Entamoeba histolytica* is also recognized as an infection of concern in developing countries. The general importance of others such as *Cyclospora* and *Isospora* is currently debated.

In developing countries, helminth infections are of greater concern. The eggs (ova) of especially *Ascaris* and *Taenia* are very persistent in the environment, and therefore regarded

as an indicator of hygienic quality (WHO, 1989). Hookworm disease is widespread in moist tropics and subtropics, and affects nearly one billion people worldwide. In developing nations, these infections exaggerate malnutrition and indirectly cause the death of many children by increasing their susceptibility to other infections that could normally be tolerated. The uninfected eggs from *Ascaris* and hookworms that are excreted in the faeces require a latency period and favourable conditions in soil or deposited faeces to hatch into larvae and become infectious (CDC, 2003).

Schistosoma haematobium has earlier been mentioned in relation to excretion with urine. Other types of *Schistosoma*, e.g. *S. japonicum* and *S. mansoni* are excreted in faeces. *S. japonicum* is mainly prevalent in the Far East and *S. mansoni* in Africa and in parts of South and Central America, mainly Brazil (WHO, 2003). More than 200 million people are currently infected with schistosomiasis. The use of faeces, as for urine, should not have an impact unless fresh and untreated faecal material is applied close to freshwater sources where the snail is present.

The pathogens of concern for environmental transmission through faeces mainly cause gastrointestinal symptoms such as diarrhoea, vomiting and stomach cramps. Several may also cause symptoms involving other organs and severe sequelae. Table 2 provides a list of a range of the pathogens of concern and their symptoms.

Table 2. Example of pathogens that may be excreted in faeces (can be transmitted through water and improper sanitation) and related diseases, including examples of symptoms they may cause (adapted from e.g. CDC, 2003c; Ottosson, 2003; SMI, 2003)

Group	Pathogen	Disease - Symptoms
Bacteria		
	<i>Aeromonas</i> spp.	Enteritis
	<i>Campylobacter jejuni/coli</i>	Campylobacteriosis - diarrhoea, cramping, abdominal pain, fever, nausea; arthritis; Guillain-Barré syndrome
	<i>Escherichia coli</i> (EIEC, EPEC, ETEC, EHEC)	Enteritis
	<i>Pleisiomonas shigelloides</i>	Enteritis
	<i>Pseudomonas aeruginosa</i>	Various; bacteraemia, skin infections, ear infections, meningitis, pneumonia
	<i>Salmonella typhi/paratyphi</i>	Typhoid/paratyphoid fever - headache, fever, malaise, anorexia, bradycardia, splenomegaly, cough
	<i>Salmonella</i> spp.	Salmonellosis - diarrhoea, fever, abdominal cramps
	<i>Shigella</i> spp.	Shigellosis - dysentery (bloody diarrhoea), vomiting, cramps, fever; Reiter's syndrome
	<i>Vibrio cholerae</i>	Cholera - watery diarrhoea, lethal if severe and untreated
	<i>Yersinia</i> spp.	Yersinioses - fever, abdominal pain, diarrhoea, joint pains, rash
Virus		
	Adenovirus	Various; respiratory illness. Here added due to the enteric types (see below)
	Enteric adenovirus 40 and 41	Enteritis
	Astrovirus	Enteritis
	Calicivirus (incl. Noroviruses)	Enteritis

Coxsackievirus	Various; respiratory illness; enteritis; viral meningitis
Echovirus	Aseptic meningitis; encephalitis; often asymptomatic
Enterovirus types 68-71	Meningitis; encephalitis; paralysis
Hepatitis A	Hepatitis - fever, malaise, anorexia, nausea, abdominal discomfort, jaundice
Hepatitis E	Hepatitis
Poliovirus	Poliomyelitis - often asymptomatic, fever, nausea, vomiting, headache, paralysis
Rotavirus	Enteritis
Parasitic protozoa	
<i>Cryptosporidium parvum</i>	Cryptosporidiosis - watery diarrhoea, abdominal cramps and pain
<i>Cyclospora cayetanensis</i>	Often asymptomatic; diarrhoea; abdominal pain
<i>Entamoeba histolytica</i>	Amoebiasis - Often asymptomatic, dysentery, abdominal discomfort, fever, chills
<i>Giardia intestinalis</i>	Giardiasis - diarrhoea, abdominal cramps, malaise, weight loss
Helminths	
<i>Ascaris lumbricoides</i>	Generally no or few symptoms; wheezing; coughing; fever; enteritis; pulmonary eosinophilia
<i>Taenia solium/saginata</i>	
<i>Trichuris trichiura</i>	Unapparent through vague digestive tract distress to emaciation with dry skin and diarrhoea
Hookworm	Itch; rash; cough; anaemia; protein deficiency
<i>Shistosomiasis</i> spp.	

Environmental transmission routes

The pathogens of concern in sanitation systems are generally transmitted through the faecal-oral route, i.e. pathogens are excreted in faeces and infect another person by ingestion. The pathogens may be transmitted via hands, through food or water and other fluids (Figure 3).

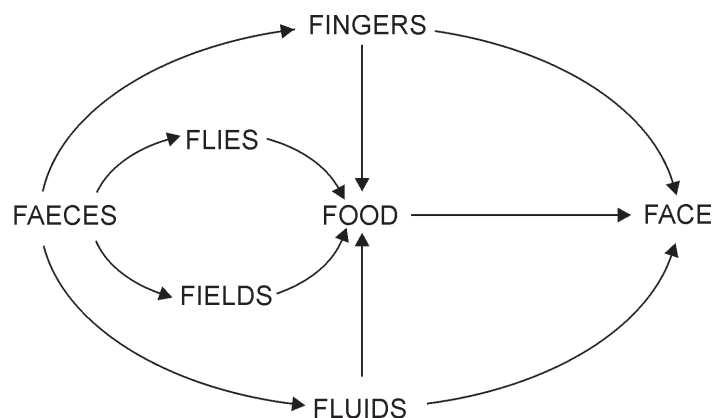


Figure 3. The transmission routes for enteric pathogens summarised in the "F-diagram", adapted from Esrey et al. (1998).

Several helminths, as well as the *Leptospira* bacteria may also infect through the skin.

For waterborne sanitation systems, sewage is an important potential transmission route when the more or less treated wastewater is discharged into a water recipient or used on agricultural land. Dry toilets are less likely to affect surface- or groundwater. This may still be the case if improperly constructed or localized. For dug latrines, like pit latrines, problems with transport of pathogens from the excreta to groundwater have been recognized in areas with high groundwater tables, or due to soil conditions favouring microbial transport. Elevating the toilet and collecting the excreta above ground as suggested in most ecological sanitation systems can generally avoid this. Shallow pits are an intermediate alternative and limit groundwater contamination. The construction needs to account for overflow during heavy rains that may result in run-off to nearby surface waters. Latrines should never be emptied in surface drainage gutters. From a hygienic point of view, a sealed toilet collection chamber above ground is preferred.



Figure 4. Material from ordinary pit latrines or dry latrines should never be excavated and drained away in drain gutters. Human exposure to faecal contamination in storm-water drains is a major risk for transmission of enteric and parasitic diseases.

In Table 3 possible routes of human exposures and transmission related to dry toilets are listed along with some counter-measures to avoid exposures. Subsequent exposures from contaminated surface- or groundwater are not accounted for here. Instead, the measures listed aim to prevent or minimize the faecal contamination of watercourses and the environment. It is important to eliminate pathogens as early as possible in the handling chain since risks are then minimized in subsequent steps.

Direct contact refers to intended or unintended contact with the excreta, e.g. touching the material and subsequent accidental ingestion from contaminated fingers or utensils. This may occur before treatment, during treatment including handling, or when the material is used/applied to soil. Contamination of foodstuffs may occur directly from use but also through unhygienic practises in the kitchen. Even if the fertilized crop will be cooked before consumption, surfaces may be contaminated and pathogens transferred to other foods or fluids.

Table 3. Potential transmission routes related to dry toilets and the use of excreta with simple technical and behavioural measures to limit exposure and minimize risks.

Area or procedure leading to pathogen exposure	Transmission route	Technical measure	Behavioural measure
Toilet	Direct contact; transport to groundwater; environmental contamination	Water for hand washing available; elevated collection chamber; lined collection chamber (no seepage to groundwater or environment)	Washing hands; keeping toilet area clean
Primary handling – collection and transport	Direct contact	Ash, lime or other means of reducing microorganisms at toilet; informed persons collecting and transporting excreta	Wearing gloves; washing hands; addition of ash, lime or other means of reducing the microbial content during use
Treatment	Direct contact; environmental contamination	Suitable choice of location; treatment in closed systems; information signs in place	Wearing gloves and protective clothing; washing hands; avoid contact in treatment areas
Secondary handling – use, fertilizing	Direct contact	Informed farmers reusing excreta; special equipment available	Wearing gloves; washing hands; washing the equipment used
Fertilized field	Direct contact; transport to surface and groundwater	Working excreta into the ground; information and signs	Avoid newly fertilized fields
Fertilized crop	Consumption; contamination of kitchen	Choice of suitable crop	Proper preparation and cooking of food products; cleanliness of kitchen surfaces and utensils

BARRIERS TO DECREASE/MINIMIZE EXPOSURE

The measures in Table 3 all function as technical or behavioural barriers against disease transmission. A systematic survey of a local system can identify potential risk factors and suggest counteractions to avoid pathogen exposure. This can be by means of reducing contact with the material or through introducing ways to decrease the number (concentration) of pathogens in the material that will be handled. Reducing contact includes factors like closed systems, wearing personal protection, using proper handling tools and reducing later contact in the field by working the excreta into the soil. General handling precautions are often defined as additional measures and not as proper barriers.

Different treatment steps of excreta are the obvious barriers to reduce the number of pathogens, rendering “the product” safer to handle and use as fertilizer. In the current WHO guidelines, treatment is however not considered necessary when a set of other barriers are fulfilled, including e.g. adequate protection of farm and sanitation workers, covering the waste with 25 cm of soil and not planting root crops (WHO, 1989). These former guidelines are currently under revision and a set of three new volumes, dealing with use of wastewater and excreta in aquaculture; use of wastewater in agriculture; and use of excreta and greywater, is planned to be issued during 2005.



Figure 5. Open defecation is a major route of contamination of enteric and parasitic diseases. Other individuals and the home environment may be affected through direct contact and also by walking barefoot. In addition, surface water sources may be heavily impacted.

Treatment could be primary, i.e. directly in the toilet in relation to defecation, e.g. by the addition of ash (further described below), or secondary where the material is collected from the toilet (or left in the toilet with no further addition of faeces) and treated in a controlled way to reduce pathogens to acceptable limits. Esrey *et al.* (1998) stated that a combination of safe storage and fast destruction of the pathogens in excreta are needed in order to prevent contamination of the environment. Barriers are exemplified in the alternate “F-diagram” (Figure 6).

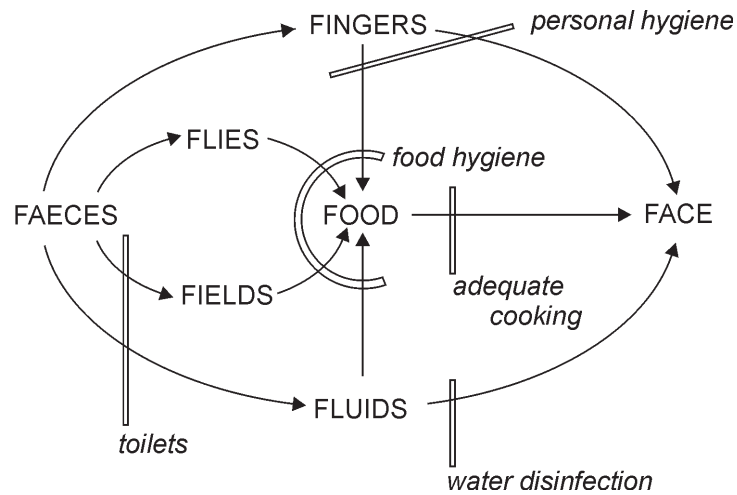


Figure 6. Barriers required to prevent the transmission of disease/spread of pathogens, adapted from Esrey *et al.* (1998).

Inactivation of pathogens will also occur on agricultural land after application of the excreta as fertilizer and on crops that may have become contaminated if fertilized during growth or from splashes from the soil during heavy rains. This inactivation with time and due to prevailing environmental conditions can provide a barrier against exposure from handling and consumption of crops and for humans and animals possibly entering the fertilized field. The inactivation is dependent on ambient temperature, moisture and sunshine (that will increase

the temperature, decrease the moisture and affect pathogens by UV-light) (see Table 4). In the soil, the naturally occurring microorganisms will also compete with the introduced pathogens and enhance their die-off. The additional reduction with time, constituting a “barrier function in agriculture” is of additional importance, especially for crops that are to be consumed raw. For safe handling of other crops and to reduce cross-contamination during food preparation, the withholding period (time between fertilization and harvest) is of importance.

In the literature, excreta-related diseases have been divided into groups depending on their features regarding transmission, survival etc. (WHO, 1989; Feachem, *et al.*, 1983). Along with this information, major control measures are given. Notable is that these general measures often include a combination of improved housing, health education, supply of water, provision of toilets and treatment of excreta before use or discharge. Independent of the type of toilets provided, interventions including the whole water and sanitation system are therefore important to improve the health situation.

Regulations and guidelines in relation to the risks

Human faeces may contain pathogens and, in developing countries, the prevalence of individuals with enteric and parasitic diseases are often high resulting in a higher likelihood and higher concentrations of pathogens in faecal material. Several of the pathogens have the potential to survive in excreta for a long time period and may thus end up in agricultural land and on crops if use of faecal material is practised without proper treatment. Even if a series of subsequent events need to happen before an infection occurs in a new host, the risk for further transmission in the environment and an increased prevalence of disease is evident if using unsanitized faeces. Different subsequent treatment steps of the human excreta are considered the most important precautions against the transmission.

Regulations and guidelines are increasingly frequently based on the risk concept. By applying quantitative microbial risk assessments, partly based on assumptions, sanitation systems can be evaluated and compared to establish limits for acceptable risks. The treatment can also be adapted to reach the set and acceptable limits. Risk assessments can thus be made largely site specific, depending on information regarding, for example, the local health status of the population, and behavioural patterns. Increase in the prevalence of infections enables the setting of acceptable local risk limits, applicable to sanitation systems where the use of the excreta products is practised. In developing countries with rather low sanitary standards, the goal will be to reduce the number of infections by implementing sanitation *per se* including introducing new alternatives, combined with other interventions related to provision of safe water supply, safe treatment and storage and hygiene/health education.

In relation to the present guidelines and recommendations for ecological sanitation, the focus is on treatment, but also includes other technical, practical and behavioural aspects, intended to minimize the risk of disease transmission. Rules of thumb considered to obtain acceptable low risks are also given, however, these do not define numeric limits.

Treatment as a barrier

A combination of barriers to decrease exposure of humans to excreta should be applied in order to reduce risks for disease transmission in ecological sanitation systems. Treatment of the excreta is considered as a necessary step for the subsequent use as fertilizer on (agricultural) land.

Treatments to sanitize excreta

FACTORS THAT INFLUENCE PATHOGEN DIE-OFF

After excretion, the concentration of enteric pathogens usually declines with time by death or loss of infectivity of a proportion of the organisms. Protozoa and viruses are unable to grow in the environment outside the host, thus their numbers will always decrease, whereas bacteria may multiply under favourable environmental conditions. Helminths may need a latency period after excretion before being infective. The ability of a microorganism to survive in the environment is defined as its persistence to withstand the prevailing conditions. Often in investigations it is expressed as the total inactivation with time of the microorganism in question under specified environmental conditions. However, for the health risk predictions of the impact of different transmission routes from human excreta, the inactivation curves or T_{90} -values (time for a 90% inactivation of organisms) are needed.



Figure 7. The environment in human settings may be heavily affected by contaminated surface water that constitutes a major risk for disease transmission and insect vector breeding. Introduction of dry collection of faecal material and separate collection of urine may substantially reduce the risks. In addition, greywater handling should be promoted.

Time and prevailing conditions are the overall features affecting survival of microorganisms in the environment. Several physicochemical and biological factors have an impact, but this impact differs between microorganisms. For overall risk estimates, the selection of the most resistant organisms is a conservative approach also accounting for other, more sensitive species. The environmental- and organism-related factors all interact, yielding varying survival

characteristics at any particular location. Factors that are especially important for the reduction of enteric microorganisms are listed in Table 4. These factors can also be used separately or in combination with time as treatment methods to produce safe fertilizers from excreta.

Table 4. Physicochemical and biological factors that affect the survival of microorganisms in the environment

Temperature	Most microorganisms survive well at low temperatures (<5°C) and rapidly die off at high temperatures (>40-50°C). This is the case in water, soil, sewage and on crops. To ensure inactivation in e.g. composting processes, temperatures around 55-65°C are needed to kill all types of pathogens (except bacterial spores) within hours (Haug, 1993).
pH	Many microorganisms are adapted to a neutral pH (7). Highly acidic or alkaline conditions will have an inactivating effect. Addition of lime to excreta in dry latrines and to sewage sludge can increase pH and will inactivate microorganisms. The speed of inactivation depends on the pH value, e.g. it is much more rapid at pH 12 than at pH 9.
Ammonia	In natural environments, ammonia (NH ₃) chemically hydrolysed or produced by bacteria can be deleterious to other organisms. Added ammonia-generating chemical will also facilitate the inactivation of pathogens in e.g. excreta or sewage sludge (Ghigletti <i>et al.</i> , 1997; Vinnerås <i>et al.</i> , 2003a).
Moisture	Moisture is related to the organism survival in soil and in faeces. A moist soil favours the survival of microorganisms and a drying process will decrease the number of pathogens, e.g. in latrines.
Solar radiation/ UV-light	UV-irradiation will reduce the number of pathogens. It is used as a process for the treatment of both drinking water and wastewater. In the field, the survival time will be shorter on the soil and crop surface where sunlight can affect the organisms.
Presence of other microorganisms	The survival of microorganisms is generally longer in material that has been sterilized than in an environmental sample containing other organisms. Organisms may affect each other by predation, release of antagonistic substances or competition (see Nutrients below).
Nutrients	If nutrients are available and other conditions are favourable, bacteria may grow in the environment. Enteric bacteria adapted to the gastrointestinal tract are not always capable of competing with indigenous organisms for the scarce nutrients, limiting their ability to reproduce and survive in the environment.
Other factors	Microbial activity is dependent on oxygen availability. In soil, the particle size and permeability will impact the microbial survival. In soil as well as in sewage and water environments, various organic and inorganic chemical compounds may affect the survival of microorganisms.

TREATMENT OF URINE

Storage

The fate of the enteric pathogens entering the urine collection container is of importance for assessing the hygiene risks related to the handling and use of the urine. The survival of various microorganisms in urine through time is affected by the storage conditions.

Studies have been performed with different microorganisms added to the urine and their inactivation followed over time (Höglund, 2001). For the urine, mainly temperature and an elevated pH (~9) in combination with ammonia have been concluded to affect the inactivation of microorganisms. Bacteria like *Salmonella* and *E. coli* (as well as and representing other Gram-negative bacteria) were inactivated rapidly. Gram-positive bacteria had similar inactivation rates as *Cryptosporidium parvum* and have a slower die-off than Gram-negative bacteria (Höglund, 2001) (Table 5).

Viruses were hardly reduced at all at low temperatures (4-5°C) (Table 5). This is supported by studies of Franzén and Scott (1999) recording an insignificant reduction of *Salmonella typhimurium* bacteriophage 28B (used as a conservative virus model) during a 6-week study in Mexico at temperatures between 14°C and 22°C and a pH around 9.5. Coliphages, normally present in faecal material, were never found in sampled urine tanks (Olsson, 1995) indicating a higher inactivation rate than for the *Salmonella* phage. Its high resistance is also shown in comparison with rotavirus (Table 5) confirming its conservative nature as a model for the inactivation.

According to Hamdy *et al.*, (1970; in Feachem *et al.*, 1983) urine is ovicidal and *Ascaris* eggs are killed within hours. Olsson (1995) however found the reduction of *Ascaris suum* in urine to be minor; at 4°C and 20°C the reduction was 15-20% during a 21-day period. Early studies have reported inactivation of *Schistosoma haematobium* in urine (Porter, 1938; in Feachem *et al.*, 1983).

Table 5. Inactivation of microorganisms in urine, given as T₉₀-values (time for 90% reduction) in days (Höglund, 2001)

	Gram-negative bacteria	Gram-positive bacteria	<i>C. parvum</i>	Rotavirus	<i>S. typhimurium</i> phage 28B
4°C	1	30	29	172 ^a	1466 ^a
20°C	1	5	5	35	71

^a Survival experiments performed at 5°C.

Based on these studies of pathogen/indicator inactivation in urine, guidelines for the urine storage time and temperature have been proposed (Table 6; Jönsson *et al.*, 2000; Höglund, 2001). The temperatures were mainly chosen based on temperate climate conditions. The guidelines have been endorsed by the Swedish Environmental Protection Agency (EPA) but are not yet implemented as national regulations. They will be accounted for in the revised new WHO Guidelines for use of excreta.

For single households, the urine mixture can be used without storage for all type of crops, provided that the crop is intended for the household’s own consumption and that one month passes between fertilizing and harvesting, i.e. time between last urine application and consumption. One reason for less stringent guidelines for single households is that person-to-person transmission will exceed the risk from urine-related environmental transmission.



Figures 8 and 9. Collection and storage of urine may occur on different scales. When the collection involves large collection tanks, or storage tanks at the fields (like in these figures) higher security level and more stringent guidelines are needed in relation to storage of material emanating from different people.

Direct use or short storage periods are also applicable for small domestic systems in developing countries. In addition, higher ambient temperatures in many developing countries will also increase inactivation rates and safety. In situations where the prevalence of some enteric infections is high, and the technical systems do not safeguard for faecal cross-contamination, an increased time of storage is recommended.

The general recommendation of storage is mainly aimed at reducing the risks from consuming urine-fertilized crops. It will also reduce the risk for the persons handling and applying the urine.

Due to the complexity of the system, the guidelines given in Table 6 can be adopted for larger (urban) systems in developing countries and regions. The withholding time of one month between fertilization and harvest should however be adhered to. Environmental factors will result in the inactivation of pathogens in the soil and on crops after application. For personal protection related to the handling see Practical Recommendations, p 29. Storage will always increase protection of humans exposed in the field.



Figure 10. In small-scale family-based systems, the urine may be used directly or after short periods of storage if the crops are intended for family use. The likelihood of transmission is larger between family members than through urine-fertilized crops.

Specific recommendations for large-scale systems may need to be adapted, based on local conditions, accounting for behavioural factors and chosen technical system. If a system is clearly mismanaged, i.e. faeces can be seen in the urine bowl or other routes of cross-contamination are envisaged, special precautions are needed. The faecal contamination generally accounted for in the recommendations (Table 6), only corresponded to milligrams per litre, as measured in one third of analysed Swedish diverting toilets (two thirds showed no signs of contamination) (Schönning *et al.*, 2002). Less stringent guidelines for developing countries compared to the Swedish ones are also justified by the generally higher health standard in developed countries, where the cautious interpretation of the precautionary principle and high safety requirements are applied. Based on the risk assessment calculations for urine it can further be concluded that

a withholding time of a few weeks corresponded to the suggested storage time of one month at 20°C (Höglund *et al.*, 2002). The only difference with not requiring storage systems would thus be exposure to potentially higher concentrations of pathogens when applying urine and entering or working in the fields.

Table 6. Recommended Swedish guideline storage times for urine mixture^a based on estimated pathogen content^b and recommended crop for larger systems^c. (Adapted from Jönsson *et al.*, 2000 and Höglund, 2001)

Storage temperature	Storage time	Possible pathogens in the urine mixture after storage	Recommended crops
4°C	≥1 month	Viruses, protozoa	Food and fodder crops that are to be processed
4°C	≥6 months	Viruses	Food crops that are to be processed, fodder crops ^d
20°C	≥1 month	Viruses	Food crops that are to be processed, fodder crops ^d
20°C	≥6 months	Probably none	All crops ^e

^a Urine or urine and water. When diluted it is assumed that the urine mixture has at least pH 8.8 and a nitrogen concentration of at least 1 g/l.

^b Gram-positive bacteria and spore-forming bacteria are not included in the underlying risk assessments, but are not normally recognized for causing any of the infections of concern.

^c A larger system in this case is a system where the urine mixture is used to fertilize crops that will be consumed by individuals other than members of the household from which the urine was collected.

^d Not grasslands for production of fodder.

^e For food crops that are consumed raw it is recommended that the urine be applied at least one month before harvesting and that it be incorporated into the ground if the edible parts grow above the soil surface.

During storage the urine should be contained in a sealed tank or container. This prevents humans and animals coming into contact with the urine and hinders evaporation of ammonia, thus decreasing the risk of odour and loss of plant-available nitrogen.

The urine should preferably not be diluted. Concentrated urine provides a harsher environment for microorganisms, increases the die-off rate of pathogens and prevents breeding of mosquitoes. Thus, the less water that dilutes the urine the better.

Other possible treatments

So far, storage at ambient temperature is the only method practised to sanitize urine. Methods to concentrate the nutrients in urine have been tested but are not yet efficient enough, commercially available or evaluated from a hygienic point of view. Some, e.g. evaporation of nitrogen (ammonia) through heat application will substantially reduce the number of microorganisms.

Drying urine in open trenches has been tested in Sweden and Mali but will result in substantial loss of nitrogen, while phosphorous and potassium will be retained. A dry urine fraction (in the form of a powder) has not been shown to pose microbial health risks.

Increased temperature or pH of the collected urine would further speed up the inactivation of potential pathogens. The relative increased inactivation rates at temperatures above 20°C have not been tested and need to be quantified.

Storage of urine

Storage at ambient temperature is considered as a viable treatment option for urine.

Recommended storage time at temperatures of 4-20°C varies between one and six months for large-scale systems depending on the type of crop to be fertilized.

For single households, urine could be applied to any crop without storage as long as one month passes between fertilization and harvest if faecal cross-contamination is avoided. Dilution of the urine should be avoided.

TREATMENT OF FAECES**Storage**

The number of pathogens in faecal material during storage will be reduced with time due to natural die off, without further treatment. The type of microorganism and storage conditions governs the time for reduction or elimination. The ambient temperature, pH and moisture etc. will affect the inactivation as well as biological competition. Since the conditions during storage vary, so do the die-off rates, which may make it harder to predict appropriate storage times.

In 1983, Feachem *et al.* compiled extensive data based on literature studies on pathogen/indicator reductions in different materials, including nightsoil and faeces. The data are presented as “less than values” as shown in Table 7, and do not consider the initial concentrations, but focus on total inactivation. From additional literature studies, Arnbjerg-Nielsen *et al.*, (2004, in press) estimated the decimal reduction times for various pathogens (T_{90} -values given for 20°C in Table 7). The prevailing studies of pathogen inactivation in human faeces are however few, and other materials such as animal manure and sewage sludge were also taken into consideration to estimate inactivation rates. Based on these T_{90} values the times needed for a decimal inactivation were similar to the ones presented as full inactivation by Feachem *et al.* (1983). If the initial concentrations are higher and a 1st order die-off kinetic applied, the time for a total die-off would be significantly longer. The 1st order kinetic is however, not necessarily applicable during extended storage. It should further be pointed out that the later calculations just consider storage and no additional treatment.

Inactivation of pathogens in soil is additionally important for the risk related to use of excreta, even though treatment of the material should aim to substantially reduce the pathogens before it is applied to land. Comparative decimal inactivation values are given in Table 7, again with longer survival times reported in more recent literature than those estimated by Feachem *et al.* (1983). On crops, however, the inactivation rate is often considered to be more rapid with T_{90} values in the range of a few days (Asano *et al.*, 1992; Petterson *et al.*, 1999).



Figure 11. Dried or composted faecal material is used as fertilizer for crop production. Photo: H P Mang, GTZ

Table 7. Estimated survival times and decimal reduction values of pathogens during storage of faeces and in soil, given in days if not stated otherwise (Feachem et al., 1983^a; Arnbjerg-Nielsen et al., in press^b; Kowal, 1985^c, in EPA, 1999). No additional treatment is applied. (norm. = normally)

Microorganism	Faeces and sludge ^a 20-30°C	Faeces T ₉₀ ^b ~20°C	Soil ^a 20-30°C	Soil T ₉₀ ^b ~20°C	Soil ^c absolute max ^d / normal max
Bacteria					1 year/ 2 months
Faecal coliforms	<90 norm. <50	15-35 (<i>E. coli</i>)	<70 norm. <20	15-70 (<i>E. coli</i>)	
Salmonella	<60 norm. <30	10-50	<70 norm. <20	15-35	
Viruses	<100 norm. <20	Rotavirus: 20-100 Hepatitis A: 20-50	<100 norm. <20	Rotavirus: 5-30 Hepatitis A: 10-50	1 year/ 3 months
Protozoa (<i>Entamoeba</i>)	<30 norm. <15 ^e	<i>Giardia</i> : 5-50 <i>Cryptosporidium</i> : 20-120	<20 norm. <10 ^e	<i>Giardia</i> : 5-20 <i>Cryptosporidium</i> : 30-400	? /2 months
Helminths (egg)	Several months	50-200 (<i>Ascaris</i>)	Several months	15-100 (<i>Ascaris</i>)	7 years/ 2 years

^a Absolute maximum for survival is possible during unusual circumstances such as at constantly low temperature or in well-protected conditions.^a

^e Data are missing for *Giardia* and *Cryptosporidium*; their cysts and oocysts might survive longer than the time given here for protozoa.^a

If applying the “safety zone” in Figure 13, at least one year of storage is needed at ambient temperature, without additional treatment, the guideline value stated for helminths by WHO (1989). Strauss and Blumenthal (1990) suggested that one year was sufficient under tropical conditions (28-30°C), whereas at lower temperatures (17-20°C) 18 months would be needed.

In a South African study, *Salmonella* was found in stored faeces after one year (Austin, 2001). Wood ash was sprinkled over the faeces, giving a pH of 8.6-9.4, thus this study is a combination of storage and alkaline treatment (Table 8). *Salmonella* could have grown in the material. Weekly turnings of the faecal heap rather than having it in a plastic container gave high reduction of pathogens and the faecal indicators, and resulted in low moisture (Austin, 2001). Aeration may increase the inactivation and a partial composting may have taken place (temperature not reported). This manual turning will however expose the person handling the material to unsanitized faeces.

In a Danish study, the subsequent risks related to the use of faeces that had been stored for 0-12 months without additional treatment, were calculated (Arnbjerg-Nielsen *et al.*, in press; Schönning *et al.*, manuscript). *Ascaris* posed the highest risk with a 100% risk of becoming infected upon exposure for vulnerable persons after accidental ingestion of the material, if one person in the household had been infected during the collection period. The protozoa *Giardia* and *Cryptosporidium*, and rotavirus, that are of greater concern in the Danish setting, resulted in risks of 10-90% after accidental ingestion during handling or using unstored faeces in the garden. After storage for 6 months the risk was extrapolated to be 10% whereas after 12 months it was typically around 1:1 000. The risk for hepatitis A or bacterial infections was generally lower. The storage was assumed to occur at temperatures around 20°C and data reported for this temperature range were used to calculate the reduction of pathogens (Table 7).



Figure 12. Mesophilic digested sludge from large wastewater treatment plants is often used as a fertilizer on agricultural land. Source-separated faecal material that has been treated often contains fewer pathogens and does not have the same disadvantages with chemical contaminants.

In a study in Mexico (Franzén & Skott, 1999), the faecal material had a moisture level of 10%, a pH of around 8 and a temperature of 20-24°C. At this low moisture content the reduction of the conservative viral indicator, the bacteriophage (*Salmonella typhimurium* 28B) was 1.5 log₁₀ after six weeks of storage. The analyses were performed in a latrine to which the phages had been added and without subsequent faecal addition.

Low moisture content was concluded to have a beneficiary effect in a study in Vietnam, with the fastest inactivation of bacteriophages in latrines with the lowest moisture content (Carlander & Westrell, 1999). These latrines also had a pH around 9 and higher temperatures than in the above study (see also *Alkaline treatments*). A total inactivation of *Ascaris* was recorded within six months. The inactivation was not statistically related to any single factor in the latrines, but a combination of high temperature and high pH was suggested to account for the main reduction (Table 8).

In El Salvador, an extensive study of the faecal material collected in urine-diverting toilets has been conducted. Material to increase pH is added by the users to the faecal material but recording of some pH-values around 6 implies that, in some toilets, treatment by storage alone

is occurring (Moe & Izurieta, 2003). Survival analysis suggested that faecal coliforms would survive >1,000 days and *Ascaris* around 600 days in latrines with a pH of less than 9.



Figure 13. Collection of faecal material should preferably be done in twin pit compartments. When full, one pit is sealed off and the storage time counted from that date, while the other pit is used. In Vietnam, representing a hot climate a full destruction of *Ascaris* eggs and model viruses were obtained within six months during these conditions. If twin pits are not used, secondary storage or other types of treatment must be planned for.

Storage is especially beneficial in dry hot climates resulting in desiccation of the material and low moisture contents aiding pathogen inactivation. If all the faecal material is dry right through, the pathogen decrease is facilitated. Esrey *et al.* (1998) suggested that there is rapid pathogen destruction at moisture levels below 25%, and that this level should be aimed for in ecological sanitation toilets that are based on dehydration (i.e. storage). Low moisture content is also beneficial in order to reduce smell and fly breeding (Esrey *et al.*, 1998; Carlander & Westrell, 1999). Regrowth of bacterial pathogens may however occur after application of moisture (water) or if the material is mixed with a moist soil as indicated by results reported by Austin (2001). Desiccation is not a composting process and when moisture is added the easily metabolized organic compounds will facilitate bacterial growth, including e.g. *E. coli* and *Salmonella*, if small amounts of these are occurring or introduced into the material.

Protozoan cysts are sensitive to desiccation, and this also affects their survival on plant surfaces (Snowdon *et al.*, 1989; Yates & Gerba, 1998). Normal moisture levels do not inactivate *Ascaris* eggs, with values below 5% needed (Feachem *et al.*, 1983). Information for the corresponding effective time is currently lacking.

Storage of faeces

Storage is the simplest form of treatment of faeces. The inactivation of pathogens is generally slow and storage times ranging from months for bacterial reduction to years for some helminths are needed to achieve a safe fertilizer product.

Simple storage at ambient temperature, pH and moisture is therefore not considered safe practice except if the storage time is for years (based on reduction of soil helminths).

Furthermore, just adding soil or sawdust after defecation as a covering and conditioning material should be discouraged.

In combination with other “safety barriers”, however, storage can be applied.

Heat treatment

Heat is one of the most effective ways of killing pathogens and is the parameter used to achieve inactivation in some of the most applied processes for e.g. sewage sludge treatment. In Figure 14 (from Feachem *et al.*, 1983) the inactivation of pathogens is plotted as a function of temperature and time. This, with a margin, create a defined “safety zone”. If the corresponding temperature-time relationship is achieved in all of the exposed material, it may be considered microbiologically safe for handling and use. For example, if a temperature $>55^{\circ}\text{C}$ has been reached for one to a few days, an efficient inactivation has occurred. The relationships between time and temperature for various pathogens have been widely accepted even though “new” pathogens have been identified and literature giving slight variations on the results has been published.

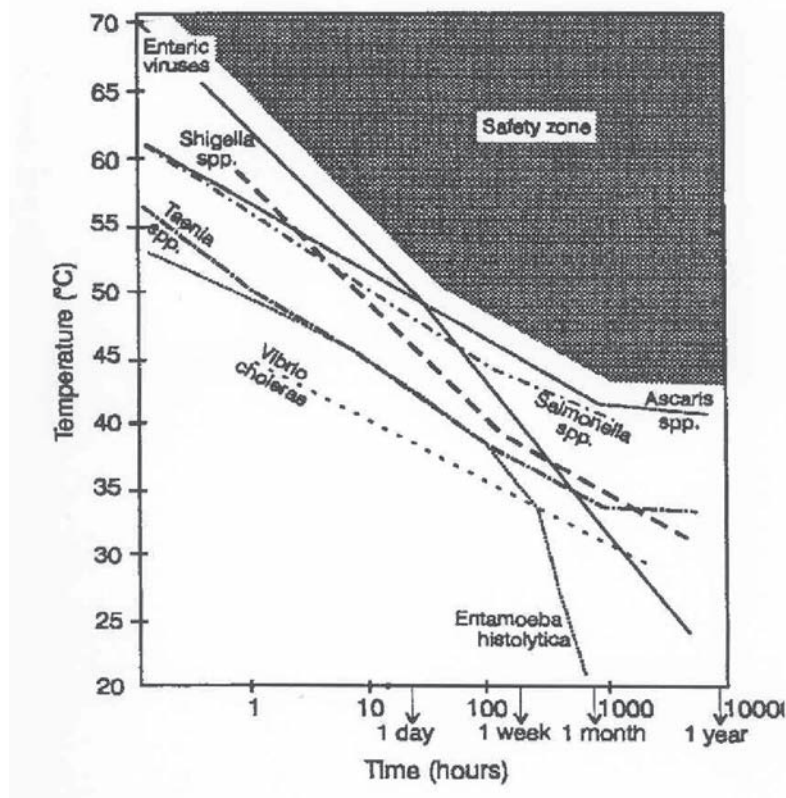


Figure 14 The “safety zone diagram” (Feachem *et al.*, 1983)

To treat excreta, thermophilic digestion (50°C for 14 days) or composting in aerated piles for one month at $55\text{--}60^{\circ}\text{C}$ (+ 2-4 months further maturation) are recommended and generally

accepted procedures (WHO, 1989). Recommendations for treatment of e.g. sewage sludge and organic household waste (food waste) also rely on such temperatures (Swedish EPA, 2002; EC, 2000; Danish EPA, 1996). Haug (1993) states that composting at 55-60°C for a day or two should be sufficient to kill essentially all pathogens. The cited regulations above rely on longer periods, to give a handling margin. It is common that cold zones are formed within the digested or compost material, resulting in local areas with less inactivation and possible regrowth of pathogenic bacteria. Digestion and composting in addition aims to degrade and stabilize organic material. For faeces, it is the inactivation of pathogens that is of most importance. A composting process will also decompose toilet paper, making the material more aesthetical and suitable for agricultural use.



Figure 15. Composting of faeces together with household waste in wind rows. Photo: J Heeb.

Faeces could also be solar heated for example in a collection bin or faecal compartment in the sun. This has been tried in simple versions in ecological sanitation systems, for example in El Salvador and in Vietnam. In El Salvador, higher peak temperatures were recorded in these toilets than in regular double-vault urine-diverting toilets (DVUDs) (Moe & Izurieta, 2003). The temperature measured in the middle of the day was however not sufficient. On average 37°C (maximum 44°C) was reached in the solar heated toilets, compared to an average of 31°C in the DVUDs, which corresponded to ~1 degree above the ambient temperature. In summerhouses in Sweden, for example, dry toilets that are electrically heated are common.

Composting

For separately collected faecal material, composting is a natural process that has been considered a viable option for treatment. Thermal composting with effective degradation of organic material and thermophilic temperatures is however difficult to achieve on a small scale. The moisture content, aeration and the C:N ratio need to be appropriate for the process to proceed along with sufficient insulation and/or bulk to allow an increase in temperature. In the WHO guidelines, composting in 10-50 m long piles of 1.5-2 m height and 2-4 m width is described (WHO, 1989). In order to compost faeces, addition of bulk material such as wood/bark chips is needed to allow aeration. If ash or lime has been added in the primary collection, additions of both energy rich materials, such as kitchen waste, and acidic material is needed for good compost. Drying or alkalifying of material should thus not be considered as composting processes. It is known that the optimal pH for the growth of bacteria and other composting organisms is in the range of 6.0 to 8.0. With alkalifying systems achieving pH of 9 or more, the composting process is hampered, while still achieving the goal of pathogen reduction. Further degradation of the organic material will instead occur when applied to the soil.

Small-scale composting of faeces and food waste mixture (also including straw as an amendment) can function as an efficient process. In well-insulated small-scale compost reactors the temperature reached over 65°C in controlled experiments, with satisfactory safety margins for pathogen destruction (Vinnerås *et al.*, 2003b). Composting of only faeces and straw also resulted in elevated temperatures (50-55°C during a couple of days) in laboratory tests (Vinnerås, 2002).

In practice, at the domestic level simple composting of faeces from urine-diverting toilets can be questioned. Only slight elevation of the temperature was recorded in some trials, probably due to insufficient insulation and the addition of ash resulting in reduced biological degradation and heat losses (Karlsson & Larsson, 2000; Björklund, 2002).

During composting, changes in pH and high biological activity will also affect the inactivation of pathogens, which is even more important under mesophilic conditions. In a study by Holmqvist and Stenström (2001), household waste mixed with straw was composted and yielded a temperature of 29-30°C and a pH that ranged from 4.5 to 8.6. The faecal indicators *E. coli* and *Enterococcus faecalis* were reduced rapidly, with a 6 and 5 log₁₀ reduction respectively during the first three days. The virus model was reduced 3 log₁₀ whereas the viability of *Ascaris* eggs (ova) only was reduced from 91% to 70% during one month (Holmqvist & Stenström, 2001).

The mesophilic processes, however, inactivate the pathogens to variable extents within weeks or months. It is therefore not recommended to rely on this temperature range in treatment of faeces, unless the mesophilic processes is combined with other process functions, or barriers.

Many toilets are called “composting toilets” without actually achieving a well-functioning process; it is rather storage and anaerobic putrefaction, desiccation or alkalization that occurs. Unless good maintenance can be ensured, mainly obtained in large and well-insulated composting units that receive faecal and food wastes from a large number of persons, it is questionable if one could rely on domestic-scale “composting” units as an efficient process for pathogen reduction. Composting is therefore not considered as a first-hand choice for primary treatment but rather as an option for secondary treatment of faeces at a municipal scale or level.

Composting of faeces

Thermophilic composting is a biological process that requires skilled management to function well. Enough feed of the right composition is important in order to reach temperatures high enough for efficient inactivation of pathogens. Composting is preferably performed as a secondary treatment on a larger scale, and the process should be insulated and monitored in order to assure that thermophilic temperatures (>50°C) are obtained in all of the material. Small-scale composting at mesophilic temperatures needs to be further evaluated.

Alkaline treatments

Addition of ash and lime

Most pathogens favour a neutral pH, i.e. around 7. A pH of 9 and above will reduce the pathogen load with time, but for rapid inactivation a pH of 11-12 is desired in treatments where lime is added (e.g. for treatment of sewage sludge) (Boost & Poon, 1998). The addition of ash or lime to excreta, practised for a long time, has several benefits:

- It reduces the smell.

- It covers the material, which in turn reduces the risk for flies and improves the aesthetical conditions.
- It decreases the moisture content.
- It promotes pathogen die-off through the elevated pH effect.

Results from a study of urine-diverting latrines in Vietnam showed that it is possible to achieve a total die-off of *Ascaris* ova and indicator viruses ($8 \log_{10}$ reduction) within a six-month period if one to two cups of ash were added after each visit (defecation). The mean temperature ranged from 31-37°C (overall maximum was 40°C), the pH in the faecal material was 8.5-10.3 and the moisture content 24-55%. The inactivation was described as a combination of factors but pH for the bacteriophage inactivation was shown to be statistically significant as a single factor (Carlander & Westrell, 1999; Chien *et al.*, 2001).

In a Chinese study by Wang *et al.* (1999), plant ash was mixed with faeces in a ratio of 1:3 and yielded a pH of 9-10. A $>7 \log_{10}$ reduction of phages and faecal coliforms, and a 99% reduction of *Ascaris* eggs was recorded after six months even though the temperature was low (-10°C to 10°C), resulting in partial freezing of the material. Coal ash and soil amendment had a lower or insufficient reduction, respectively. The coal ash gave an initial pH of 8.

According to Lan *et al.*, (2001) a pH >8 resulted in inactivation of *Ascaris* within 120 days (no detailed information on additives given).

A large number of collection toilets (double-vault urine-diverting toilets and single-vault toilets with solar heating) in seven rural communities in El Salvador were evaluated based on the physical and microbiological properties of the collected faeces (Moe & Izurieta, 2003). The households added lime (pH 10.5), ash (pH 9.4) or a specific lime-mixed soil (pH 8.8), resulting in variable final pH levels. By multiple regression analysis, pH was identified as the most important single factor determining inactivation of bacterial indicators and coliphages, whereas temperature was the strongest predictor for *Ascaris* die-off. A pH of 9-11 gave faster inactivation of faecal coliforms and *Ascaris* than a pH of <9 . A surprising result was that even at these high pH levels, faecal coliforms were re-found around 500 days, with a smaller fraction surviving $>1,000$ days in the latrines with pH >11 . For *Ascaris* the survival was around 450 days and 700 days for pH ranges >11 and 9-11, respectively (Table 8). The presence of *Trichuris*, hookworm, clostridia and coliphages were also measured and, with the exception of hookworm, found in some of the latrines with an average storage time of nearly one year (306 days).

The findings of the above studies are therefore somewhat contradictory. A lower limit for the pH in combination with time may be affected by local factors and the design. In Moe and Izurieta's study (2003), most of the toilets were no solar heated urine-diverting toilets (n=118) and 38 were solar heated. The study reports *Ascaris* viability in 40% of the no solar heated urine-diverting toilets, whereas viable *Ascaris* ova were reported in none of the 38 (0%) solar heated toilets. It is however generally clear that pathogen die-off is increased at pH levels above 8. The amount and quality of ash added may vary and further studies on appropriate amounts are probably needed but as a general rule of thumb at least 1-2 cups (approx. 200-500 ml) should be added after each defecation (enough ash/lime to cover the material should be added). The alkalinity and final pH of different types of ashes does vary, which hamper the prediction of pathogen inactivation just based on quantities. In China, automatic ash dispensers that can be used in a similar way as a water flush have been developed. If profuse and watery diarrhoea are common, these amounts will not be enough to keep the toilet dry. Other amendments, like peat, soil or other adsorbents, may then be necessary *in addition to* the ash or lime.

Table 8. Summarized results from studies where faeces have been treated with a pH-elevating additive

Area of investigation	Type of toilet	Additive	pH, temp, moisture	Most important findings- Inactivation of pathogens and indicators	Reference
Vietnam (during hot and dry season)	12 latrines, 2 of each type. All urine-diverting, most double-vault or multi-bucket	Ash from firewood and leaves. 200-700 ml per visit	pH: 8.5-10.3 temp: 31.1-37.2°C moisture: 24-55% (mean values for each latrine)	Controlled die-off experiments in challenge tests: T_{90} for <i>Salmonella typhimurium</i> phage 28B varied from 2.4 to 21 days. pH most important factor for die-off <i>Ascaris</i> viability 0-5% after 9 weeks (except in 2 latrines). pH in combination with temperature affect die-off	Carlander & Westrell, 1999
South Africa (hot to cold climate)	Various urine-diverting toilets	Wood chips	pH: 8.6-9.4 moisture: 4-40%	Organisms present in material: After 10 months: All indicators present in high numbers (10^2 - 10^6 /g). <i>Salmonella</i> present After 12 more months: Faecal streptococci $\sim 10^4$ /g, clostridia & coliphages present, <i>Salmonella</i> absent	Austin, 2001
South Africa	2 urine-diverting toilets	Wood chips + turning	pH: 8.4-8.6 moisture: 4-9%	Organisms present in material: After 2 months: Indicators except coliphages present ($\sim 10^2$ /g). <i>Salmonella</i> absent	Austin, 2001
El Salvador	118 double-vault urine-diverting latrines. 38 single-vault solar latrines.	Lime, ash or lime-mixed soil	pH: 6.2-13.0	Organisms present in material: Faecal coliforms inactivated after 500 days. pH most important factor <i>Ascaris</i> inactivated after 450 days (pH >11), after 700 days (pH 9-11). Temperature strongest predictor for inactivation	Moe & Izurieta, 2003
China	2 latrines	Plant ash mixed with faeces in ratio 1:3	pH: 9-10 temp: -10-10°C	Controlled challenge test and organisms present in material: After 3 months: $>7 \log_{10}$ reduction of <i>Salmonella typhimurium</i> phage 28B and faecal coliforms. 1% viability of <i>Ascaris</i>	Wang <i>et al.</i> 1999*
China		No detailed information given	pH >8	Controlled challenge test: Inactivation of <i>Ascaris</i> within 120 days	Lan <i>et al.</i> , 2001

* Other additives, coal ash, sawdust and loess were also tested and resulted in lower pH and lower inactivation.

Addition of a pH-elevating chemical will have several benefits and have the potential to inactivate pathogens. The conditions to achieve complete removal of pathogens may vary due to local circumstances. On a large scale, secondary treatment of collected material, may function as an additional treatment barrier, resulting in a higher safety level, when the material is used as a fertilizer. The additives and an additional mixing with energy rich material may affect secondary composting and acidic material needs to be validated. Wood ash is, according to Chinese practice, not recommended to add as an absorbent if the faecal material should be

composted, since that would result in higher losses of nitrogen. Incineration of the material after alkaline treatment may also be difficult due to the low energy content of the material, see below. These aspects need to be further evaluated.

After alkaline treatment, the resulting fertilizer will have an elevated pH (>8). This is not of concern from a hygienic point of view and may be beneficial for many soils but may affect crop production in alkaline soils.

Addition of ash or lime to faeces

Addition of ash or lime in the primary treatment of faeces is recommended as it will facilitate pathogen inactivation and decrease the risk for disease transmission during handling and reuse of the material. It also reduces the risk of odour and flies in the toilet. The additives may influence the choice of secondary treatment options. Further evaluation is needed to establish the amounts and quality of additives that are needed for sufficient pathogen reduction and their influence on secondary treatment.

Addition of urea

Urea is a pH-elevating additive that has been considered for large-scale treatment of faeces on a municipal level. Urea also adds value to the fertilizer value and inactivates pathogens by a combined elevated pH and high ammonia concentration.

The addition of 3% urea-nitrogen to faeces results in a pH of ~9.3, that at 20°C corresponds to 8,000 mg/l of free ammonia. During these conditions no *E. coli* or *Salmonella* were detected after five days, enterococci were reduced 2 log₁₀ and the viability of *Ascaris* eggs was 90% (Vinnerås *et al.*, 2003a). After 50 days, no viable pathogens or indicators were recorded, except for spore-forming clostridia. Since the ammonia will remain in the material if it is properly stored, the risk for regrowth of pathogenic bacteria in the treated matter should be minimized.

Ammonia generated at high pHs may act as an inactivating agent for viruses (Pesaro *et al.*, 1995), and has also been demonstrated to affect *Cryptosporidium* oocysts (Jenkins *et al.*, 1998). The viability of *Ascaris* eggs was reduced in ammonia-treated sewage sludge (Ghigletti *et al.*, 1997).

Chemical treatment of faeces

Chemicals could be added to faeces in order to eliminate pathogens. These types of treatment are mainly considered an option for secondary large-scale systems, and trained personnel should preferably handle the chemicals.

Incineration

Incineration of the faeces will minimize the risk for transmission of disease related to the final use of the ash since essentially all pathogens will be removed. Systems utilizing incineration have not been introduced on a planned level so far. The primary handling will still involve hygienic risks but systems with incineration in direct connection to the toilet may be developed in the future. As an alternative, high temperature levels will have the same beneficial effect

from a microbial point of view. The ash is a potent fertilizer with phosphorous and potassium retained, although the nitrogen will be lost.

Incineration of faeces

Incineration of faeces will render a fertilizer product that is pathogen-free and may have a potential in secondary treatments, both on small- and large-scale levels. Systems utilizing incineration have not yet been properly developed and evaluated.

Conclusion

A range of treatment options is available for faeces. Incineration is the safest method where all pathogens will be eliminated but has not been used in practice. The nitrogen will be lost but phosphorous and potassium retained in the remaining ash. Other methods to reduce the pathogen content rely on elevation in pH and temperature, and desiccation, or solely on time (ambient conditions). The current number of practical evaluation studies, as well as process monitoring, of these factors alone or in combination are limited.

All the currently used recommended treatment methods, except storage, are based on either temperature or pH (for urea in combination with ammonia). Other factors also affect microbial survival but are less easily controlled or measured. Biological competition with naturally occurring soil bacteria will be effective after application in the soil. However, this is not recommended as a primary treatment process due to difficulties in reproducibility. Our human senses are not a predictor of safety; a good smelling, humus-like material does not necessarily mean that it is a safe fertilizer product. The recommendations should therefore be related to measurable parameters and conditions that, in theory and practice, are known to achieve an expected result.

The practical options depend on the scale of the system, i.e. at household or municipal level. For the latter, more technical options are available. As stated by WHO (1989), implementation

of treatment on an individual level has added difficulties involving people's habits and practices sometimes established long ago. The scale also influences the combinations of suitable primary and secondary treatments and barriers. Handling systems need to be developed and adapted to the different treatments.



Figure 16. Indoor urine-separating toilet with squatting pan in China

THE POSSIBLE USE OF A TREATMENT INDICATOR

A standard analytical measure, i.e. an indicator organism, to control the “production” of a safe fertilizer product would be the ideal situation but is not regarded as a viable option due to various constraints. Detailed recommendations on how to safely manage a sanitation system including use of faeces and urine may therefore be more valuable. Suitable candidates exist, representing the most resistant organisms in the groups of bacteria, viruses, parasitic protozoa and helminths. These can be used as conservative index organisms for validation of different treatment options in challenge experiments. The enterococci, selected bacteriophages, *Cryptosporidium* oocysts and *Ascaris* eggs may function as such index organisms.

For faeces (or excreta, i.e. faeces and urine mixed), the Engelberg guidelines (stated in WHO, 1989) for nematode eggs and faecal coliforms have prior been in focus, even though it is stated that these are not intended as standards for quality surveillance but rather as design goals for treatment systems. Problems with quality control include costs, lack of local laboratory capacity and the lack of routine methods for indicators or specific pathogens that could represent various groups of pathogens. Thermotolerant (faecal) coliforms are still widely used even though it has been questioned how representative they are of the pathogens of concern.

In urine, the commonly used faecal indicator organism *E. coli* is unsuitable due to its rapid inactivation, which does not mimic the die-off of different pathogens. Enterococci (faecal streptococci) on the other hand were shown to grow within the urine-piping system and may therefore give false positive results in the prediction of faecal contamination. It had a slower reduction and can thus be used as a predictor of storage efficiency. Neither of these two indicators is however suitable to use for predicting the degree of faecal contamination and associated risks. The search for specific pathogens in urine is time consuming and expensive.

Instead an assumed faecal contamination can be used as a predictor for prescribed storage times and subsequent time between fertilization and harvest.

Results from mesophilic composting (Holmqvist & Stenström, 2001) imply that the indicators *E. coli* and enterococci were not suitable for this type of process since their inactivation was so much faster than for viruses and *Ascaris* eggs. Even if many regulations for treatment of sewage sludge and food waste are based on *E. coli* and *Salmonella* as quality indicators, a monitoring of the process parameters (e.g. temperature) is more relevant and considered as the main control. If included for monitoring purposes, these two indicators should be related to risk of regrowth during subsequent handling of the materials.



Figure 17. Elevated urine-separating toilet in Vietnam

Practical recommendations in relation to agricultural use

URINE

The major recommendations for urine are:

- (1) direct use after collection or a short storage time is acceptable on the single household level
- (2) storage should be made for larger systems (where the time and conditions, stated in Table 6, should be followed),
- (3) at least one month should apply between fertilization and harvest,
- (4) additional stricter recommendations may apply on a local level, if frequent faecal cross-contamination is envisaged. The recommendations for storage times is directly linked to agricultural use and choice of crop (Table 6). Additional practises to minimize the risks include the following:
 - When applying the urine, precautions related to the handling of potentially infectious material should be taken. These precautions could include wearing gloves and thorough hand washing.
 - The urine should be applied using fertilizing techniques close to the ground which avoid aerosol formation.
 - The urine should be incorporated into the soil. This could in practice be done mechanically or by subsequent irrigation with water.

A close to the ground application/fertilizing method is recommended to minimize aerosol formation. On a large scale this is often done by using special agricultural equipment, while on a smaller scale it is often applied manually. Handling smaller volumes is often safe, and the urine should preferably not be diluted before application.

FAECES

The agricultural use practices (and recommendations) will be dependent on the preceding treatment. Even if a treatment is aimed at elimination of the risk of pathogen transmission and its potential has been proven in laboratory and/or field experiments, process steps may malfunction, resulting in a fertilizer product that is not completely hygienically safe. Therefore additional measures should be taken in order to further minimize the risk for disease transmission. Thus:

- Equipment used for e.g. transportation of unsanitized faeces should not be used for the treated (sanitized) product.
- When applying faeces to soil, precautions related to the handling of potentially infectious material should be taken. These precautions should include personal protection and hygiene. Hand washing should naturally be done.
- Faeces should be worked into the soil as soon as possible and not be left on the soil surface.
- Improperly sanitized faeces should not be used for vegetables, fruits or root crops that will be consumed raw, excluding fruit trees.

Incinerated faeces will be hygienically safe. The subsequent handling of the resulting ash is outside the scope of this summary recommendation.

Working the excreta into the soil will minimize further human or animal exposure except for some soil-borne helminths, and will decrease the risk for pathogen run-off to nearby waters. A withholding period between fertilizing and harvest, as suggested for urine above (Table 6), is recommended also for faeces. This will allow further reduction of pathogens due to ambient factors such as microbial activity, UV-light and desiccation, thus adding another barrier against disease transmission. This withholding period should to be at least a month.



Figure 18. Squatting pans with urine separation

Alternative use of urine

Urine diversion is generally recommended for practical reasons, even if the urine and/or the faeces will not be used. Use of urine, concentrated or diluted with water, is the best way to utilize the plant nutrients. If not favoured due to practical reasons or cultural beliefs, alternative options exist. Addition of urine to a compost (consisting of food waste and/or faeces) usually has a beneficial impact on the composting process. From a study in Thailand it was shown that urine facilitated the composting process (only food waste included) (Pinsem & Vinnerås, 2003). Most of the nitrogen will be lost but the phosphorous and potassium retained. The hygienic quality of the compost will not be degenerated by the addition of urine if the compost contains faeces. The potential of achieving a higher temperature, due to the resulting adjustment of the C:N ratio will be beneficial for pathogen die-off.

Cultivation of plants in direct connection to the toilet is a better alternative than to soak away the urine into the ground. Such a toilet has been constructed in e.g. India with subsurface infiltration in combination with water for anal cleansing (Calvert, 1999). In subsurface plant resorption systems, the urine fraction may also be combined with greywater use.

Alternative use of faeces

Use of faeces enables utilization of the additional nutrients in excreta that are not found in urine. They also function as a soil conditioner. Incineration of faeces yields an ash product that can be used as a fertilizer, which in some settings may increase the acceptance for use.

Anaerobic digestion is another option if direct use is not possible. Anaerobic digestion requires a moist material and is sometimes applicable when flush-water is used for the faeces, a system not considered in these guidelines.

Material from dry toilets can also be mixed with animal manure in biogas digesters, where biogas is utilized as energy and the residual faeces-manure mixture is used on agricultural fields. This is extensively practised in China and India. Temperatures obtained are most likely to be in the mesophilic range and evaluations of pathogen inactivation are largely lacking.

Planting of trees in shallow pit latrines with faeces will make use of part of the nutrients. This has been practised for example in Zimbabwe (Arbor Loo) (Morgan, 1998). Faeces can also be moved to a hole that has been dug especially for this purpose, which however, adds to handling risks. When there is no risk for seepage to groundwater or overflow and if the faeces is properly handled and covered with other material, the need of storage before this type of use is small.

If use is not possible, safe disposal of the faeces is necessary. It should never be left openly on the ground due to direct exposure of humans and animals. It is important that safe handling systems, with minimal exposure of residents and others, are developed both on the household and municipal level. Disposal on the municipal level could include transportation to a sewage treatment plant if there is one in the municipality.

Aquaculture

The current EcoSanRes guidelines have not specifically considered the use of excreta in aquaculture. The concept of ecological sanitation is mainly built on the use of nutrients in the soil environment. In aquaculture, the treatment options need to be adapted, except perhaps for storage. According to WHO, a few weeks storage of excreta will inactivate parasites of concern, and to reach the faecal coliform guideline quality, digestion or composting is recommended (WHO, 1989). Furthermore, the exposure is considered difficult to control especially if the fish and shellfish cultivated in ponds are consumed raw (WHO, 1989) and if the ponds are used for swimming. In areas that lack proper water supplies, the pond water may also be used for other activities. Aquaculture pond workers are another group of consideration and necessary protective equipment may be expensive and unavailable. Use or controlled disposal of faeces in water environments is therefore currently not recommended. New WHO Guidelines on the safe use of wastewater and excreta in aquaculture will be issued in 2005.

Identified needs for further investigations – Knowledge gaps

According to present knowledge, thermophilic temperatures are recommended for treatment of various organic wastes. This may be achieved for example by incineration or composting, provided that the right conditions prevail. In many of the existing systems only mesophilic temperatures are reached and these processes need to be further evaluated.

The use of ash or lime will have several benefits for the user of the toilet and for minimizing the risk if handling the product. However, this addition will change the properties of the material and needs further evaluation in secondary treatment like composting and incineration.

For large-scale systems additional studies on appropriate handling and use systems are essential, including a systematic microbial risk assessment and epidemiological follow-up investigations. When secondary treatment is applied, different methods need to be considered, including pH elevation with lime and other alkaline chemicals, including urea. For lime, experience from large-scale treatment of sewage sludge exists, and laboratory scale studies with faeces are presently ongoing.

For future studies, it would be valuable to consider a harmonization of treatment methods under different local conditions and using the same type of analytical methods, so that the results easily could be compared. All methods need to be evaluated in a systematic analytical way regarding environmental effects.

Identified needs to adapt guidelines to local conditions

The present guidelines need to be developed and adapted to various settings and local conditions around the world. The guidelines should be developed practically and technically for local implementation of full ecological sanitation systems accounting for stakeholders like residents, sanitation personnel and farmers. Need for specified regional guidelines and case studies should be considered where aspects such as climate, culture, technical system and farming practices are further accounted for. For the EcoSanRes programme this will specifically be related to the pilot project areas. The selection of system set-ups needs to be based on the local conditions, i.e. the suitability of the sanitation system should be evaluated before full implementation. This would include adaptation of the collection system, primary treatment, handling and transportation, and secondary treatment, as well as the use system. In a systematic risk assessment approach, the risks and benefits need to be evaluated from a hygienic viewpoint.

Climatic conditions like temperature, moisture (including rainfall) and UV-light (sunshine) will affect the treatment efficiency of both urine and faeces. A higher temperature, lower moisture and more UV-radiation is, as earlier stated, beneficial for pathogen die-off and shorter treatment periods could be accepted instead of those given in these guidelines.

Cultural and religious beliefs may have an impact on the whole system, including attitudes towards the use of the excreta products. A differentiation into faeceophilic and faeceophobic societies has been suggested (Esrey *et al.*, 1998). The former may have a long tradition of reusing faeces, whereas in faeceophobic societies, excreta may be connected to taboos, concerning both handling and talking about faeces. In some areas where faeces previously have been used without appropriate treatment, the hygienic situation could be improved if the suggested recommendations are followed. In areas where this is not practised it is very important that the risks and benefits are clearly communicated so that degradation in the health situation will not result. Acceptance by users is naturally necessary to achieve a well-functioning system. Information and community involvement may be crucial when accounting for behavioural and management aspects of the toilets as well as the collection and use practices.

The use of material for anal cleansing varies between areas. The use of toilet paper as well as leaves for cleansing will have an effect on the structure of the material, facilitating aeration and resulting in a better structure and possibilities for degradation in composting if that is an option for secondary treatment. If the material is incinerated, there is neither a problem with the paper or other dry organic material, instead it will aid in the process. With alkaline treatments, toilet

paper should preferably be placed in a separate bin and handled as solid waste or incinerated. In areas where stones are used for anal cleansing (Esrey *et al.*, 1998), these should be collected separately and not placed in the dry toilets.

Anal cleansing with water after defecation is practised in most Muslim societies. This results in an additional fraction that needs to be handled. The cleansing water contains faecal matter and should not be mixed with the urine. Local soil infiltration of the small amounts of water is acceptable. If the climate is dry, small volumes of cleansing water could probably be added to the faeces in composting processes. An option is to mix this water with greywater from bath, kitchen and laundry if this water is used in subsurface plant resorption systems. In India, a double-vault toilet has been developed where the cleansing water and the urine flow into an adjacent evapotranspiration bed where plants are grown (Esrey *et al.*, 1998).

Children's diapers need to be taken care of. Different practices occur in different cultural settings. Since young children are more prone to have an enteric infection, their faeces should be handled with precaution. Open defecation of children should be discouraged.

During menstruation women use tampons, disposable sanitary napkins or washable cloth rags. The napkins can, if they are degradable, be thrown in the faecal compartment. Otherwise they should be collected as solid waste. The menstruation blood does not involve any risks for disease transmission through ecological sanitation toilets or use of excreta. Still, there may be taboos in some countries towards such materials. In these cases, the woman's excreta can be collected separately and e.g. incinerated. This could then still allow for use of faeces in these cultures.

Concluding recommendations

ECOLOGICAL SANITATION TOILETS – GENERAL

- Urine diversion is recommended for several reasons; one is decreased risk for disease transmission.
- Faecal collection should normally occur above ground.
- Faecal collection should occur in a closed compartment without risk of seepage to groundwater or to the surrounding environment. Twin-pit collection is preferred
- Urine should be collected with minimal risk for faecal contamination. Urinals are a good complement to urine-diverting toilets.
- Solar heating of the collection devices for urine and faeces may be beneficial for pathogen inactivation.
- Handling and transport systems should involve minimal contact with the faecal material.

URINE – TREATMENT AND USE

- Urine involves low risk for transmission of disease.
- Dilution of the urine should be avoided.
- Faecal contamination of urine is possible and therefore urine may contain enteric pathogens. The technical constructions should be done in ways to minimize faecal cross-contamination.

- At household level the urine can be used directly.
- Urine should, in large-scale systems, be stored for one month at 20°C before use. In addition a withholding period of one month between fertilization and harvest should be applied (Table 9).

Table 9. Suggested alternative recommendations for use of urine collected from large-scale systems (municipal level)

Treatment	Criteria	Comment
1) Storage	Temperature >20°C during 1 month	Time should be extended at lower temperatures, pH should be >8.5
2) Additional withholding period*	Time >1 month	

* Withholding period is the period that passes between fertilization and harvest.

- For vegetables, fruits and root crops consumed raw, a one-month withholding period should always be applied.
- In areas where *Schistosoma haematobium* is endemic, urine should not be used near freshwater sources.
- Urine should be applied close to ground and preferably mixed with or watered into the soil.

FAECES – TREATMENT AND USE

- Faeces should be treated before it is used as fertilizer.
- Treatment methods need further evaluation (recommendations should be considered preliminary).
- Primary treatment (in the toilet) includes storage and alkaline treatment by addition of ash or lime.
- 1-2 cups (200-500 ml; enough to cover the fresh faeces) of alkaline material should be added after each defecation.
- In small-scale systems (household level), the faeces can be used after primary treatment if the criteria in Table 10 are fulfilled.
- The treatments in Table 10, along with incineration, can be used as secondary treatment (material removed from toilet and treated) at household level.

Table 10. Suggested alternative recommendations for primary (and secondary) treatment of dry faeces before use at the household level. No addition of new material.

Treatment	Criteria	Comment
Storage (only treatment); Ambient temperature 2-20°C	1.5–2 years	Will eliminate most bacterial pathogens; regrowth of <i>E. coli</i> and <i>Salmonella</i> not considered if re-wetted; will substantially reduce viruses, protozoa and parasites. Some soil-borne ova may persist
Storage (only treatment) Ambient temperature 20-35°C	>1 YEAR	As above
Alkaline treatment	pH >9 during >6 months	If temperature >35°C and moisture <25%, lower pH and/or wetter material will prolong the time for absolute elimination

- Secondary treatments for larger systems (municipal level) include alkaline treatments, composting and incineration (Table 11).
- Alkaline treatment can be done by (further) addition of ash, lime or urea.
- The pH after alkaline treatment should be at least 9 and the material should be stored at this pH for at least six months to one year. (Total elimination may not occur, but a substantial reduction will be achieved).
- Composting is mainly recommended as a secondary treatment at large scale, since it is a difficult process to run. Temperatures $>50^{\circ}\text{C}$ should be obtained during at least one week in all material.

Storage at ambient conditions is less safe, but acceptable if the conditions above apply. Shorter storage times can be applied for all systems in very dry climates where a moisture level $<20\%$ is achieved. Sun-drying or exposure to temperatures above 45°C will substantially reduce the time. Re-wetting may result in growth of *Salmonella* and *E. coli*.

Table 11. Alternative secondary treatments suggested for faeces from large-scale systems (municipal level). No addition of new material

Treatment	Criteria	Comment
Alkaline treatment	pH >9 during >6 months	Hypothesis: If temperature $>35^{\circ}\text{C}$ or moisture $<25\%$. Lower pH and/or wetter material will prolong the time for absolute elimination.
Composting	Temperature $>50^{\circ}\text{C}$ for >1 week	Minimum requirement. Longer time needed if temperature requirement can not be ensured
Incineration	Fully incinerated ($<10\%$ carbon in ash)	
Storage	AS ABOVE (TABLE 10).	Time modification needed based on local conditions. Large systems needs a higher level of protection than at household level. Additional storage adds to safety

- Personal protection equipment should be used when handling and applying faeces.
- Faeces should additionally be mixed into the soil in such a way that they are well covered.
- A withholding period of one month should additionally be applied, i.e. one month should pass between fertilization and harvest.
- Faeces should not be used for fertilization of vegetables, fruits or root crops that are to be consumed raw, excluding fruit trees.

PRACTICAL ASPECTS

- Toilet paper can be thrown in the faecal compartment if the material is to be composted or incinerated. Otherwise it should be collected separately.
- Anal cleansing water should not be mixed with urine.
- Vegetable materials used as cleaning material can be put in the faecal compartment. Stones should be collected separately.
- Content of children's diapers (i.e. children's faeces) should be put in the faecal compartment.
- Potty faecal content should be put in the faecal compartment.
- Other materials such as sanitary napkins should only be put in the toilet if they are degradable – otherwise they should be treated as solid waste.
- Further addition of absorbent material may be needed when diarrhoea is prevalent.

References

- Ambjerg-Nielsen, K., Hansen, N.J., Hansen, L., Kjølholt, J., Stuer-Lauridsen, F., Hasling, A.B., Stenström, T.A., Schönning, C., Westrell, T., Carlsen, A. and Halling-Sørensen, B. In press. *Risk assessment of partly composted faeces for use in private gardens*. (Risikovurdering af anvendelse af helt eller delvist opsamlet komposteret human fæces i private havebrug. (In Danish, English summary.)) Danish EPA report, Copenhagen, Denmark.
- Asano, T., Leong, L.Y.C., Rigby, M.G. and Sakaji, R.H. 1992. 'Evaluation of the California wastewater reclamation criteria using enteric virus monitoring data.' *Water Science and Technology* **26**(7-8): 1513-1524.
- Austin, A. 2001. 'Health aspects of ecological sanitation.' *Abstract Volume, First International Conference on Ecological Sanitation*. 5th-8th November, Nanning, China: 104-111.
- Björklund, A. 2002. 'The potential of using thermal composting for disinfection of separately collected faeces in Cuernavaca, Mexico.' *Minor Field Studies no. 200*. Swedish University of Agricultural Sciences, Uppsala, Sweden.
- Boost, M.V. and Poon, C.S. 1998. 'The effect of a modified method of lime-stabilization sewage treatment on enteric pathogens.' *Environment International* **24**(7): 783-788.
- Calvert, P. 1999. 'Dry sanitation in Kerala, South India.' In: *Abstracts from the 9th Stockholm Water Symposium*. 9th-12th August, 1999, Stockholm, Sweden: 390-392.
- Carlander, A. and Westrell, T. 1999. *A microbiological and sociological evaluation of urine-diverting, double-vault latrines in Cam Duc, Vietnam*. Report no. 91, International Office, Swedish University of Agricultural Sciences, Uppsala, Sweden.
- CDC. 2003a. http://www.cdc.gov/ncidod/dbmd/diseaseinfo/leptospirosis_t.htm. Last reviewed March 7, 2003.
- CDC. 2003b. http://www.cdc.gov/ncidod/dbmd/diseaseinfo/typhoidfever_g.htm. Last reviewed June 20, 2003.
- CDC. 2003c. <http://www.cdc.gov>.
- Chien, B.T., Phi, D.T., Chung, B.C., Stenström, T.A., Carlander, A., Westrell, T. and Winblad, U. 2001. 'Biological study on retention time of microorganisms in faecal material in urine-diverting eco-san latrines in Vietnam.' *Abstract Volume, First International Conference on Ecological Sanitation*. 5th-8th November, Nanning, China: 120-124.
- Danish EPA. 1996. *Statutory order from the ministry of environment and energy no. 823 of September 16, 1996, on application of waste products for agricultural purposes*. Denmark.
- EC. 2000. *Working document on sludge*. 3rd draft. European Communities, Brussels.
- Esrey, S.A., Gough, J., Rapaport, D., Sawyer, R., Simpson-Hébert, M., Vargas, J. and Winblad, U. 1998. *Ecological Sanitation*. Swedish International Development Cooperation Agency, Stockholm, Sweden.
- Feachem, R.G., Bradley, D.J., Garelick, H. and Mara, D.D. 1983. *Sanitation and Disease - Health aspects of excreta and wastewater management*. John Wiley and Sons, Chichester, UK.
- Franzén, H. and Skott, F. 1999. *A study of the use and functioning of urine-diverting dry toilets in Cuernavaca, Mexico - Virus survival, user attitudes and behaviours*. Report no. 85, International Office, Swedish University of Agricultural Sciences, Uppsala, Sweden.
- Ghiglietti, R., Genchi, C., Di Matteo, L., Calcaterra, E. and Colombi, A. 1997. 'Survival of *Ascaris suum* eggs in ammonia-treated wastewater sludges.' *Bioresource Technology* **59**: 195-198.
- Haug, R.T. 1993. *The practical handbook of compost engineering*. Lewis Publishers, Boca Raton, FL, USA.
- Jenkins, M.B., Bowman, D.D. and Ghiorse, W.C. 1998. 'Inactivation of *Cryptosporidium parvum* oocysts by ammonia.' *Applied and Environmental Microbiology* **64**(2): 784-788.
- Jönsson, H., Vinnerås, B., Höglund, C., Stenström, T.A., Dalhammar, G. and Kirchmann, H. 2000. *Recycling source separated human urine*. (Källsorterad humanurin i kretslopp (In Swedish, English summary)). VA-Forsk Report 2000-1, VAV AB, Stockholm, Sweden.
- Hamdy, E.I. 1970. 'Urine as an *Ascaris lumbricoides* ovicide.' *Journal of the Egyptian Medical Association* **53**: 261-264. In: Feachem, R.G., Bradley, D.J., Garelick, H. and Mara, D.D. 1983. *Sanitation and Disease - Health aspects of excreta and wastewater management*. John Wiley and Sons, Chichester, UK.
- Holmqvist, A. and Stenström, T.A. 2001. 'Survival of *Ascaris suum* ova, indicator bacteria and *Salmonella typhimurium* phage 28B in mesophilic composting of household waste.' *Abstract Volume, First International Conference on Ecological Sanitation*. 5th-8th November, Nanning, China: 99-103.
- Höglund, C. 2001. *Evaluation of microbial health risks associated with the reuse of source separated human urine*. PhD thesis, Department of Biotechnology, Royal Institute of Technology, Stockholm, Sweden. ISBN 91-7283-039-5.
- Available at: <http://www.lib.kth.se/Sammanfattningar/hoglund010223.pdf>
- Höglund, C., Stenström, T. A. and Ashbolt, N. 2002. 'Microbial risk assessment of source-separated urine used in agriculture.' *Waste Management Research* **20**(3): 150-161.
- Karlsson, J. and Larsson, M. 2000. *Composting of latrine products in Addis Ababa, Ethiopia*. Minor Field Studies No. 32, Luleå University of Technology, Luleå, Sweden.

- Kowal, N.E. 1985. 'Health effects of land application of municipal sludge.' Pub. No.: EPA/600/1-85/015. Research Triangle Park, NC: US EPA Health Effects Research Laboratory. In: EPA. 1999. *Environmental regulations and technology – Control of pathogens and vector attraction in sewage sludge*. EPA/625/R-92-013, U.S. Environmental Protection Agency, Cincinnati, Ohio, USA.
- Lan, Y., Xueming, L., Qinhuo, W., Hongbo, X., Caiyun, N. and Lianghong, N. 2001. 'Observation of the inactivation effect on eggs of *Ascaris suum* in urine diverting toilets.' *Abstract Volume, First International Conference on Ecological Sanitation*. 5th-8th November, Nanning, China:125.
- Matsui, S. 1997. 'Nightsoil collection and treatment in Japan.' In: Drangert, J.-O., Bew, J. and Winblad, U. (eds) *Ecological Alternatives in Sanitation, Proceedings from Sida Sanitation Workshop, 6th-9th August, Balingsholm, Sweden*. Swedish International Development Cooperation Agency, Stockholm, Sweden: 65-72.
- Moe, C. and Izurieta, R. 2003. 'Longitudinal study of double vault urine diverting toilets and solar toilets in El Salvador.' *Proceedings from the 2nd International Symposium on Ecological Sanitation*. Lübeck, Germany, 7th-11th April 2003.
- Morgan, P. 1999. *Ecological sanitation in Zimbabwe - A compilation of manuals and experiences*. Conlon Printers, Harare, Zimbabwe.
- Olsson, A. 1995. *Source separated human urine – occurrence and survival of faecal microorganisms and chemical composition*. (Källsorterad humanurin - förekomst och överlevnad av fekala mikroorganismer samt kemisk sammansättning (In Swedish, English summary)). Report 208, Department of Agricultural Engineering, Swedish University of Agricultural Sciences, Uppsala, Sweden.
- Ottosson, J. 2003. *Hygiene aspects of greywater and greywater reuse*. Licentiate thesis, Department of Land and Water Resources Engineering, Royal Institute of Technology, Stockholm, Sweden.
- Pesaro, F., Sorg, I. and Metzler, A. 1995. 'In situ inactivation of animal viruses and a coliphage in nonaerated liquid and semiliquid animal wastes.' *Applied and Environmental Microbiology* **61**(1): 92-97.
- Petterson, S.R., Ashbolt, N.J. and Sharma, A. 1999. 'Microbial risks from wastewater irrigation of salad crops: Are risks dictated by rare virus events?' *Proceedings from the 4th International Conference, Managing the Wastewater Resource – Ecological Engineering for Wastewater Treatment*. June 7th-11th, 1999, Ås, Norway.
- Pinsem, W. and Vinnerås, B. 2003. 'Composting with human urine: Plant fertilizer approach.' *Proceedings from the 2nd International Symposium on Ecological Sanitation*. Lübeck, Germany, 7th-11th April 2003.
- Porter, A. 1938. 'The larval Trematoda found in certain South African Mollusca with special reference to schistosomiasis (bilharziasis).' *Publications of the South African Institute for Medical Research* **8**: 1-492. In: Feachem, R.G., Bradley, D.J., Garelick, H. and Mara, D.D. 1983. *Sanitation and Disease – Health aspects of excreta and wastewater management*. John Wiley and Sons, Chichester, UK.
- Schönning, C., Leeming, R. and Stenström, T.A. 2002. 'Faecal contamination of source-separated human urine based on the content of faecal sterols.' *Water Research* **36** (8): 1965-1972.
- Schönning, C., Westrell, T., Stenström, T.A., Arnbjerg-Nielsen, K., Hasling, A.B., Hansen, L. and Carlsen, A. *Microbial risk assessment of local handling and reuse of human faeces*. Manuscript.
- SMI. 2003. <http://www.smittskyddsinstitutet.se>
- Snowdon, J.A., Cliver, D.O. and Converse, J.C. 1989. 'Land disposal of mixed human and animal wastes: A review.' *Waste Management and Research* **7**: 121-134.
- Sondén, K. 1889. *The wastewater of Stockholm and its influence on the water courses around the city. Appendix to the annual report of the health authorities of Stockholm city 1888*. (Stockholms afloppsvatten och dess inflytande på vattendragen kring staden. Bihang till Stockholms stads hälsovårdsnämnds årsberättelse 1888 (In Swedish)). K. L. Beckman, Stockholm, Sweden.
- Strauss, M. and Blumenthal, U.J. 1990. *Human waste in agriculture and aquaculture: utilization practises and health perspectives*. IRCWD, Dübendorf, Switzerland.
- Svensson, L. 2000. Diagnosis of foodborne viral infections in patients. *International Journal of Food Microbiology* **59**(1-2): 117-126.
- Swedish EPA. 2002. *Action plan for recycling of phosphorous and sludge*. (Aktionsplan för bra slam och fosfor i kretslopp (In Swedish, English summary)). NV report 5214, Stockholm, Sweden.
- Tauxe, R.V. and Cohen, M.L. 1995. 'Epidemiology of diarrheal diseases in developed countries.' In: Blaser, M.J., Smith, P.D., Ravdin, J.I. and Greenberg, H.B. (eds) *Infections of the gastrointestinal tract*. Raven Press, Ltd., New York, NY, USA: 37-51.
- Vinnerås, B. 2002. *Possibilities for sustainable nutrient recycling by faecal separation combined with urine diversion*. PhD-thesis, Agraria 353, Swedish University of Agricultural Sciences, Uppsala, Sweden.
- Vinnerås B., Holmqvist A., Bagge E., Albiñ A. and Jönsson H. 2003a. 'The potential for disinfection of separated faecal matter by urea and by peracetic acid for hygienic nutrient recycling.' *Bioresource Technology* **89**: 155-161.
- Vinnerås B., Björklund A. and Jönsson H. 2003b. 'Thermal composting of faecal matter as treatment and possible disinfection method – laboratory-scale and pilot-scale studies.' *Bioresource Technology* **88**: 47-54.
- Wang, J.Q. 1999. 'Reduction of microorganisms in dry sanitation due to different adsorbents under low temperature

- conditions.' *Abstracts from the 9th Stockholm Water Symposium, 9th-12th August*. Stockholm, Sweden: 396-398.
- WHO. 1989. *Guidelines for the safe use of wastewater and excreta in agriculture and aquaculture*. World Health Organization, Geneva, Switzerland.
- WHO. 2003. <http://www.who.int/ctd/schisto/epidemio.htm>. Last reviewed June 30, 2003.
- Yates, M.V. and Gerba, C.P. 1998. 'Microbial considerations in wastewater reclamation and reuse.' In: Asano, T. (ed.) *Wastewater reclamation and reuse*. Technomic Publishing Company, Inc., Lancaster, PA, USA: 437-488.



EcoSanRes is an international research and development programme sponsored by Sida (Swedish International Development Cooperation Agency). It involves a broad network of partners with knowledge/expertise in various aspects of ecological sanitation ranging from management and hygiene to technical and reuse issues. The partners represent universities, NGOs and consultants and they are involved in studies, promotion activities and implementation of projects in Asia, Africa and Latin America.

The network hub is Stockholm Environment Institute (SEI) which holds a formal contract with Sida. EcoSanRes has become an authoritative networking body within the field of ecological sanitation and also collaborates with other bilateral and multi-lateral organisations such as WHO, UNICEF, UNDP, UNEP, GTZ, WASTE, IWA, WSP, etc.

The EcoSanRes programme has three main components:

- outreach
- capacity
- implementation

The outreach work includes promotion, networking and dissemination through seminars, conferences, electronic discussion groups and publications.

Capacity building, is achieved through training courses in ecological sanitation and the production of studies and guidelines, with content ranging from eco-toilet design, greywater treatment, architectural aspects, agricultural reuse, health guidelines, planning tools, etc.

Implementation puts theory into practice with ecological sanitation pilot projects in diverse regions around the world. Because the most important factor to successfully implementing an ecosan system is local adaptation, EcoSanRes provides a logical framework for prospective pilot projects and insists the projects meet stringent criteria before approval.

EcoSanRes is currently running three major urban pilot projects in China, South Africa and Mexico. In addition preparations are being made to develop similar projects in Bolivia and India.

For more information about the partner organisations and programme activities please consult

www.ecosanres.org