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Technical Support Document for Reduction of Pathogens and Vector Attraction in Sewage Sludge

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TECHNICAL SUPPORT DOCUMENT FOR REDUCTION OF PATHOGENS AND VECTOR ATTRACTION IN SEWAGE SLUDGE

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SECTION ONE

INTRODUCTION

1.1 BACKGROUND

Sewage sludge, which is generated during the treatment of domestic sewage in a treatment works, must be used or disposed properly. It can be used or disposed in a number of ways, including: application to the land, placement on a surface disposal site, incineration in a sewage sludge incinerator, and codisposal with municipal solid waste. This document discusses pathogen and vector application reduction requirements for sewage sludge that is either land-applied or placed on a surface disposal site.

The term **land application** encompasses all methods of applying sewage sludge or material derived from sewage sludge to the soil or incorporating it into the soil. The purposes of applying sewage sludge to the land are to fertilize crops grown in the soil and to condition the soil using the organic material in the sewage sludge. Two public health concerns about land application of sewage sludge are the potential risk posed by pathogens (disease-causing organisms) in sewage sludge and the potential of the sewage sludge to attract vectors (e.g., insects or birds) that can transmit pathogens from sewage sludge to humans.

Surface disposal is the placement of the sewage sludge on land for final disposal. The major purpose of this practice is to dispose of the sewage sludge rather than to fertilize or condition the soil. There also are concerns about the risks from pathogens in sewage sludge placed on a surface disposal site and about the potential of the sewage sludge to attract vectors.

Concerns about pathogen and vector attraction of sewage sludge applied to the land or placed on a surface disposal site were addressed originally in 1979. At that time, EPA adopted guidelines for sewage sludge applied to land or disposed in landfills. These guidelines were incorporated into 40 CFR Part 257, Criteria for Classification of Solid Waste Disposal Facilities and Practices, which contained specific requirements for managing sewage sludge. Part 257.3-6 included a requirement that sewage sludge be treated before it is applied to land to reduce pathogen levels and to reduce vector attraction. Appendix II of Part 257 listed specific processes that may be used to treat sewage sludge for pathogen and vector attraction reduction. These processes were divided into two categories based on the level of pathogen control achieved: "Processes to Significantly Reduce Pathogens" (PSRPs), which reduce pathogens to a level comparable to that achieved by a well-run anaerobic digester, and "Processes to Further Reduce Pathogens" (PFRPs), which reduce pathogens to below detectable levels. Part 257 also specifies management practices designed to minimize the potential for direct and indirect exposure to PSRP-treated sewage sludge; a PSRP sewage sludge may still contain some pathogens. Similar, but slightly less stringent requirements were given for septic tank pumpings. (The Part 257 requirements and their relationship to the Part 503 requirements are discussed further in Section 7.)

In 1982, EPA established an Intra-Agency Sludge Task Force to recommend procedures for implementing a comprehensive regulatory program for sewage sludge management. The Task Force recommended that such a regulatory program be developed using the combined authorities of Section 405 of the CWA and other existing regulations so that comprehensive coverage could be provided. Accordingly, two additional regulations were recommended: one that would establish requirements for state sewage sludge management programs, and the other that would provide technical criteria for the use or disposal of sewage sludge.

Acting on that recommendation, EPA proposed State Sludge Management Program Regulations (51 *Federal Register*, February 4, 1986, page 4458). These regulations proposed that states develop management programs that comply with existing federal criteria for the use or disposal of sewage sludge. The proposed State Sludge Management Program Regulations focused on the procedural requirements for submission, review, and approval of state sewage sludge management programs. On March 9, 1988, these regulations were proposed again at 53 *Federal Register* 7642 to reflect changes in requirements for sewage sludge management programs imposed by the 1987 Water Quality Act. After public comment, these regulations were promulgated under 40 CFR Part 501 on May 2, 1989 (54 *Federal Register* 18716, May 2, 1989).

EPA's Office of Solid Waste (OSW) began the task of preparing the technical criteria (i.e., 40 CFR Part 503) for the use or disposal of sewage sludge in 1980. This task was transferred to the Office of Water in 1984. After the Office of Water was reorganized, the Office of Water Regulations and Standards (OWRS) was renamed the Office of Science and Technology (OST), and the Wastewater Solids Criteria Branch was renamed the Sludge Risk Assessment Branch (SRAB). The SRAB developed the pathogen and vector attraction reduction requirements in Subpart D of the Part 503 regulation based on information in this technical support document.

1.2 DESCRIPTION OF A PART 503 STANDARD

A standard for the use or disposal of sewage sludge consists of general requirements, pollutant limits, management practices, and operational standards. For land application and surface disposal, operational standards are included in the Part 503 regulation for pathogens and vector attraction reduction. A Part 503 standard also contains requirements concerning the frequency of monitoring, recordkeeping, and reporting when sewage sludge is used or disposed through one of the practices addressed by the regulation.

1.3 SCOPE OF THIS DOCUMENT

This document provides technical support for the pathogen and vector attraction reduction operational standards in 40 CFR Part 503 (Standards for the Use or Disposal of Sewage Sludge). Section 2 of this document describes the components of disease risk in sewage sludge, including the types of pathogens found in sewage sludge that pose a potential public health risk, how well pathogens survive after sewage sludge use or disposal, how they are transported and come in contact with humans, and what dose of a pathogen is necessary to cause infection. Section 2 also discusses the microorganisms addressed in Part 503 and vector attraction reduction in sewage sludge. Section 3 describes the applicability of the Part 503 pathogen and vector attraction reduction requirements. Section 4 discusses the requirements that have to be met for a sewage sludge to be classified Class A with respect to pathogens. Section 5 discusses the Class B pathogen requirements, and Section 6 discusses the vector attraction reduction requirements in Part 503. Section 7 compares the type of pathogen and vector attraction reduction requirements in Part 503 to the type of pathogen and vector attraction reduction requirements in 40 CFR Part 257. An appendix to this document provides a copy of Subpart D of the Part 503 regulation.

SECTION TWO

COMPONENTS OF DISEASE RISK IN SEWAGE SLUDGE

The disease risk from pathogens in sewage sludge this is used or disposed originates from the pathogens in the incoming wastewater at a treatment works. The ultimate risk to public health and the environment depends on several factors:

- How well these organisms survive wastewater and sewage sludge treatment.
- How well these organisms survive exposure to sunlight, ambient temperatures, and other environmental factors.
- The existence of a pathway or route by which organisms can travel from the sewage sludge to contact with humans and animals.
- The likelihood that disease results if these organisms are ingested.

This section discusses these factors.

2.1 PATHOGENS OF CONCERN

A pathogen is a disease-causing organism. Sewage sludge can contain many different pathogens. Pathogens that propagate in the enteric or urinary systems of humans and are discharged in feces or urine pose the greatest risk to public health. Other pathogens in sewage sludge originate outside the enteric system (e.g., from soil). Clostridium sp. are a good example. Because fecal matter is not the primary source of pathogens that originate outside the enteric system, these pathogens are of less concern with respect to the use or disposal of sewage sludge. The following section discusses the enteric pathogens in sewage sludge that represent the most significant risk to humans.

2.1.1 Bacteria

Pathogenic enteric bacteria can colonize portions of the enteric system; indeed the primary reservoir of these organisms is the enteric systems of animals and humans. These organisms are not, however, normal inhabitants of the healthy human enteric (intestinal) system. They are present when an individual contracts a bacterial disease or illness. Consequently, they occur rarely in an individual's fecal waste, but when they do, high levels can be found. Because wastewater discharged to a treatment works contains wastes from many people, pathogens are usually present, but their densities vary depending on the prevalence of bacterial disease outbreaks or the presence of asymptomatic carriers in the local community. Frequently, there are periods when certain pathogenic bacteria are below detection limits in the wastewater and in the sewage sludge generated during the treatment of the wastewater. Farrell et al. (1990) found that salmonellae were frequently undetectable in untreated domestic sewage at small treatment works. Bacterial species present in wastewater and their densities are therefore highly unpredictable.

2.1.1.1 Types

Kowal (1985) lists several pathogenic enteric bacteria and bacterial species of major concern in sewage sludge and a greater number of less concern. The selection was based on the density of the bacteria in sewage sludge, the extent of the disease, and the seriousness of the illness produced. Among bacterial species singled out are Shigella sp., Salmonella sp., and Yersinia sp. All cause enteric disease in large numbers of people in the United States.

2.1.1.2 Densities

The density of pathogenic bacteria in the stool of an infected person may be 1 million per gram of solids (Kowal, 1985). Typical values in sewage sludge are much lower, because only a small percentage of the population is discharging pathogenic bacteria at a given time. For example, densities of Salmonella sp. over 1,000 per gram in sewage sludge are encountered infrequently. On the other hand, the normal bacterial inhabitants of the lower intestines are found at much higher densities. Obligate anaerobic bacteria have average densities approaching 1,000 million per gram in feces. Facultative bacteria, such as the fecal coliform group, have average densities around 100 million per gram in feces.

2.1.1.3 Survival

Most research on bacterial survival in sewage sludge has focussed on Salmonella sp., which include over 2,300 serotypes. These organisms may cause salmonellosis, an acute gastroenteritis. Salmonellae have been emphasized because they are more frequently identified in sewage sludge than are other bacterial species, they cause severe illness with relative frequency (substantially more cases of salmonellosis are reported annually in the United States than yersiniosis and shigellosis combined), and a reliable quantitation method exists that can detect them.

Typically, densities of pathogenic bacteria are reduced but not eliminated by conventional sewage sludge treatment processes like anaerobic digestion (see Section 5.2.2), but special processing such as pasteurization eliminates them (Section 4.4). Bacterial densities in sewage sludge applied to plants decline to low values in less than 30 days (Kowal, 1985). Decline in surface soil is rapid—slightly slower than for sewage sludge on plants—but the decline is much slower in the soil immediately below the surface. The rate of decline is highest under adverse environmental conditions such as high temperature, sunshine, and desiccation (Sorber and Moore, 1987).

2.1.1.4 Monitoring

Monitoring sewage sludge on a regular basis to determine the types and densities of pathogenic bacteria present is desirable but impractical. Quantitation methods for some bacterial species are difficult and unreliable, and require high skill levels. Too many species have to be measured, even if measurement is restricted to bacteria of major concern. Fortunately, the bacterial pathogens most frequently present at high densities, the salmonellae, can be quantified with reasonable accuracy, although the method is difficult and time-consuming. Monitoring for salmonellae has an advantage over monitoring indicator organisms because salmonellae are pathogens.

The best indicators of the potential presence of bacterial enteric pathogens in unprocessed sewage sludge are the facultative enteric organisms that normally inhabit the intestines, such as Escherichia coli, the fecal coliforms, and fecal streptococci. Though these indicators do not correlate well with any individual enteric bacterial pathogen species, they do indicate the presence of human fecal waste, which is the carrier of the pathogens. Thus, they are good long-term indicators of pathogenic bacteria, but will not always correlate well in the short term. A substantial body of research (for example, Berg and Berman, 1980; Farrell et al., 1985) indicates that, as sewage sludge is processed, densities of salmonellae and fecal indicators fall in about the same proportion, so the fecal indicators remain good indicators at least of salmonellae, and probably for other enteric bacterial pathogens.

When sewage sludge is highly processed to reduce pathogens to below detectable levels, a sufficient reduction in bacterial indicator densities can be used to indicate absence of bacterial and other pathogens. This approach is used in the drinking water industry, where absence of fecal coliform (detection limit of approximately 1 MPN [most probable number]/100 mL) is used to indicate adequate disinfection. Indicator densities are seldom reduced to these levels even in highly processed sewage sludge—fecal coliform densities of 1,000 MPN per gram of sewage sludge solids are used in some circumstances to indicate the absence of pathogens in sewage sludge. To be more certain that a specific pathogen is absent, one can specifically test for that pathogen. This is frequently done for salmonellae. When salmonellae are known to be abundant in the unprocessed sewage sludge, their absence in the processed material not only indicates their own absence, but can also indicate absence of other pathogens.

2.1.1.5 Regrowth

The bacteria of concern are not spore formers so they are relatively easy to destroy by adverse conditions. On the other hand, they are facultative (i.e., able to grow in the presence or absence of oxygen) and grow readily over a broad temperature range, about 10 to 40°C, if nutrients are available and competitors and predators are few. The ability to regrow is a particular disadvantage in instances where processing kills most predators and competitors. If nutrients are available when the stress (e.g., elevated temperature) is removed, very rapid regrowth of the bacteria can occur.

Fecal indicators can still be used as conservative indicators of regrowth of bacteria. Because the initial densities of fecal indicators are much higher than are pathogen densities, the fecal indicators survive adverse conditions better than the pathogens survive. Processing may totally eliminate pathogenic bacteria most of the time but nearly always leaves some fecal indicators. These can regrow and indicate the presence of pathogenic bacteria when in fact none are present. Thus, fecal indicators may be too conservative in some cases. When this situation is likely, a relatively hardy pathogenic bacterial species such as Salmonella sp. may be used as an indicator of pathogenic bacterial contamination. Yanko (1988) used a combination of these two approaches to assure product quality at a composting site. He set a coliform standard (10 MPN/g) before a compost batch could be released to a customer. If the compost could not be brought down to this level, he tested the pile for salmonellae and released it if results were negative.

2.1.2 Viruses

Kowal's extensive review lists the human enteric viruses likely to be present in wastewater and sewage sludge (Kowal, 1985). These enteric viruses are not normal inhabitants of the gastrointestinal tract and their presence in the gastrointestinal tract indicates an infection that may show no symptoms. These enteric viruses are released into the intestines from cells in the gastrointestinal tract where they replicate. Consequently, they are present in fecal discharges. They are generally adsorbed to solid particles or enmeshed in clumps of solid particles.

2.1.2.1 *Types*

Kowal lists several enteric viruses of concern: five subclasses of the genus enterovirus (e.g., polio-, Coxsackie-, Echo-) as well as other enteric viruses, including hepatitis A virus and rotaviruses. These viruses cause a wide variety of illnesses; for example, hepatitis A virus causes approximately 40,000 to 50,000 cases of infectious hepatitis in the United States. Rotaviruses cause acute gastroenteritis, primarily in children. Viral diseases caused by enteroviruses include paralysis, diarrhea, meningitis, heart disease, and respiratory illness. Most infections are asymptomatic, so many more infected people shed viruses than is indicated by disease incidence numbers. A particular enteric virus may or may not be present in the wastewater, depending on the presence or absence of infected people in the community.

2.1.2.2 *Densities*

The densities of enteric viruses in sewage sludge range widely. Brashear and Ward (1982) report 5-145 PFU/mL (plaque-forming units per milliliter) of a raw sewage sludge. Assuming 2 percent solids in the sewage sludge, this is equivalent to 250-7,000 PFU/g of solids. Other sewage sludge could show higher or lower densities. Less information is available on enteric virus densities than on indicator bacteria or Salmonella sp. densities because of the complexity of the method for determining densities and the special skills and equipment needed.

2.1.2.3 *Monitoring*

There are a variety of methods for identifying viruses in sewage sludge. The most common procedure, the plaque assay method, is described by Bitton (1980). A viral suspension extracted from sewage sludge is placed on the surface of an animal cell monolayer that has been grown on the interior wall of a glass bottle. After providing time for adsorption of the viruses to the cell layer, an overlay of agar is poured over the monolayer to immobilize the system and provide nutrient and moisture for the cells. Time is allowed for the viruses to invade the cells and replicate. Each virus invasion leads to an infection zone where cells have been destroyed.

This localized area is called a plaque. Staining or other techniques are used to identify plaques. Unfortunately, this and other virus identification methods are expensive and require skilled personnel.

The plaque-forming method currently in use identifies a wide variety of enteroviruses (Bitton, 1980). The number depends on the types of cells used in the test. Some important enteric viruses—Hepatitis A and rotaviruses—are not enumerated by this method. Serological methods can be used to determine the specific viruses that form the plaques, but this adds another level of complexity to an already complex procedure.

The plaque-forming method could serve as a useful indicator test for all enteric viruses. Goyal et al. (1984) report on a round robin comparison of the EPA method and the sonication-extraction method for determining viruses in sewage sludge that resulted in the recommendation to accept both as tentative American Society of Testing Materials standard methods.

An alternative to using a virus test to indicate viral densities is to use the fecal coliforms and/or fecal streptococci test for this purpose. As with pathogenic bacteria (see Section 2.1.1.4), the fecal indicators are not expected to correlate over the short term with virus densities; however, because they indicate the presence of fecal wastes, they will correlate well over the long term.

Another area of interest is whether indicator organism densities can be used to indicate the effect of sewage sludge processing conditions (e.g., time and temperature) on viral densities. Indicator organisms can be used for this purpose if available data indicate a satisfactory correlation between the effect of the condition on viral densities and indicator organisms. Such correlations appear adequate for most but not all processing procedures. For example, Berg and Berman (1980) demonstrated that, in anaerobic digestion, the decline in viruses showed a reasonable relationship to the decline in fecal coliforms and fecal streptococci. On the other hand, irradiation of sewage sludge by gamma rays or high-energy electrons requires 20-30 kilorads to reduce coliforms by a factor of 10 (Ward, 1981), but 10 times that dose is needed to achieve the same reduction in viruses. With irradiation, a relationship exists between the ıeclines in the two types of organisms, but it does not allow coliforms to be an indicator for ·iruses. Coliforms could be reduced to negligible densities while viruses are still present.

2.1.2.4 Regrowth

Unlike bacteria, viruses cannot regrow outside their hosts. Consequently, viruses are ·educed permanently by treatment.

2.1.3 Protozoa

2.1.3.1 Types

Numerous protozoa invade the human gastrointestinal system and cause disease. Their ·ysts are found in municipal wastewater and sewage sludge. The three most important noted by ⟨owal (1985) are Entamoeba histolytica, Giardia lamblia, and Balantidium coli. These organisms ıre known to transmit human disease through a water route and by direct contact. The ·haracteristic illness is diarrhea.

2.1.3.2 Densities

Protozoan cysts are excreted in great numbers from infected persons. Infection rates in he population are low except for Giardia lamblia, where the carrier rate may range from 1.5 to :0 percent (Benenson, 1975). Levels in wastewater have been estimated to be 4 cysts/L for Entamoeba histolytica (Foster and Englebrecht, 1973) and 10^4 to 2 x 10^5 cysts/L for Giardia amblia (Jakubowski and Ericksen, 1979). More recently, Sykora et al. (1991) reported similar lensities for Giardia lamblia in untreated wastewater from 11 treatment works. Madore et al. 1987) reported Cryptosporidium oocyst densities as high as 10,000 in wastewater and 1,000 in ·ffluent from the activated sludge process.

Little information is available on the densities of protozoa in sewage sludge. If, as expected, most are trapped in the sewage sludge, their density in unprocessed sewage sludge on a volume basis would be about 200 times the density in untreated wastewater. Processing of solids in any wastewater or sewage sludge treatment process reduces these densities.

In the investigation noted above, Sykora et al. (1991) reported densities in sewage sludges that ranged up to several thousand per gram. Densities were probably higher because recoveries were on the order of 10 percent. All these sewage sludges had been processed by anaerobic digestion except one. The ratio between densities in sewage sludge and wastewater ranged from 0.28 to 1.45 for processed sewage sludges and was 2.7 for unprocessed sewage sludge. These data indicate that digestion reduces protozoan densities substantially. (Because current viability techniques were not applicable to indigenous protozoan cysts in sewage sludge, the authors made no conjectures about the public health hazard represented by the cysts.)

2.1.3.3 Survival

Quantitative information on survival of protozoan forms in processing of wastewater and sewage sludge and subsequent survival on the land is scant. Protozoa and protozoan cysts are reported to be more sensitive to the adverse effects of sewage sludge treatment processes than other pathogens. Pedersen (1981) suggested they do not survive anaerobic digestion. Studies of the effect of anaerobic digestion on survival of G. lamblia are being conducted by Sykora (EPA, 1992a) but results are not yet available. Kowal (1985) cited several publications showing survival less than 2 weeks, even on damp soil.

Despite the shortage of information, the consensus of opinion from the literature is that survival for protozoan cysts is much shorter than for the other pathogens. Like viruses and unlike bacteria, the protozoa of concern do not multiply outside their animal hosts. Consequently, meeting the Part 503 requirements for pathogen reduction (see Sections 4 and 5), which limit survival of the other pathogens, will eliminate risk from protozoa. For this reason, no further consideration is given to protozoan forms in this document.

2.1.4 Helminths

2.1.4.1 Types

The helminths of concern are the nematodes, or roundworms, and the cestodes, or tapeworms. The most common helminths pathogenic to man and likely to be found in sewage sludge are:

Ascaris lumbricoides (human roundworm)

Ascaris suum (pig roundworm)

Trichuris trichiura (human whipworm)

Taenia saginata (beef tapeworm)

Taenia solum (pork tapeworm)

Toxacara canis (dog roundworm)

Details of the intricate life cycles of these helminths and the diseases they cause are discussed by Kowal (1985) and Faust et al. (1976). Ascaris create pneumonitis when the ingested larvae migrate through the lungs. The human roundworm develops in the small intestine with blockage possible if a number of worms are present. Toxacara canis larvae migrate blindly in the human body, where they can seriously damage viscera and other organs, including the eyes. Whipworms develop from eggs to larvae to worms in the intestines, lodging finally in the large intestines. Light infestations are asymptomatic, but heavy infestations can be life-threatening. Tapeworms can cause pain and digestive disturbances. Tapeworm eggs are primarily a hazard to livestock. When eggs are ingested, the larvae produced eventually form cystercerci that damage the animal's organs. Humans ingest the cysts from poorly cooked meat, develop the tapeworm, and release the eggs in the feces. Animals ingest eggs when they graze, which completes the cycle.

2.1.4.2 Survival

Helminth ova are extremely resistant to environmental exposure and the effects of chemicals such as lime and chlorine, although they are easily inactivated by temperatures above 50°C (Lee et al., 1989). Of the helminths, ova of Ascaris sp. survive the longest in the environment. Survival of 7 years under favorable conditions has been reported (Little, 1980). Reimers et al. (1981) report that in the United States, Ascaris sp. have the highest concentration of any helminth in sewage sludge. Because of their prevalence and their hardiness, Ascaris sp. are used as a conservative indicator of viable helminth ova.

2.1.4.3 Monitoring

Except for processes using temperatures above 50°C, the exceptional hardiness of helminth eggs prevents use of reduction in indicator organism densities to indicate reduction in helminth eggs. At temperatures above 50°C, a reduction in the densities of indicator organisms can be used to infer that processing was of sufficient duration to reduce helminth eggs.

2.2 SURVIVAL OF PATHOGENS IN THE ENVIRONMENT

When sewage sludge is applied to land or placed on a surface disposal site, pathogen densities are reduced by adverse environmental conditions. How rapidly densities decline depends on the media: in the air, on plants, on the soil surface, or in soil. Each media is discussed separately.

2.2.1 Air

Sewage sludge may be present in air in several forms:

- Large droplets, such as might be created when liquid sludge sewage is applied using a splash plate on the back of a truck.
- Smaller drops formed when a 2- to 4-percent solid sewage sludge is sprayed from a high-pressure nozzle.
- As particles in dust when a field to which sewage sludge has been applied is cultivated.

The large sewage sludge droplets formed by low-pressure sprays present no risk outside the sewage sludge site, because large droplets do not travel far from the application point. Spray from a high-pressure nozzle needs more consideration. Kowal (1982) reviewed the health risks of aerosols formed in spray application of wastewater. The substantial research in this area shows that the infection risk from pathogens in the aerosols is small. Pathogen densities are reduced by "aerosol shock," by desiccation, and by solar radiation. Pathogens reaching a human host are reduced by dilution with ambient air. In a later publication, Kowal (1985) cites results by Harding et al. (1981) that showed elevated levels of bacteria at sewage sludge spray irrigation sites but significantly less than at wastewater spray irrigation sites. He cites the conclusion of Sorber et al. (1984) that spray application of sewage sludge does not represent a serious threat to health of individuals more than 100 m downwind.

No quantitative data are available on the presence of pathogens in dust raised when fields to which sewage sludge has been applied are plowed or cultivated, but consideration of the problem shows that risks will be minimal. Before dust can be raised, the soil surface must be dry. The exposure to sunlight, as well as the desiccation that occurs during drying (Ward and Ashley, 1977; Yeager and Ward, 1981), will reduce the density of pathogenic bacteria and viruses to very low levels. Viable helminth ova would survive better but they are relatively large and would be expected to settle out close to the point where the dust was raised.

Workers on the site can be adequately protected from both droplets and dust by wearing air filtering masks and by changing clothing after exposure.

2.2.2 Vegetation

Sewage sludge is sometimes applied to soil where plants are growing (e.g., in a field of alfalfa or a woodland). It gets on plant surfaces during application and when rain falling on the field spatters sewage sludge upward. The leaves of some plants, such as the bottom leaves of tobacco plants, frequently have an ash content as high as 30 percent, mostly from soil splashed onto the leaves by rainfall.

Kowal (1985) concluded from his literature review that pathogens in sewage sludge on plant surfaces die off more quickly than those in sewage sludge on the soil surface, because of more exposure to sunlight and greater desiccation. Bacteria and viruses are quickly destroyed. Larkin et al. (1976) show that viral densities are reduced by a factor of one hundred 14 days after spray irrigation with sewage sludge. Rudolfs et al. (1951) found Ascaris eggs to be completely degenerated after 27-35 days. On the other hand, Mueller (1953) found that Ascaris eggs remained viable for several years in the shaded surface soil of a strawberry plot. Nevertheless, Kowal indicated that the risk from pathogens deposited on plant surfaces during application should be minimal 1 month after application.

2.2.3 Soil

The survival of pathogens in soil is complicated by many factors: soil moisture, temperature, pH, sunlight, organic matter, and antagonistic soil microflora (Gerba et al., 1975). This large number of variables and their nature make experimentation difficult—several of these factors cannot be controlled by the experimenter in field experiments, and laboratory experiments do not simulate field conditions well. As a result, experiments measuring pathogen survival have produced a wide range of results. Sorber and Moore (1987) reviewed the available literature and summarized the most representative data, including microbial die-off rates from several studies in which sewage sludge was introduced in the upper layer of soil. These die-off rates are summarized as regression equations that relate days required for 90- and 99-percent die-off (T90 and T99) to soil temperature (t). These equations were used to calculate the die-off rates presented in Table 2-1 below.

TABLE 2-1

DIE-OFF RATES FOR SALMONELLAE, FECAL COLIFORM, AND VIRUSES IN SOIL[1]

Microorganism	Depth (cm)	Temperature (°C)	T90[2] (days)	T99[2] (days)
Salmonella sp.	5-15	5	15	30
		15	6.3	12
fecal coliform	0-5	5	23	44
		15	10	18
viruses	0-15	5	24	47
		15	10	19

[1]Calculated from summary equations developed by Sorber and Moore (1987) from die-off data in the literature (presented in Sorber and Moore's Table 17).

[2]T90, T99—days required for microorganisms to be reduced to 90 and 99 percent of the original value.

The T90 and T99 days in Table 2-1 show that fecal coliforms survive longer than salmonellae, which makes them a suitable indicator for salmonellae. Their survival is slightly less than for viruses in the upper layer of the soil. If allowance is made for this minor difference, fecal coliform can be used as an indicator for the survival of viruses in the soil.

Viruses evidently survive better when they are below the topsoil. For deeper application (15 cm), Sorber and Moore (1987) cite the work of Damgaard-Larsen et al. (1977) that showed that 56 and 100 days were required for 1- and 2-log reductions in viruses.

The ova from helminths such as Ascaris and Toxocara are extremely resistant to environmental stress. Pedersen (1981) observed that conventional treatment processes have very little effect on these ova, so they arrive in sewage sludge at a land application site or surface disposal site virtually at their original concentration in the sewage sludge. Sorber and Moore (1987) cite results that indicate relatively short survival of the ova when sewage sludge is applied to the land surface, but much longer survival under a few centimeters of soil. Jakubowski (1988) reported research with Ascaris that indicated long survival if the sewage sludge is tilled into the soil. His results indicated 50-percent survival of Ascaris ova after 3 years of exposure in fallow or tilled plots. On the other hand, Ascaris survival in sewage sludge applied to the surface of grassed plots was much shorter. Within 3 months, densities were reduced by more than 90 percent at three field locations.

2.3 TRANSPORT OF PATHOGENS TO HUMANS

The pathogens in sewage sludge applied to land or placed on a surface disposal site pose a disease risk only if there are routes by which the pathogens can contaminate humans. The principal routes of contamination are ingestion and inhalation. Absorption through the skin is believed to be a minor exposure route. Sewage sludge may be transported to humans by many routes: aerial; ground water or surface water; adherence to objects that come into contact with humans; surficial or internal contamination of crops eaten by humans; and vectors. The vectors may be flies, mosquitoes, fleas, or rodents, as well as other animals that transport disease organisms to humans either mechanically or by biological processes.

2.3.1 Air Transport

Some sewage sludges and sewage sludge application methods create dust or spray that may be inhaled by operators or by others if transported from the site. Inhaled dust or aerosol usually ends up in the gastrointestinal system. Methods that may create dust or spray include:

- *Splash Plate*. Sewage sludge is frequently applied to land as a liquid using a splash plate on the back of a truck; sometimes the sewage sludge applicator is a high-pressure nozzle.
- *Heat Drying*. Heat-dried sewage sludge is dry enough to create a dust when handled and applied.
- *Incorporation*. Incorporation of surface-applied sewage sludge into the soil may create dust if the soil has dried out after sewage sludge application.

The likelihood that liquid sewage sludge dripped from the back of a truck or sewage sludge cake thrown on the soil by a manure spreader transports aerially from the site is extremely low. Therefore, the risk to humans not engaged in work on the site is negligible.

2.3.1.1 High-Pressure Spray Application

Sewage sludge application with a high-pressure spray designed to reach a distance of 100 m is low in risk (see Section 2.2.1) only if a sufficient distance is provided (100 m) from individuals downwind. This is usually the case. Spray application is used only on large sites or on remote sites so irregular or full of obstacles (e.g., a forest) that direct application from the back of a truck is impossible. Distances to individuals or residences are generally much greater than 100 m.

2.3.1.2 Heat-Dried Sewage Sludge

Heat-dried sewage sludge, although dry and potentially dusty, is not a problem, because the particles are too large and hard to cause generalized dusty conditions when applied from a spreader. Limited local dusting may occur, exposing the operator to dust, but this can be controlled by using dust masks. Also, heat-dried sewage sludge is usually free of pathogens.

2.3.1.3 Incorporation

Incorporation of sewage sludge into the soil creates no hazard if the soil and sewage sludge are moist. If they are dry, dust can form and travel for several kilometers. Only light fine particles travel any distance. By the time the sewage sludge has dried sufficiently to create dust, however, the pathogens have been greatly reduced (Yeager and Ward, 1981). Exposure to sunlight further lowers any residual pathogen densities. The hazard for incorporation is expected to be less than the hazard for spray application, which has been demonstrated to be minimal to humans off site (see Section 2.3.1.1). Workers on site can be protected by using dust masks.

2.3.2 Ground-Water Transport

When sewage sludge is applied to the land surface or placed on a surface disposal site, the soil and sewage sludge particles form an effective filter mat. For the most part, only soluble and colloidal particles enter the soil. The larger organisms, such as helminth eggs, are retained on the land surface; however, virus particles and, sometimes, bacteria are small enough to pass through the soil to ground water. The mechanisms that remove these organisms during soil transport are quite different: bacteria are removed primarily by filtration whereas viruses are removed by adsorption.

Coarse sand is the soil medium most conducive to pathogen transport (Kowal, 1985); it does not provide a good filter medium to remove bacteria and is a poor adsorbent for viruses. Fine-grained soils, on the other hand, are effective at removing both bacteria and viruses. Cracks in soils caused by desiccation and root, insect, and animal holes can allow substantial transport of organisms to the subsoil. Fissured rock and limestone beneath the soil also can allow transport. However, because free liquid is only occasionally present in soil—as a result of sewage sludge application or rainfall—the risk of transport of sewage sludge or sewage sludge pathogens to ground water is minimized. By contrast, a septic tank leach field creates a far greater risk of ground-water contamination because the leach field contains flowing pathogen-laden water that directly encounters all the subsurface pathways in the soil. Similarly, a wastewater application site that receives a wastewater loading equivalent to 200 cm of rainfall per year provides a far greater driving force for virus movement than does liquid sewage sludge addition, which ordinarily contributes only about 2 to 4 cm additional water loading to the annual rainfall loading at a site.

Viruses in particular appear to have a potential to migrate to ground water; however, their movement to and within ground water is slow because the water itself moves slowly, and because the viruses adsorb and desorb on the soil, further slowing their progress (Landry et al., 1980). Gerba et al.'s recent work (1991) at a wastewater infiltration site showed that adsorption and/or filtration substantially reduces virus density. Taking into consideration the effect of time on virus density, densities were reduced at least 2 logs by 15 feet of soil when wastewater was applied at an infiltration rate of 2 feet per day on a sandy soil. Adsorption at a sewage sludge application site is expected to produce greater virus reductions because bulk flow of water occurs only occasionally and at rates almost two orders of magnitude lower than at an infiltration site. Virus densities also would decline with time. A typical maximum survival time for viruses within the soil at low temperature (3 to 10°C) is 170 days (see Table 12 in Kowal's 1985 review). If, as is likely, movement to ground water is slow, and the movement of ground water itself beyond the site boundary also is slow, the potential for virus contamination of ground water beyond the site is negligible.

2.3.3 Surface-Water Transport

Surface water can be contaminated by runoff (flow over the surface of the land) from a land application site or a surface disposal site, or by rainwater leaching pathogens downward and then moving laterally below the ground surface through root holes, animal burrows, and fissures in rock strata until a stream is reached. Movement through fissures is likely only for sewage sludge applied to forest soil. Helminth eggs are transported by rainwater but, because of their high density, they tend to drop out of rivulets and concentrate in deposits in a manner roughly analogous to deposits of gold in stream beds. On the other hand, bacteria and viruses can be carried by fine solids wherever the runoff goes. As noted earlier, bacteria and viruses generally die off to low densities about 1 month after application to the soil surface, so the potential health hazard from runoff after a rainfall disappears about 1 month after sewage sludge is applied.

2.3.4 Transport by Fomites

Fomites are inanimate objects that may be contaminated with infectious organisms and then transmit those organisms. Crops, soil, equipment, and workers' clothing are fomites because they are easily contaminated with sewage sludge and are transported off the site. Viruses and bacteria on exposed crop surfaces die off in less than a month; some helminths probably die off less rapidly. Restricting the movement of crops from the site until at least 1 month following application reduces the potential for transporting pathogens from either a land application site or a surface disposal site. Good sanitary standards at the application site minimizes the transport of organisms from the site on clothing and equipment.

Crops grown below the soil surface present a much more serious problem than crops grown above the soil surface. Helminths eggs survive below ground for years rather than months. The cumulative risk of ingesting a viable helminth egg as a result of ingesting 0.1 gram of sewage sludge-treated soil per year for 10 years was calculated to be 1 in 70 (Farrell, 1991). This calculation assumed that sewage sludge containing five viable helminth eggs per gram was applied once in the 10 years at a rate of 10 metric tons per hectare; helminth egg half-life was 3 years; and the first crop was harvested 20 months after sewage sludge application. To adequately protect against this rather large risk, a longer period between sewage sludge application and harvesting appears appropriate when root crops are grown. This provides protection by allowing a longer time for the helminth eggs to die off.

2.3.5 Transport by Vectors

Vectors are agents capable of transmitting a pathogen from one organism to another either mechanically (by simply transporting the pathogen) or biologically by playing a specific role in the life cycle of the pathogen (for example, the role of mosquitos in relation to malaria). Consideration of vector transport is essential to any disease risk containment effort.

2.3.5.1 Conventional Vectors

Insects are the conventional vectors of disease. Flies of several varieties are attracted to fecal matter including sewage sludge. Unconventional vectors include humans working on the site who can become ill and become a vector to their families. Animals that graze on land to which sewage sludge has been applied also can serve as vectors.

The hazards from vector transport in sewage sludge utilization are difficult to quantify and thus tend to be underestimated. A study reported by Gemmell (1986) demonstrated the ability of vectors to spread disease. The parasite eggs from fecal wastes from a dog pen were transported by flies, heavily contaminating 30 hectares of grazing land. Eggs were dispersed over 30,000 hectares. Soil contamination was determined by observing infestation in sentinel animals grazed at various distances from the source of contamination.

Transport of disease by vectors traditionally has been controlled by eliminating either the vectors or the reservoir of infection. In this case, sewage sludge is the reservoir of infection. Injection of sewage sludge into soil so that it is not available to almost all vectors effectively eliminates it as a reservoir of infection, but this method is not always practical. Disease vectors could be eliminated by applying toxic material to the sewage sludge, but adding a toxicant to the environment is clearly not desirable. Vectors can be discouraged from approaching the sewage sludge by adding a repellent. Heavy applications of chlorine to sewage sludge evidently act at least partially by this mechanism. Vectors also can be controlled by eliminating whatever is attracting them. Chemicals can be added that cause biostasis, thereby preventing further production of compounds that attract vectors. Application of lime appears to have this effect.

Another common practice is to biologically treat the sewage sludge by aerobic or anaerobic processes so thoroughly that vectors no longer have an interest in it.

2.3.5.2 Unconventional Vectors

These approaches may need to be supplemented to eliminate problems from unconventional vectors. Some vectors, such as birds, are attracted by the appearance of visible food wastes. Physical pretreatment such as screening and grinding eliminates most of this problem and the vector attraction reduction process usually eliminates the remainder. The potential for grazing animals to become disease vectors can be minimized through management practices.

Transport by humans working on site can be controlled by management practices such as cleanliness and wearing protective equipment. Tracking medical histories and sickness in the workers' households is valuable for monitoring this risk.

Risks posed by public use of a site can be controlled by limiting access to the site. The length of the period of access control needed depends on all the factors that control the die-off of microorganisms at the site.

2.4 TRANSPORT OF PATHOGENS TO AND THEIR IMPACT ON PLANTS AND ANIMALS

Pathogens in sewage sludge enter the environment when sewage sludge is applied to the land or placed on a surface disposal site. Typically, these organisms do not harm plant life. The adverse conditions of the environment cause a steady decline in their densities.

Animal life, particularly warm-blooded animals, can be harmed by sewage sludge applied to land or placed on a surface disposal site. Enteric viruses can often cross species lines. This is even more likely with pathogenic bacteria. The risk to animals is small when sewage sludge is applied to agricultural soil or placed on surface disposal sites. Domestic animals are not grazed on such sites, and wild animal life on these sites is much lower than in grassland, meadows, and forests, where soil is typically not disturbed by plowing and cultivating.

There is little reliable information on the effect of pathogens in sewage sludge on wild animal life. More information is available on its effect on grazing animals. In the United States, the major impact of sewage sludge pathogens is likely to be to cattle grazing on pasture to which sewage sludge has been applied. Cattle generally ingest substantial amounts of roots and soil as well as above-ground plant matter when they graze. They thus ingest sewage sludge solids that have been more protected from environmental stress than the sewage sludge on the above-ground parts of the plant. A report of the World Health Organization (1981) focuses on salmonellosis and infestations of Taenia saginata (beef tapeworm) as the diseases of greatest risk to grazing animals.

2.4.1 Salmonella sp. Bacteria

There is considerable controversy about the effect of salmonellae in sewage sludge applied to pasture. Germany and Switzerland require disinfection of sewage sludge before it is applied to pasture. Strauch (1980) reviews several convincing studies that indicate that sewage sludge application to the land has been responsible for an increase in salmonellae carriers in the cattle population and epidemics of salmonellosis in cattle. On the other hand, Pike and Davis (1984) review data of investigators from the United Kingdom and the Netherlands that show that salmonellae densities in sewage sludge applied to land fall in less than 4 weeks to densities far below those required to cause infection in cattle. They conclude that these findings taken together with epidemiological evidence indicate no substantial risk to cattle if sewage sludge is stabilized and a no-grazing period of about a month is imposed.

Experience in the United States parallels the experience in the United Kingdom. Dorn et al. (1985) report several investigations in the United States that show infection of domestic grazing animals only at extremely high densities of salmonellae. Dorn et al. (1985) carried out a study of the incidence of disease in farm inhabitants and domestic animals on farms where sewage sludge was applied to croplands and pastures at agronomic rates following EPA and state requirements. Their study showed no increase in incidence of disease on farms where sewage sludge was used over incidence at control farms that did not use sewage sludge.

The experience of the United States appears to parallel that of the United Kingdom more than Europe. For these reason, there appears to be little reason to impose a stricter requirement to protect against salmonellae in sewage sludge applied to grazing lands than exists in the Part 257 regulation. This is the course of action that has been followed in the Part 503. Part 503 requires that if sewage sludge is processed to reduce fecal indicator densities to 2,000,000 CFU or MPN per gram and if vector attraction is reduced, animals cannot be grazed for 1 month after sewage sludge application.

2.4.2 Taenia sp.

There is general acknowledgment of a risk from Taenia to cattle grazed on land to which sewage sludge has been applied. In the United Kingdom, beef tapeworm is a recognized, although not major, problem. Pike and Davis (1984) describe guidelines for sewage sludge application to agricultural land in the United Kingdom, which require a no-grazing period of 3-4 weeks after sewage sludge application if the sewage sludge has been anaerobically digested, and a 6-month no-grazing period if the sewage sludge has been aerobically digested or treated with lime. Evidently, these latter treatments are not as effective in destroying Taenia eggs as anaerobic digestion.

The United States requirement in the Part 257 regulation and the Part 503 regulation includes a 1-month no-grazing period. This is not as stringent as the United Kingdom requirement. A major difference in circumstances, however, is the extremely rare occurrence of Taenia saginata in sewage sludges in the United States. For example, Reimers and coworkers (1981 and 1986) report finding Taenia (possibly dog or cat tapeworm and not beef tapeworm) only once in sewage sludge from 54 treatment works, whereas Ascaris was found in the sewage sludge from nearly all the treatment works. Evidently, the total meat inspection practices in the United States, which remove contaminated carcasses from the food supply, as well as the infrequent consumption of uncooked meat breaks the cycle of infection. Since a Taenia problem essentially does not exist in the United States, there seems to be little reason to increase the no-grazing period to more than 1 month for stabilization processes that might not destroy the infective capabilities of the eggs of this parasite.

2.5 INFECTIVE DOSE

To establish a level of concern about the disease risk posed by a particular sewage sludge pathogen, the infective dose for that organism must be known. Infective dose is the minimum dose of a pathogen needed to cause infection.

2.5.1 Salmonella sp. Bacteria

Kowal (1985) critically reviewed the literature on infective dose for all pathogen groups of concern. For bacteria, he concluded that although infective doses for most species of bacteria are high (i.e., many thousands of organisms are required to cause infection), they can be low in some circumstances. He cited Blaser and Newman (1982), who indicated that the infective dose for Salmonella sp. may be less than 1,000 organisms. For Shigella, the infective dose is low—10 to 100 organisms (Keusch, 1970). Ward and Akin (1984) are even more pessimistic, citing work by D'Aoust (1985) indicating that Salmonella sp. may be infective at doses below 10 organisms. Ingestion of only 0.1 grams of sewage sludge containing 100 MPN/gram of salmonellae would provide a dose of 10 organisms.

Infective dose for salmonellae or other pathogenic bacteria is less relevant than for viruses and helminths because of the capacity of bacteria for regrowth. Bacteria densities in sewage sludge could be lower than the density needed to cause an infection, but there would still be cause for concern because the bacteria could grow to higher densities if conditions favorable for regrowth are created (for example, a poorly composted sewage sludge, cooled in a storage pile from the thermophilic temperature range to the mesophilic range—the temperature range most compatible with enteric pathogens), or if the sewage sludge contacts a source of nutrients such as a moist foodstuff.

2.5.2 Enteric Viruses

Currently, the infective dose for enteric viruses is thought to be low (Kowal, 1985)—on the order of 10 virus particles or less. Because the infective dose is low, it is prudent to minimize exposure. If the conditions of land application make sewage sludge ingestion probable (e.g., sewage sludge is applied to food crops to be harvested shortly after application), the sewage sludge should be essentially devoid of enteric viruses.

2.5.3 Helminths

For helminths, single eggs are infective to humans. The magnitude or period of infection is dose-related because most of the worms produced do not multiply in man. However, an infection may sensitize individuals so that subsequent light infections cause allergic reactions. Because the infective dose is low, exposure should be minimized. If risk of ingestion is probable, the sewage sludge should be devoid of viable helminth ova.

2.6 SELECTION OF MICROORGANISMS FOR PART 503

As noted in Sections 2.1-2.4, numerous pathogenic species present in sewage sludge can cause human disease. Monitoring all these organisms is both unnecessary and impossible. Many—including protozoa—are easily destroyed by minimal treatment and are therefore of no concern. For this reason, protozoa are not regulated under Part 503. Other pathogens do not need to be enumerated individually. Usually, there is a surrogate organism that behaves similarly under adverse conditions to the pathogens of concern and can be enumerated more easily than the pathogens. A single test on a surrogate organism generally can eliminate the need for several tests on individual pathogens.

Part 503 includes requirements for monitoring of certain bacteria, enteric viruses, and viable helminth ova. This section explains why those organisms were selected.

2.6.1 Bacteria

Part 503 requires monitoring of fecal coliforms using standard procedures (APHA, 1989). These organisms have been selected as a surrogate for monitoring individual bacterial pathogens. Fecal coliforms behave similarly to most of the enteric bacterial pathogens of concern and respond similarly to adverse conditions. For example, if fecal coliforms are reduced in density by a factor of 10, enteric bacterial pathogens are expected to be reduced by a similar extent.

Fecal coliform densities can be used to estimate that bacterial pathogens are below detectable limits. Fecal coliforms occur in untreated sludge at extremely high densities—around 100 million per gram. If these densities are reduced by processing to 1,000 per gram (a factor of 100,000), one would expect bacterial pathogens to be reduced to below detection limits because their initial densities in unprocessed sewage sludge are rarely above 2,000 per gram.

Part 503 also requires monitoring of Salmonella sp. under certain circumstances. Salmonellae are the bacterial pathogens of principal concern in sewage sludge. Their relative reduction can be followed by monitoring for fecal coliforms under the approach described above. However, some members of the regulated community may prefer to monitor for salmonellae, rather than for a nonpathogen like fecal coliforms. Obviously, a direct test for Salmonella sp. is the best indicator of the absence of salmonellae. Also, salmonellae are good indicators of reduction of other bacterial pathogens because they are present in higher densities than other bacterial pathogens and are at least as hardy. If salmonellae are present in an unprocessed sewage sludge and below detection limits in the processed material, this is good evidence that other bacterial pathogens have also been reduced to below detection limits. For all these reasons, a test for Salmonella sp. can be substituted for fecal coliform monitoring in all the alternatives included under the Class A pathogen reduction requirements (see Section 4).

2.6.2 Enteric Viruses

Some of the Part 503 Class A pathogen requirements include monitoring of enteric viruses by a method developed specifically for enumeration of enteroviruses (ASTM, 1992), which is a genus constituting many but not all enteric viruses. This method enumerates many but not all enteric viruses. Important viruses not enumerated are rotaviruses and hepatitis viruses. The methods for measuring densities of these latter viruses are still under development and are not yet practical for field use. A reasonable assumption is that the enteric viruses not detected by the required method behave similarly to those that are detected.

In some circumstances, enteric viruses can be monitored by bacterial indicators such as fecal coliforms. For example, viral densities are reduced by high temperatures to approximately the same degree as fecal indicator organisms. This holds true for modest reductions in densities as well as reduction to densities below detection limits. As noted above in Section 2.5.1, a fecal coliform density of 1,000 per gram in processed sewage sludge indicates a reduction intensity of a factor of 100,000. Maximum enteric virus densities in unprocessed sewage sludge are around 2,000 per gram. Consequently, if fecal coliform densities are reduced to 1,000 per gram, enteric viruses are expected to be below detection limits of 1 plaque-forming unit per 4 grams of sewage sludge.

There are circumstances where bacterial indicators are not good indicators of virus destruction. For example, viruses are much more resistant to high-energy irradiation than bacteria, so absence of bacteria in irradiated sewage sludge would not indicate absence of viruses. At temperatures below the mesophilic range, viruses may survive much better than bacteria. Under such circumstances, only the virus test can be used to monitor virus densities.

2.6.3 Helminth Ova

Some of the Part 503 pathogen requirements include monitoring of helminth ova using a method described by Yanko (1987). Helminth ova are extremely resistant to most adverse processing and environmental conditions at temperatures in the mesophilic range and below. In these circumstances, viable helminth egg densities can only be enumerated by a specific test for viable helminth eggs. At temperatures of 50°C and above, surrogate organisms such as the bacterial fecal indicator organisms can be used to indicate reduction in helminth densities.

2.7 VECTOR ATTRACTION REDUCTION

As noted in Section 2.3.5, transport of pathogens by vectors can play a major role in disease transmission. The health risk to humans and animals posed by this transmission route can be reduced substantially by reducing the attractiveness of sewage sludge to vectors.

2.7.1 Vector Attraction Reduction vs. Stabilization

Vector attraction reduction is a relatively new concept in sewage sludge treatment technology. It was first introduced with the publication of the Part 257 regulation (EPA, 1979). Until then, it was common to "stabilize" sewage sludge before use or disposal by processes such as anaerobic or aerobic digestion. Stabilization was carried out for a variety of reasons, but the principal reason was to make the sewage sludge aesthetically acceptable (i.e., odor and appearance were changed so that its origin was less evident). Important side effects of stabilization were a reduction in pathogen densities and a reduction in the characteristics that attract vectors.

The 1979 regulation reversed the priorities of this treatment step. Reduction in pathogen densities and vector attraction became paramount. Reduction in odor was not specifically a concern of the requirement to reduce vector attraction. Nevertheless, the unpleasant odors that make untreated sewage sludge aesthetically unacceptable also contain the chemical attractants that draw vectors to the area where the sewage sludge is present.

The chemical nature of these attractants is unknown. It is known that when certain physical, chemical, or biological processes are carried out on sewage sludge, odors apparent to humans and attractiveness to vectors both diminish. Typical processes that achieve these effects are aerobic and anaerobic digestion, drying, treatment with chemicals such as ozone or lime, and composting. It is reasonable to assume a direct correspondence between odor intensity and degree of vector attraction, although this has not been proven scientifically.

2.7.2 Measures of Vector Attraction

The vector attraction reduction requirements of Part 257 were based on field experience rather than objective scientific criteria. In this approach, the degree of vector attraction of sewage sludge with a range of values of a parameter thought to be associated with vector attraction was observed. This route was followed formally for lime stabilization of sewage sludges (Farrell et al., 1974; Noland et al., 1978; Counts and Shuckrow, 1975) and informally for the other processes. Use or disposal sites were observed, the treated sewage sludge was examined, the literature was reviewed for comments on problems, and a judgment was made based on this information. In all cases, when the pathogen requirement was met, the vector attraction reduction was, at a minimum, satisfactory.

Obviously, it is desirable to have objective scientific tests to measure the attractiveness of a sewage sludge to vectors and the degree of reduction produced by treatment, but achieving this is not simple. Wolf (1955) showed that degree of attraction of house flies to sewage sludge drying on sand beds is reduced as the degree of digestion of a sewage sludge is increased, but that moisture content could be critical; if sufficiently dry spots are not available, the flies would not land on the sewage sludge. Thus, a liquid sewage sludge applied to soil might not attract vectors when first applied, would start attracting vectors when there were enough dry landing sites, and probably would stop attracting vectors when the sewage sludge dried out to perhaps 60-percent solids. A thick application of sewage sludge probably would be far more attractive than a thin application because a lower wet layer would be protected by a dried layer on the surface that would provide ideal landing sites.

An objective vector attractant test, although difficult to develop, could be worked out, but it might almost be irrelevant, because field conditions of sewage sludge application vary widely. Temperature and humidity are uncontrolled in the field and sewage sludge application rates can vary widely. An objective test designed to simulate a worst-case scenario is not a reasonable approach, because it would impose excessive requirements on many facilities.

The low likelihood that an objective scientific test would yield universally applicable results encouraged simpler approaches. Field experience has shown that percent reduction of volatile solids content of a sewage sludge correlates satisfactorily with reduced vector attraction. Also, if a sewage sludge is dry enough, it will not attract vectors. Adding an alkali to bring sewage sludge to a high-enough pH deters vectors. Several different process-dependent standards have been developed for measuring vector attraction reduction or indicating satisfactory reduction: solids content, percent volatile solids reduction, rate of oxygen uptake, and pH. Evidence of their effectiveness is based on field observation of reduced vector attraction or odors.

2.7.3 Use of Barriers to Reduce Vector Attraction

Just as a screened-in porch protects people from insects, a physical barrier such as a covering of soil prevents insects from contacting sewage sludge. Burial of sewage sludge in trenches has been practiced and effectively prevents vector attraction. Similarly, the daily covering of sewage sludge prevents all but temporary vector attraction. The relatively shallow injection of sewage sludge practiced at land application sites also prevents vector attraction if application is done carefully and little sewage sludge is left on the soil surface. Application of sewage sludge to the land surface followed by the incorporation of sewage sludge in the soil also is effective provided the application rate is not excessive. The soil mass dilutes the sewage sludge by a factor of approximately 100, and dehydrates the sewage sludge. The very small amount of sewage sludge that remains on the land surface is typically about as dry as the soil, which makes it unattractive to vectors.

SECTION THREE

APPLICABILITY OF PART 503 PATHOGEN AND VECTOR ATTRACTION REQUIREMENTS

3.1 INTRODUCTION

As described below, Subpart D (the pathogen and vector attraction reduction requirements) of the Part 503 regulation applies to sewage sludge (both bulk sewage sludge and sewage sludge that is sold or given away in a bag or other container) and domestic septage applied to the land or placed on a surface disposal site. Both sewage sludge and domestic septage must meet pathogen and/or vector attraction reduction requirements. These two types of reduction requirements are separated in Part 503 (they were combined in Part 257), which allows flexibility in how they are achieved.

The pathogen requirements for sewage sludge are separated into Class A and Class B requirements. The Class A requirements are the more stringent requirements. They are designed to produce sewage sludges with pathogens reduced to below detectable levels. Sewage sludges that meet the Class B requirements will likely still contain some pathogens, and therefore require restrictions on the site where the sewage sludge is applied to ensure protection of public health and the environment.

This section discusses the applicability of the Subpart D requirements. The pathogen and vector attraction reduction requirements are described in Sections 4-6.

3.2 LAND APPLICATION

3.2.1 Bulk Sewage Sludge

3.2.1.1 Pathogen Requirements

The final Part 503 regulation requires that bulk sewage sludge applied to agricultural land, forest, a public contact site, or a reclamation site meet either Class A or Class B pathogen requirements. When the sewage sludge is Class B with respect to pathogens, restrictions (e.g., harvesting of root crops) are imposed on the site where the sewage sludge is applied. Under this approach, the sewage sludge can be treated to reduce pathogens (Class A) or a combination of treatment and environmental attenuation (i.e., Class B with site restrictions) can be used to reduce pathogens.

Bulk sewage sludge applied to a lawn or a home garden must meet the Class A pathogen requirements. The reason for this requirement is that it is not feasible to impose site restrictions on a lawn or a home garden on which bulk sewage sludge is applied. To avoid having to impose site restrictions, which are required when the bulk sewage sludge meets the Class B pathogen requirements, the bulk sewage sludge has to meet the Class A pathogen requirements.

3.2.1.2 Vector Attraction Reduction Requirements

One of 10 vector attraction reduction requirements also must be met when bulk sewage sludge is applied to the agricultural land, forest, a public contact site, or a reclamation site. These requirements are designed to reduce the characteristics of the sewage sludge that attract vectors such as mosquitos and flies.

One of eight vector attraction reduction requirements has to be met when bulk sewage sludge is applied to a lawn or a home garden. The two vector attraction reduction requirements that cannot be used when bulk sewage is applied to a lawn or a home garden are injection of the bulk sewage sludge below the land surface and incorporation of sewage sludge into the soil.

Implementation of these requirements for bulk sewage sludge applied to a lawn or a home garden is difficult, if not impossible.

3.2.2 Sewage Sludge Sold or Given Away in a Bag or Other Container

3.2.2.1 Pathogen Requirements

Sewage sludge sold or given away in a bag or other container for application to the land must meet Class A pathogen requirements. It is impossible to impose the site restrictions required for a sewage sludge that meets the Class B pathogen requirements in this situation.

3.2.2.2 Vector Attraction Reduction Requirements

One of eight vector attraction reduction requirements also has to be met when sewage sludge is sold or given away in a bag or other container for application to the land. In this situation, it is not feasible to inject the sewage sludge below the land surface or to incorporate the sewage sludge into the soil. For injection and incorporation, control of the application site must be maintained by the appropriate person. There is no site control when sewage sludge is sold or given away in a bag or other container for application to the land.

3.2.3 Domestic Septage Applied to Agricultural Land, Forests, or a Reclamation Site

3.2.3.1 Pathogen Requirements

When domestic septage is applied to agricultural land, forest, or a reclamation site, either site restrictions (i.e., the same site restrictions that have to be met when a Class B sewage sludge is applied to the land) have to be met or a pH requirement for the domestic septage has to be met along with site restrictions concerning the harvesting of crops. The first requirement relies on the environment to reduce pathogens by restricting certain activities on the site. These restrictions prohibit harvesting of crops, grazing of animals, and public access to the site for a certain period. The second requirement relies on treatment of the domestic septage (i.e., pH adjustment) and restrictions on harvesting crops to reduce pathogens. Restrictions on harvesting of crops are part of the second requirement because the Agency concluded that pH adjustment alone does not achieve adequate pathogen reduction to allow crops to be harvested immediately after applying the domestic septage. Domestic septage applied to other types of land must meet the appropriate pathogen requirement for sewage sludge that is applied to the land.

3.2.3.2 Vector Attraction Reduction Requirements

Vector attraction reduction is achieved when domestic septage is applied to agricultural land, forest, or a reclamation site if the domestic septage is injected below the surface of the land, incorporated into the soil after being applied to the land surface, or when the pH of the domestic septage is raised to 12 or higher and remains at 12 or higher for 30 minutes. When vector attraction reduction is achieved by raising the pH of the domestic septage, each container of domestic septage that is applied to the land must be monitored to demonstrate compliance with that requirement.

3.3 SURFACE DISPOSAL

3.3.1 Sewage Sludge (Other Than Domestic Septage)

3.3.1.1 Pathogen Requirements

The pathogen requirements in the final Part 503 regulation for sewage sludge (other than domestic septage) placed an active sewage sludge unit are similar to the existing requirements for the disposal of sewage sludge on the land in 40 CFR Part 257. Sewage sludge (other than domestic septage) placed on a surface disposal site has to meet either Class A or Class B pathogen requirements, except site restrictions, unless a cover is placed on the active sewage sludge unit at the end of each operating day. When a daily cover is placed on an active sewage sludge unit, the sewage sludge does not have to meet a separate pathogen requirement. The daily cover isolates the sewage sludge and allows the environment to reduce the pathogens in the sewage sludge.

Pathogen-related site restrictions do not have to be met when the sewage sludge meets the Class B pathogen requirements because similar site restrictions are already imposed on an active sewage sludge unit for other than pathogen reduction (i.e., to prevent exposure to pollutants). Management practices that address these site restrictions are included in the surface disposal subpart of Part 503 because the exposure pathway analysis for the surface disposal pollutant limits did not address activities such as harvesting of crops, grazing of animals, and exposure to the sewage sludge by the public.

3.3.1.2 Vector Attraction Reduction Requirements

The vector attraction reduction requirements in the final Part 503 regulation for sewage sludge placed on a surface disposal site also are similar to the Part 257 vector attraction reduction requirements. Part 257 requires that the sewage sludge be covered daily or that other appropriate techniques be used to reduce vector attraction. The final Part 503 regulation requires that 1 of 10 vector attraction reduction requirements (i.e., "other techniques") be met when sewage sludge (other than domestic septage) is placed on an active sewage sludge unit or that daily cover be placed on the active sewage sludge unit. As mentioned above, when daily cover is placed on an active sewage sludge unit, the sewage sludge does not have to meet a separate pathogen requirement. The daily cover prevents access to the sewage sludge by vectors.

3.3.2 Domestic Septage

Domestic septage placed on a surface disposal site does not have to meet a pathogen requirement. The existing requirements in Part 257 for septic tank pumpings indicate that septic tank pumpings applied to the land have to be treated in a Process to Significantly Reduce Pathogens (PSRP) or restrictions concerning grazing of animals and access by the public have to be imposed on the site where the domestic septage is disposed. Because site restrictions for those two activities, as well as a restriction on the harvesting of crops, are imposed on all active sewage sludge units for other than pathogen reduction (i.e., to prevent exposure to pollutants), the site restrictions for applying domestic septage to the land are met at every active sewage sludge unit. For this reason, domestic septage placed on an active sewage sludge unit does not have to meet an additional pathogen requirement.

Vector attraction reduction is achieved when domestic septage is placed on a surface disposal site if the domestic septage is injected below the land surface or incorporated into the soil; if the pH of the domestic septage is raised to a certain level and remains at that level for 30 minutes (i.e., "other techniques"); or if the active sewage sludge unit receives a daily cover. The "other techniques" for domestic septage are limited to injection, incorporation, and pH adjustment because the EPA concluded that other techniques available for sewage sludge (e.g., volatile solids reduction and percent moisture) are not feasible for each container of domestic septage placed on an active sewage sludge unit. When daily cover is placed on an active sewage sludge unit, access to domestic septage placed on the unit by vectors is prevented.

3.4 WHEN REQUIREMENTS MUST BE MET

The Part 503 pathogen and vector attraction reduction requirements have to be met at various times, as discussed below.

3.4.1 Sewage Sludge That Is Used or Disposed

The phrase "sewage sludge that is used or disposed" is used in the final regulation to indicate that the appropriate pathogen and vector attraction reduction requirements can be met any time before the sewage sludge is actually used or disposed. For example, sewage sludge may be stored for a period of time after the time-temperature pathogen requirements are met. In this case, the time-temperature requirements do not have to be met again just prior to when the sewage sludge is used or disposed.

3.4.2 At the Time of Use or Disposal

The phrase "at the time of use or disposal" is used to indicate that the appropriate pathogen requirements have to be met just prior to when the sewage sludge is used or disposed. Enough time must be allowed to test the sewage sludge and obtain the test results before the sewage sludge is used or disposed. The main reason this phrase is used in the regulation is to ensure that the pathogen regrowth requirement (i.e., either fecal coliform or Salmonella sp. bacteria density value must be below the specified value) is met at the time the sewage sludge is used or disposed.

3.4.3 At the Time Sewage Sludge Is Prepared for Sale or Give Away in a Bag or Other Container for Application to the Land

The phrase "at the time sewage sludge is prepared for sale or give away in a bag or other container for application to the land" also is used to indicate when certain pathogen requirements must be met. When sewage sludge is sold or given away in a bag or other container, the pathogen regrowth requirements cannot be met just prior to when the sewage sludge is actually applied to the land (e.g., when applied to a home garden). For this reason, those requirements have to be met when the sewage sludge is prepared for sale or give away in a bag or other container.

3.4.4 At the Time the Sewage Sludge or Material Derived from Sewage Sludge Is Prepared to Meet the Requirements in 503.10(b), 503.10(c), 503.10(e), or 503.10(f)

The phrase "at the time the sewage sludge or material derived from sewage sludge is prepared to meet the requirements in 503.10(b), 503.10(c), 503.10(e), or 503.10(f)" also is used in the final Part 503 regulation to indicate when certain pathogen requirements have to be met. In these cases, sewage sludge that meets three quality requirements is not subject to the land application general requirements and management practices. Because the sewage sludge is not subject to further control under Part 503 after it meets the three quality requirements, it may not be known when the sewage sludge is actually applied to the land. In that situation, the pathogen regrowth requirement cannot be met just prior to when the sewage sludge is used or disposed. For these reasons, the pathogen regrowth requirements have to be met at the time the sewage sludge is prepared to meet the quality requirements. In most cases, this is the last point at which there is control over the sewage sludge with respect to the Part 503 requirements.

SECTION FOUR

PART 503 CLASS A PATHOGEN REQUIREMENTS

4.1 INTRODUCTION

This section explains and provides justifications for the specific Class A pathogen requirements of Subpart D of the Part 503 regulation. The Class A requirements include six alternative requirements for demonstrating Class A pathogen reduction. Sewage sludge can meet any one of these six alternatives to qualify as a Class A sewage sludge. The objective of all these requirements is to reduce pathogen densities to below detectable limits which are:

Salmonella sp.	less than 3 MPN per 4 grams total solids
enteric viruses	less than 1 PFU per 4 grams total solids
viable helminth ova	less than 1 PFU per 4 grams total solids

Class A sewage sludges must also meet one of the requirements for vector attraction reduction (see Section 6). Because Class A sewage sludges are vulnerable to regrowth of bacterial populations, reduction of vector attraction generally must occur at the same time as or after pathogen reduction (see Section 4.3).

This section is organized according to the specific paragraphs in Subpart D, and uses the same numbering as the Part 503 paragraphs. Section 4.2 discusses some of the special definitions in the regulation that pertain to the pathogen and vector attraction requirements. Section 4.3 discusses the requirement for vector attraction reduction to occur with or after pathogen reduction. The six alternative requirements for pathogen reduction are presented in Sections 4.4 to 4.9.

4.2 SPECIAL DEFINITIONS [503.31]

Both the Class A and B and the vector attraction reduction requirements refer to certain terms and units of measurement. These are defined in Part 503.31 of the regulation. Definitions where explanations are useful are discussed below.

4.2.1 Density of Microorganisms

Density of microorganisms is defined as number of microorganisms per unit mass of total solids (dry weight). Ordinarily, microorganism densities are determined as number per 100 mL of wastewater or sewage sludge. They are reported in this manner for wastewater, but are less appropriate for sewage sludge. The microorganisms in sewage sludge are associated with the solid phase. When sewage sludge is diluted, thickened or filtered, the number of microorganisms per unit volume changes markedly, whereas the number per unit mass of solids remains almost constant. This argues for reporting densities as number per unit mass of solids. For this reason, sewage sludge solids content should always be determined when measuring microorganism densities in sewage sludge. A second reason for reporting densities per unit mass of solids is that sewage sludge application to the land is typically measured and controlled in units of mass of dry solids per unit area of land. If pathogen densities are measured as numbers per unit mass of solids, the rate of pathogen application to the land is thus directly proportional to the mass of dry sewage sludge solids applied.

Density of microorganisms is expressed in different ways for different organisms. Helminth ova are observed and counted as individuals under a microscope. Viruses are usually counted in plaque-forming units (PFUs—see Section 2.1.2 for an explanation of this term). For bacteria, the count is in colony-forming units (CFU) or most probable number (MPN). CFU is a count of colonies on an agar plate or filter disk. Because a colony might have originated from a clump of bacteria instead of an individual, the count is not necessarily a count of separate individuals. MPN is a statistical estimate of numbers in an original sample. The sample is diluted at least once into tubes containing nutrient medium; there are several duplicates at each dilution. The original bacterial density in the sample is estimated based on the number of tubes that show growth.

The detection limits for the pathogens are expressed as numbers, PFUs, CFUs, or MPNs per 4 grams. This terminology is used because most of the tests started with 100 mL of sewage sludge which typically contained 4 grams of sewage sludge solids.

4.2.2 Specific Oxygen Uptake Rate (SOUR)

SOUR is defined as the mass of oxygen consumed per unit time per unit mass of total solids (dry weight basis) in the sewage sludge. SOUR is usually based on total suspended volatile solids rather than total solids, because it is assumed that it is the volatile matter in the sewage sludge that is being oxidized. The SOUR definition in Part 503 is based on total solids primarily to reduce the number of different determinations needed. Generally, the range in the ratio of volatile solids to total solids in aerobically digested sewage sludges is not large. The standard required for SOUR based on total solids is slightly lower than if it had been based on volatile suspended solids.

4.2.3 Percent Volatile Solids Reduction

Percent volatile solids reduction is defined for a continuous or semi-continuous steady state process as 100 times the difference between the masses of volatile solids in the influent and effluent sewage sludges divided by the mass of volatile solids in the influent sewage sludge. For a batch process, it is defined as 100 times the difference between the masses of volatile solids in the influent and effluent sewage sludges divided by the mass of volatile solids in the influent sewage sludge. The typical operation of an anaerobic digester is semi-continuous feed—sewage sludge is charged to a digester at least once a day and an equal volume is withdrawn at least once a day. Provided the amount and composition of sewage sludge in the digester remain approximately constant, the relationship defined above for continuous processing applies. In the additional digestion tests described later under vector attraction reduction methods, the digestion is a batch operation. Volatile solids reduction is determined according to the definition above.

The definitions for continuous, semi-continuous, and batch digestion are appropriate for simple processing schemes, but they need to be interpreted for more complex situations. For example, when supernatant is removed from a digester, there are two instead of one exiting streams that can carry off volatile solids. EPA has provided guidance (EPA, 1992b) on ways to calculate volatile solids reduction for these complex situations.

4.3 VECTOR ATTRACTION REDUCTION TO OCCUR WITH OR AFTER CLASS A PATHOGEN REDUCTION [503.32(a)(2)]

For Class A pathogen reduction, the order of pathogen reduction is important when certain of the vector attraction reduction requirements are met. Part 503.32(a)(2) requires that Class A pathogen reduction be accomplished before or at the same time as the vector attraction reduction except for vector attraction reduction by alkali addition [503.33(b)(6)] or drying [503.33(b)(7) and (8)].

4.3.1 Need for the Requirement

The need for specifying the order in which vector attraction and pathogen reduction occur is based on evidence that regrowth of bacterial pathogens can occur if pathogen reduction follows the vector attraction reduction step. In the early 1980s, both Germany and Switzerland had regulations requiring disinfection of digested sewage sludge before it could be used on pasture in the summer. The method of choice was generally pasteurization—exposure to 70°C for 0.5 hour. Clements (1983) describes experience in Switzerland where over 70 treatment works were using pasteurization after sewage sludge digestion. After receiving reports of the presence of salmonellae in these treated sewage sludges, the government conducted an investigation that revealed that most of the pasteurized products were contaminated with pathogenic bacteria. The presence of the bacteria was attributed to downstream bacterial contamination in the absence of competitive bacteria. These bacteria grew rapidly to dangerous levels, even though the sewage sludges had been well digested. Since that time, post-pasteurization has been abandoned in Switzerland and Germany. Current practice is to pasteurize the sewage sludge before digestion, or to use aerobic thermophilic digestion, a process that simultaneously reduces sewage sludge volatile solids content and pathogen densities.

The discovery that bacteria can grow to high densities when vegetative bacteria are eliminated, even when a sewage sludge is well digested, demonstrates that it is unwise to have the pathogen reduction process as the terminal processing step unless there is some kind of a deterrent to regrowth that remains in the sewage sludge. Examples of such deterrents are dryness, a chemical residual, or the presence of a competitive but nonpathogenic bacterial population.

A much more limited regrowth of pathogenic bacteria can occur when the vector attraction process follows the pathogen reduction process. Burge et al. (1987) established that if a well-composted sewage sludge product is inoculated with salmonellae, regrowth will occur but will diminish to low densities in a few days. If the material is sterilized by radiation, regrowth will be explosive and prolonged. On the other hand, Yanko (1988) found high frequent occurrence of salmonellae, most likely from regrowth, in many compost samples. Frequency of detection of salmonellae and density when detected increased in proportion to fecal coliform density. Presumably, these composts were low in vegetative bacteria that deter regrowth and contained too much residual decomposable matter that provided a food source for microorganism growth. Yanko's finding supports the need for a requirement to check the microbiological character of sewage sludge from processes that reduce bacterial densities to extremely low levels, even when pathogen reduction does not follow vector attraction reduction.

4.3.2 Scientific Basis for the Requirement

The potential for regrowth of pathogenic bacteria in sewage sludges that have been greatly reduced in pathogens makes it important to ensure that substantial regrowth has not occurred. The experimental work carried out by Yanko (1988) provides a relatively simple monitoring requirement. Yanko's extensive data on microbiological properties of compost and compost products show that in his weekly samples, salmonellae were detected 165 times in 365 measurements, but no salmonellae were detected in the 86 measurements for which the fecal coliform densities were less than 1,000 MPN per gram. This indicates that if fecal coliform densities were below 1,000 MPN per gram, likelihood of salmonellae detection would be rare.

Yanko's data demonstrate a good correlation between fecal coliform densities and frequency of salmonellae detection. Farrell (1992) re-plotted these data on slightly different coordinates and obtained the correlation shown in Figure 4-1. This correlation can be used to give an estimate of the frequency of detection of salmonellae when fecal coliform are below 1,000 MPN per gram. Yanko's data show that when the log fecal coliform density was below 3, the frequency of detection measurements were uniformly distributed in the range of 0 to 3. It is reasonable to expect that the same behavior will occur in future measurements. In this case, the expected frequency of detection can be calculated, using the relationship in Figure 4-1, to be about 2 in 100.

Both estimates show that if fecal coliform densities are below 1,000 MPN per gram, the likelihood of salmonellae detection is low. As noted earlier, when fecal coliform density was low and salmonellae were detected, the salmonellae densities were low. For these reasons—low likelihood of occurrence and low density when detected—a fecal coliform density of 1,000 MPN per gram indicates that regrowth has not occurred to a substantial extent and that salmonellae are unlikely to be present.

Anecdotal reports suggest that some composted sewage sludges may have difficulty meeting the requirement of below 1,000 MPN fecal coliform per gram even when salmonellae are never detected. This might be expected under several circumstances. For example, very severe thermal treatment of sewage sludge during composting can totally eliminate salmonellae yet leave residual fecal coliforms. If the sewage sludge has been poorly composted and thus is a good food source, fecal coliforms may have regrown after the compost cooled down from thermophilic temperatures. Because the salmonellae are absent, they cannot regrow. An even more probable circumstance could occur if the sewage sludge had been treated with lime before composting. Lime effectively reduces salmonellae in sewage sludge to below detectable limits

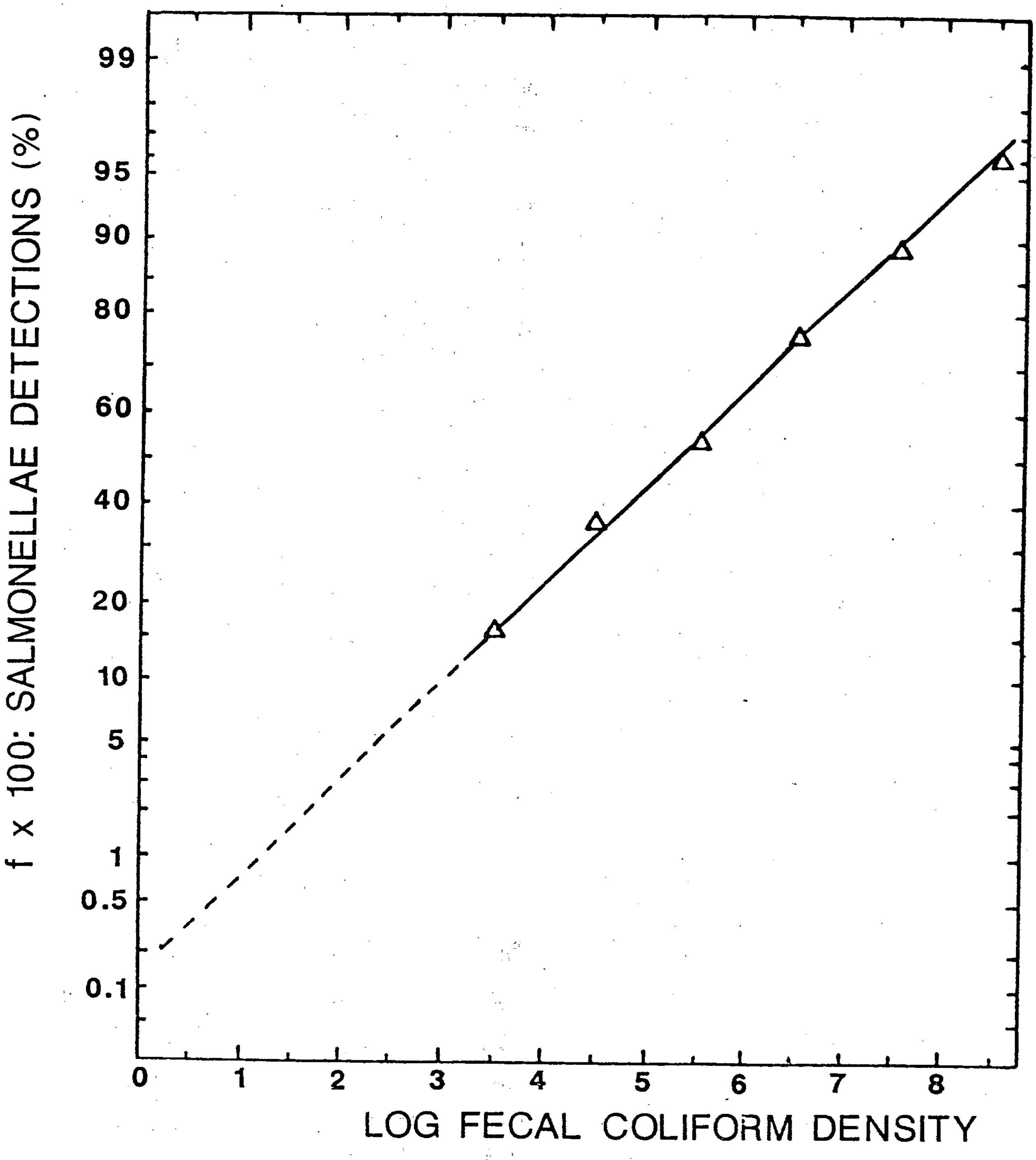

Figure 4-1: Relationship between Log Fecal Coliform Density and Fraction of Salmonellae Detections (based on Yanko [1988] Weekly Data)

and leaves surviving fecal coliforms (Farrell et al., 1974). Under conditions favorable for regrowth, the fecal coliforms can regrow to levels higher than 1,000 MPN per gram, but salmonellae, once totally eliminated, can never regrow.

For this reason, Part 503 allows use of a test to determine that Salmonella sp. are below detectable limits as a substitute for meeting the fecal coliform requirement. This approach uses salmonellae as an indicator of the reduction of bacterial pathogens to below detectable limits rather than of the presence of bacterial pathogens.

4.4 CLASS A, ALTERNATIVE 1—FOR THERMALLY TREATED SEWAGE SLUDGES [503.32(a)(3)]

This alternative may be used when the pathogen reduction process uses specified time-temperature regimes to reduce pathogens. Under these circumstances, tests for the presence of specific pathogens can be avoided. It is only necessary to demonstrate (1) that fecal coliform densities are below 1,000 MPN per gram of total solids (dry weight basis) or, alternatively, that Salmonella sp. are below detection limits, *and* (2) that the required time-temperature regimes are met.

Four different time-temperature regimes are given in Alternative 1. These regimes are based on the percent solids of the sewage sludge and on operating parameters of the treatment process. Experimental evidence (described in Sections 4.4.2-4.4.5) demonstrates that these four time-temperature regimes are adequate for reduction of the pathogenic organisms to below detectable limits.

The time-temperature requirements specified apply to every particle of sewage sludge processed. Time at the desired temperature is readily determined for batch operations, turbulent flow in pipes, or even laminar flow in pipes (time of contact is one-half the contact time calculated from the bulk throughput rate). Time can be calculated for a number of completely mixed reactors in series, but for the very large reductions required to reduce densities to below detection limits, the required time for this type of processing would require so many reactors in series as to be totally impractical.

The fecal coliform and Salmonella sp. requirements in this alternative are designed to ensure that the microbiological reductions expected as a result of the time-temperature regimes have actually been attained, and to ensure that regrowth of bacterial pathogens has not occurred.

Sections 4.4.1-4.4.5 below discuss the individual microbiological and time-temperature requirements that comprise Alternative 1.

4.4.1 Microbiological Monitoring to Demonstrate Pathogen Reduction [503.32(a)(3)(i)]

For processes that reduce pathogens through elevated temperature, Part 503 sets a fecal coliform density of 1,000 MPN per gram of solids or, alternatively, a reduction of salmonellae to below detection limits of 3 MPN per 4 grams of solids as the means to demonstrate that enteric viruses, viable helminth eggs, and pathogenic bacteria in the sewage sludge have been reduced to below detectable limits. (As discussed in Section 4.3.2, this monitoring also protects against the possibility of regrowth.)

4.4.1.1 Fecal Coliform as an Indicator

There is ample research information that demonstrates that the pathogens of concern are reduced to below detection limits before the fecal coliform densities are reduced to 1,000 MPN per gram of solids. Results of studies by Lee et al. (1988) and by Yanko (1988) show that helminths are easily reduced by temperatures above 50°C under time-temperature conditions that leave high density levels of fecal coliforms. Martin et al. (1990) showed that at temperatures above 35°C, virus density decline in log density per unit time is more rapid than the decline in indicator organism densities. Fecal coliforms start out with densities of about 100 million per gram versus about 1,000 per gram for viruses. When the fecal coliform have been reduced by about a factor of 100,000 by the thermal treatment, it is expected that viruses will have been reduced by a least a factor of 1,000. Yanko (1988) analyzed several hundred samples of sewage sludge composted at temperatures exceeding 55°C. Viruses and viable helminth ova were not detected in any of the samples, whereas fecal coliforms were present at levels exceeding 1,000 MPN per gram, even shortly after processing (that is, with no opportunity for regrowth).

4.4.1.2 Salmonellae as an Indicator

The Alternative 1 microbiological requirement also allows demonstration that salmonellae are below detection limits to indicate that other bacterial pathogens, enteric viruses, and viable helminth ova are below detection limits. Yanko's (1988) results discussed for fecal coliforms in compost samples in Section 4.4.1.1 above are strong evidence that salmonellae frequently survive (or regrow, or are introduced by contamination and then regrow) composting at what nominally were EPA's thermal requirements (see the composting requirement in the technologies listed under 40 CFR Part 257); whereas viable helminth ova and viruses were never found. Yanko's data also indicate that, when fecal coliform are at a density of 1,000 MPN/gram of solids or lower, salmonellae are generally below detection limits or are occasionally detected (see discussion of Yanko data in Section 4.3.2).

Absence of salmonellae is not quite as good as indicator of presence of pathogens as are fecal coliforms at 1,000 MPN/gram, but it has the important advantage that salmonellae are probably the pathogen of greatest concern. For the salmonellae requirement to be effective as an indicator of the absence of pathogens, salmonellae must be present in the incoming wastewater solids to a treatment works. This is common enough in all treatment works that routine monitoring of the sewage sludge for salmonellae will detect failure of the process to reduce pathogens.

4.4.2 Time-Temperature Alternative 1(A)—For Sewage Sludges with at Least 7-Percent Solids [503.32(a)(3)(ii)(A)]

The time-temperature requirement for sludges with solids contents of 7 percent or higher is given in Equation 1:

$$D = (131{,}700{,}000) / (10^{0.1400t}) \qquad \text{(eq. 1)}$$

where: **D = time required in days**
t = temperature in °C

The temperature must be at least 50°C and the time at least 20 minutes. This requirement does not apply when small particles of sewage sludge are heated by either warmed gases or an immiscible liquid [such cases are covered by Alternative 1(B)—see Section 4.4.3, below].

4.4.2.1 Explanation of Time-Temperature Equation

The thermal condition required under Alternative 1(A) is similar to the thermal requirements in 40 CFR Part 257. Part 257 contains two time-temperature conditions which, if met, are expected to reduce pathogens of concern to below detection limits.

- Pasteurization by treatment at 70°C for 30 minutes.
- Composting at 55°C for 3 days.

The pasteurization condition of 70°C for 30 minutes is based on German recommendations and practice. Recommended values (IRGRD, 1968) were 20-25 minutes at 70°C, but practice settled on 30 minutes at 70°C (Barker, 1970).

The requirement to compost for 3 days at 55°C was based on the recommendation of Burge et al. (1978). This group developed a predictive equation (Burge et al., 1980) based on the effect of temperature on reduction in density of bacteriophage f-2, an organism with much greater resistance to elevated temperatures than any of the pathogens of concern in sewage sludge. Die-off data for the bacteriophage were determined in a tryptone yeast extract medium and not in sewage sludge. The predicted log reduction at 3 days and 55°C was about 23 logs, which is extremely conservative. Burge et al. (1978) suggested that, because composting was done in the field with limited ability to assure that all parts of the composting pile achieved the desired temperature, this conservatism was necessary. In later research of a field compost operation, Burge and coworkers (ARS, 1982) showed that, at average temperatures around 55°C, the f-2 bacteriophage was easily destroyed. Surprisingly, fecal and total coliform survival was greater than survival of the bacteriophage, despite their expected poorer thermal resistance. At least in this instance, the conservatism of the recommended requirement appeared warranted.

Figure 4-2 compares EPA's time-temperature requirements for Class A Alternative 1(A) to data drawn from the literature by Feachem et al. (1983) for the organisms of concern in sewage sludge, and to the U.S. Department of Health and Human Services requirements for eggnog (1989). A third EPA time-temperature requirement—5 days at 53°C—is shown on Figure 4-2. Burge et al. (1978) showed that this condition is equivalent to 3 days at 55°C. As previously mentioned, the EPA curve for sewage sludge requires about a 5°C higher temperature than suggested by Feachem et al. and is clearly conservative. It is similar to the requirements for eggnog, a food product with flow characteristics similar to sewage sludge and which, like sewage sludge, contains ingredients that might protect organisms against heat.

The FDA requirements and the estimates of Feachem et al. indicate a linear relationship between the temperature in degrees Celsius and the logarithm (base 10) of time of exposure. Consequently, a straight line was constructed through the points at the extremes of the EPA curve in Figure 4-2 (70°C, log 1/48 day) and (53°C, log 5 days). The resulting equation was rearranged, converting from logarithmic to exponential form, and is given in Equation 1.

4.4.2.2 Explanation of Restrictions

The use of Equation 1 is restricted to times greater than or equal to 20 minutes and to temperatures greater than or equal to 50°C. The reason for the minimum time of 20 minutes is

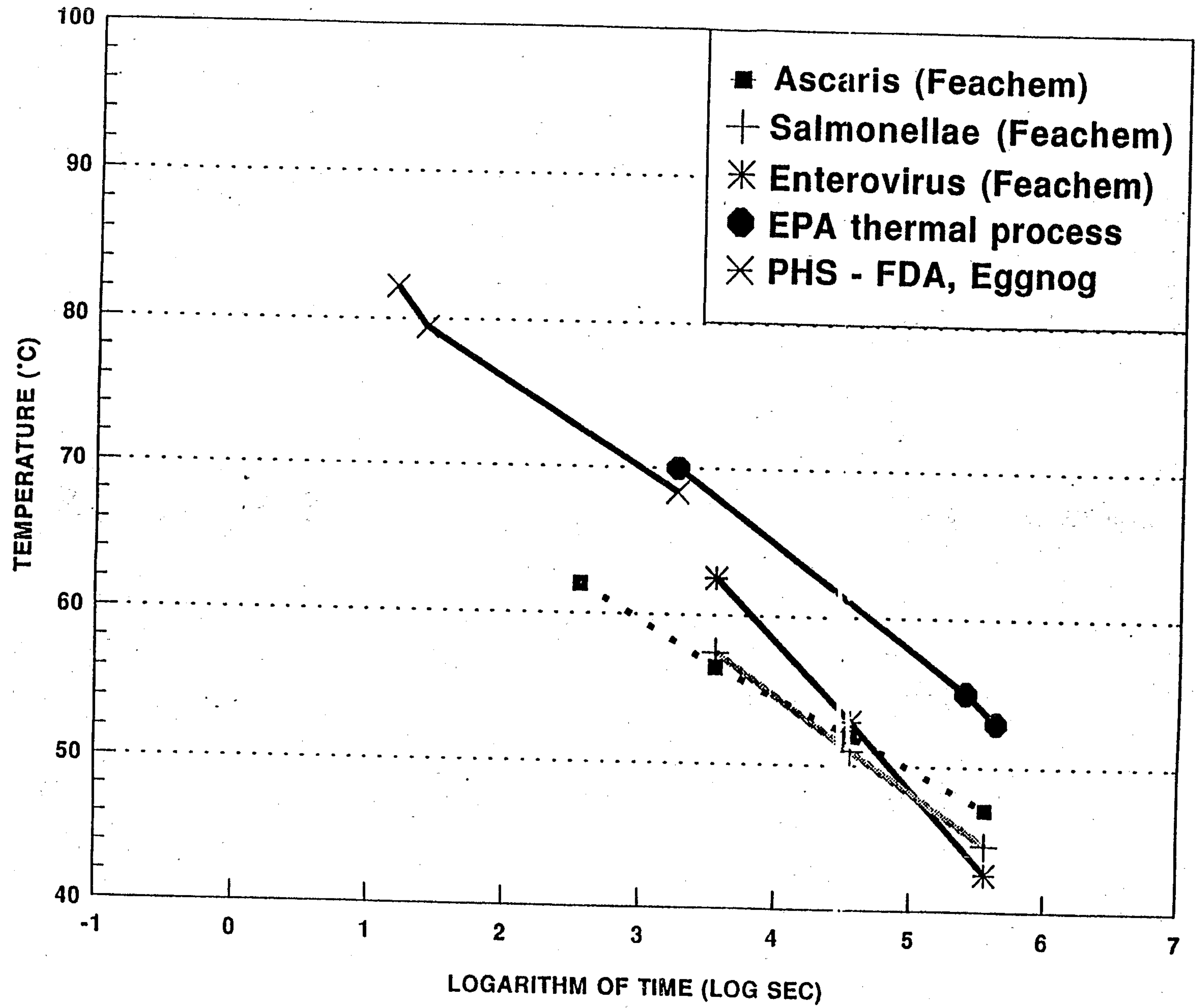

Figure 4-2: EPA's Time-Tem[illegible]ature Relationship for Thermal Disinfection Compare[illegible] Other Time-Temperature

that it is difficult to heat a sewage sludge with higher solids than 7 percent uniformly. Sewage sludge of this consistency forms an internal structure that inhibits the mixing caused by the thermal and hydraulic gradients that contribute to uniform distribution of temperature.

The restriction to temperatures of at least 50°C is imposed because information on the temperature-time relationship at lower temperatures is uncertain. For example, Brannen et al. (1975) report that Ascaris ova are destroyed quickly at temperatures over 51°C but are unaffected by long exposure at 47°C, indicating that much longer times than expected could be required to inactivate viable helminth ova at temperatures below 50°C.

4.4.3 Time Temperature-Alternative 1(B)—For Sewage Sludges with Suspended Small Particles and at Least 7-Percent Solids [503.32(a)(3)(ii)(B)]

This alternative applies to sewage sludges with 7 percent or higher solids content that are small particles heated by contact with either warmed gases or an immiscible liquid. For these sewage sludges, Equation 1 is applied to times not less than 15 seconds and temperatures not less than 50°C. Two examples of sewage sludges to which this requirement applies are:

- Sewage sludge cake that is mixed with previously dried solids to make the entire mass a mixture of separate particles, and is then dried by contact with a hot gas stream in a rotary drier.
- Sewage sludge dried in a multiple-effect evaporator system in which the sewage sludge particles are suspended in a hot oil that is heated by indirect heat transfer with condensing steam.

The reason for the restriction of the use of Equation 1 to temperatures not less than 50°C is explained in Section 4.4.2 above. The time at temperature of 15 seconds or more is allowed because heat transfer between particles and the heating fluid is excellent. Uniformity of temperature of the sewage sludge particles is expected to be excellent. Note that the temperature is the temperature achieved by the sewage sludge particles, not the temperature of the carrier medium.

The minimum time selected is not unusually short. For example, a minimum time of contact of 15 seconds is also allowed by FDA for pasteurization of eggnog (U.S. Department of Health and Human Services, 1989), but much shorter times are allowed for milk (0.01 seconds at 100°C or greater).

4.4.4 Time-Temperature Alternative 1(C)—For Sewage Sludges with Less Than 7-Percent Solids and Less Than 30 Minutes Contact Time [503.32(a)(3)(ii)(C)]

If sewage sludge has less than 7-percent solids content, Equation 1 is used for the time-temperature relationship. The equation applies for times greater than or equal to 15 seconds, but less than 30 minutes. The maximum time of less than 30 minutes is specified because, as explained in Section 4.4.5 below, a less stringent condition applies for times above 30 minutes. Insufficient information is available to apply this less stringent condition to times less than 30 minutes.

The minimum time of 15 seconds is allowed because the sewage sludge with less than 7-percent solids does not develop the internal structure that inhibits development of a uniform temperature within the sewage sludge when it is heated. As noted in Section 4.4.2 above, the FDA has applied this same minimum time to eggnog—a material of comparable viscosity to 7-percent solids sewage sludge.

Suggested German standards for pre-pasteurization at contact times of 30 minutes or less are presented in Table 4-1 (see discussion of this table in Section 4.4.5 below). At contact times less than 25 minutes, the German standards are more stringent than those required by Equation 1. They are also more stringent than the standards required by FDA to process eggnog. Probably the German requirements were made excessively stringent to allow for less- than-perfect plug flow in the pre-pasteurizer, or for the presence of large clumps of sewage sludge. Because each particle of sewage sludge has to achieve the desired time-temperature conditions and it is not unusually difficult to meet these conditions for a sewage sludge with less than 7-percent solids, the high degree of conservatism in the suggested German standards is not warranted for the Part 503 requirements.

TABLE 4-1

GERMAN RECOMMENDED STANDARDS[1] FOR PRODUCING HYGIENICALLY SAFE SEWAGE SLUDGE COMPARED WITH THE TIME-TEMPERATURE REQUIREMENTS OF EPA'S EQUATIONS 1 AND 2

		Temperature (°C)		
Process	**Time**	**German Standard**	**Equation 1**	**Equation 2**
Pre-pasteurization	30 min.	65	70	67
	25 min	70	70.6	
	20 min.	75	71.3	
	10 min.	80	73.4	
Aerobic thermophilic digestion	20 hr.	50		55.1
	10 hr.	55		57.7
	4 hr.	60		60.6

[1]Recommendations of a Joint Working Group of the German Association for Wastewater Technology (Abwassertechnische Vereinigung) and the Association of Public Cleansing Enterprises (Verband Kommunaler Stadreiningungsbetriebe). See D. Strauch, 1987.

4.4.5 Time-Temperature Alternative 1(D)—For Sewage Sludges with Less Than 7-Percent Solids and at Least 30 Minutes Contact Time at 50°C or Higher [503.32(a)(3)(ii)(D)]

The time-temperature requirement for sewage sludges with less than 7-percent solids and at least 30 minutes contact time at 50°C or higher is given by Equation 2:

$$D = (50{,}070{,}000) / (10^{0.1400t}) \qquad \text{(eq. 2)}$$

where: **D = time required in days**
t = temperature in °C

Equation 2 is similar to Equation 1 except that, for any given time, the temperature calculated by Equation 2 is 3°C lower than the temperature calculated by Equation 1. It is the equation of a straight line through the points (67°C, log 1/48 day) and (50°C, log 5 days), with the resulting logarithmic equation converted into exponential form.

As noted in Section 4.4.2.1, the time-temperature relationship given by Equation 1 is conservative. Conservatism is required because sewage sludges with 7-percent or higher solids content may be pasty masses or clumps of particles several inches in diameter that are very difficult to bring to uniform temperatures. For sewage sludges with less than 7-percent solids, which are easier to bring to uniform temperatures, a less conservative time-temperature relationship, such as that given in equation 2, is reasonable.

Some years ago, Swiss and German requirements that sewage sludge be disinfected before application to pasture land sparked substantial research in the microbiological performance of pre-pasteurization of sewage sludge before digestion and thermophilic aerobic digestion (TAD) that resulted from this research. These conditions have been verified by several studies. For TAD, Strauch (1988) has shown 100,000-fold reductions in enterobacteriaceae at time-temperature regimes consistent with the German standard. Fecal coliforms are enterobacteriaceae and would therefore have similar behavior. Salmonellae would also behave in this manner. Strauch et al. (1975) observed the complete destruction of salmonellae at a pilot plant operated within these time-temperature limits. Albrecht and Strauch (1978) showed that enteric viruses are destroyed by these conditions. These investigators observed that elevated pH level (above 7) and the presence of sewage sludge (as compared to results on enteric viruses in ampoules protected from the sewage sludge) increased the rate of reduction of enteric virus densities. Several investigators, including Lee et al. (1989), have shown destruction of Ascaris sp. under these conditions.

As Table 4-1 shows, the temperatures at a given time from Equation 2 for sewage sludges of less than 7-percent solids and 30 minutes treatment or longer exceed the suggested German standards. The additional safety factor provided by the higher temperatures has been included in the U.S. standard because some effects (e.g., the effect of pH on enteric virus reduction) are not well understood.

4.5 CLASS A, ALTERNATIVE 2—FOR SEWAGE SLUDGE FROM A HIGH pH-HIGH TEMPERATURE PROCESS [503.32(a)(4)]

Part 503.32(a)(4) describes the conditions of a process scheme recommended by EPA's Pathogen Equivalency Committee as equivalent to the Processes to Further Reduce Pathogens (PFRPs) listed in Appendix II of Part 257. This process, described in an EPA guidance document (EPA, 1989a), successfully reduces pathogens to below detectable limits. Part 503.32(a)(4) describes the process conditions, which include elevating pH to greater than 12 for 72 hours, maintaining the temperature above 52°C for at least 12 hours, and then air drying to over 50-percent solids. The hostile conditions of high pH and high temperature allow a variance to a less severe time-temperature regime than EPA's thermal condition requirements described above. It is only necessary to determine that either fecal coliform densities are reduced to less than 1,000 MPN/g or that Salmonella sp. densities are reduced to less than 3 MPN per 4 grams of total sewage sludge solids to ensure that pathogens have been reduced to below detectable levels and regrowth has not occurred (see Section 4.4).

4.6 CLASS A, ALTERNATIVE 3—FOR SEWAGE SLUDGE FROM OTHER PROCESSES [503.32(a)(5)]

Part 503.32(a)(5) applies to processes used to treat sewage sludge to meet the Class A requirements that do not meet EPA's thermal conditions. For a sewage sludge to be Class A, either the fecal coliform requirement of less than 1,000 MPN/g or salmonellae density requirement of less than 3 MPN/4 g must be met. The treated sewage sludge must also meet a requirement of less than 3 PFU/4 g for enteric viruses and less than 1/4 g for viable helminth ova. Testing for these latter organisms can be complicated by the fact that sometimes they are not detected in the untreated sewage sludge. When this happens, it is not possible to demonstrate that the process is able to reduce these organisms to below detection limits. Part 503.32(a)(5) includes an approach devised to overcome this difficulty.

If, for example, enteric viruses are not found in the sewage sludge that enters a stabilization process (i.e., the feed sewage sludge), the sewage sludge is presumed to be Class A until the next time samples of the sewage sludge are tested. No statement is made about the pathogen-reducing process as yet. Monitoring is continued until enteric viruses are found in the feed sewage sludge. At that time, the treated sewage sludge is analyzed to see if enteric viruses survive the treatment. If densities are below detection limits, the process meets Class A requirements. Monitoring of this type is continued until the required pathogen reduction is demonstrated, unless otherwise specified by a permitting authority. For the sewage sludge to continue to be Class A, the process must be operated under the same conditions that successfully reduced densities in the treated sewage sludge to below detection limits. The procedure to be followed when viable helminth ova are not detected in the untreated sewage sludge is the same as for enteric viruses.

One problem can still cause difficulty. Tests for enteric viruses and viable helminth ova take substantial time: 2 weeks to determine whether helminth ova are viable, and 2 weeks or longer for enteric viruses. The operator does not know whether the feed sewage sludge has enteric viruses or viable helminth ova until 2 or more weeks after the first samples were taken. The solution to this problem is to sample both the feed sewage sludge and the same batch of sewage sludge after treatment during each monitoring episode and to preserve the samples of treated sewage sludge until results of the feed sewage sludge analysis indicate whether analysis of the treated sewage sludge is necessary. For enteric viruses, the sewage sludge should be stored frozen. For viable helminth ova, the sewage sludge should be stored at about 4°C.

An advantage of this approach is that it reduces analytical costs. After the pathogen reduction is demonstrated, only the process parameters have to be monitored.

4.7 CLASS A, ALTERNATIVE 4—FOR SEWAGE SLUDGE FROM UNKNOWN PROCESSES [503.32(a)(6)]

Part 503.32(a)(6) has been introduced into the Part 503 regulation to handle cases where either a process in which the sewage sludge is treated is not known, the sewage sludge was treated by a process operating at conditions less stringent than the operating conditions at which the process qualified as Class A, or the past history of the sewage sludge is not known. This alternative requires that the sewage sludge be monitored for (1) fecal coliform or salmonellae, (2) enteric viruses, and (3) viable helminth eggs. The enteric virus requirement or the viable helminth egg requirement may be waived at the discretion of the permitting authority. An example of a situation where waiving some requirements is appropriate would be a pile of sewage sludge that had been stored for many years. If fecal coliform densities are sufficiently low, enteric virus survival is unlikely. In such a case, the permitting authority may waive the requirement to test for enteric viruses, but would probably insist on measuring viable helminth egg densities.

4.8 CLASS A, ALTERNATIVE 5—USE OF PFRPs [503.32(a)(7)]

Under Part 503.32(a)(7), sewage sludge is considered to be Class A if it is treated in one of the Processes to Further Reduce Pathogens (PFRPs) listed in Appendix B of the regulation *and* if the treated sewage sludge meets the following microbiological requirements: fecal coliform density of less than 1,000 MPN per gram of total solids (dry weight basis) *or* Salmonella sp. density of less than 3 MPN per 4 grams of total solids (dry weight basis).

This requirement is similar to the PFRP requirement in the Part 257 regulation. The PFRP list in Appendix B of Part 503 differs from the PFRP list in Part 257 in that all requirements related to vector attraction reduction have been removed (the sewage sludge must now separately meet the vector attraction reduction requirements of Part 503). The processing conditions required for the processes listed in the Part 257 regulation are expanded in an EPA publication (EPA, 1989a). Background for the choice of these conditions is given by Farrell (1980).

The Part 503 requirement also differs from the PFRP requirement in Part 257 in that microbiological monitoring is now required. The implicit microbiological goal a PFRP process is expected to meet is reduction of pathogenic bacteria, enteric viruses, and viable helminth ova to below detectable levels. Under Part 257, no microbiological monitoring was required and therefore very little information has been collected since the publication of Part 257 on whether sewage sludge of the desired microbiological quality was being produced by the PFRPs. To fill this information gap, an experimental program that focussed primarily on composted products was carried out by Yanko (1988). This investigation showed that pathogenic bacteria (salmonellae) were frequently observed in composted sewage products that presumably had met the required processing conditions.

Consequently, based on these results and a lack of confidence that a pure technology-based standard was adequate, a microbiological monitoring requirement has been added in the Part 503 regulation. The monitoring required for the PFRPs is the same as is required for the other Class A alternatives—reduce fecal coliform density to below 1,000 MPN/gram or salmonellae to below 3 MPN/gram (see Section 4.4.1). When either of these requirements is met, the potential for regrowth of Salmonella sp. bacteria is mitigated.

One of the processes described in Appendix B to Part 503 is aerobic digestion for 10 days at 55 to 60°C. Appendix B does not specify how to operate this process. Conceivably, it could be operated as a well-mixed continuously fed reactor, in which case it would probably not achieve the desired pathogen reduction. The original communication (Farrell, 1980) supporting use of this process as a PFRP stated that the process should be operated to avoid by-passing, possibly by staging the reactors. It is more effective to avoid by-passing by using draw-and-fill feeding, and this procedure should be used with thermophilic aerobic digestion. If operation is not correct and by-passing does occur, the monitoring requirement will reveal the deficiency.

As has been noted in Section 2.6.2, reductions in indicator organism densities to low values are not a good indicator of equivalent reductions in viral densities when the sewage sludge is treated by high-energy irradiation. Effectiveness of high-energy radiation in deactivating organisms is inversely related to organism size, so enteric viruses are reduced to a lesser degree by a given radiation dose than bacteria. Nevertheless, the specified radiation dose of 1 megarad specified in Appendix B of Part 503 is an extremely conservative dose that was chosen to ensure that no enteric viruses survive. In addition, there is very little uncertainty in the design of an irradiation process. If the dose is being delivered, the pathogens will be reduced to below detectable limits.

4.9 CLASS A, ALTERNATIVE 6—USE OF PROCESSES EQUIVALENT TO PFRPs [503.32(a)(8)]

This alternative is similar to Alternative 5, described above. Under Part 503.32(a)(8), sewage sludge is Class A if treated in any process that is *equivalent to* a Process to Further Reduce Pathogens *and* if the treated sewage sludge meets the following microbiological requirements: fecal coliform density of less than 1,000 MPN per gram of total solids (dry weight basis) *or* Salmonella sp. density of less than 3 MPN per 4 grams of total solids (dry weight basis).

The Part 257 regulation also allowed use of processes determined to be equivalent to PFRPs. However, the Part 257 regulation did not require any microbiological monitoring. This has been added under Part 503 to address regrowth of pathogens.

Under Part 257, recommendations on the equivalency of a process were made by EPA's Pathogen Equivalency Committee (PEC) to the permitting authority. The permitting authority made the final determination on equivalency based on the PEC's recommendation. The Part 503 regulation also indicates that equivalency determinations will be made by the permitting authority.

SECTION FIVE

PART 503 CLASS B PATHOGEN REQUIREMENTS

5.1 INTRODUCTION

This section provides explanations and justifications for the Class B pathogen requirements in subpart D of the Part 503 regulation. These requirements include pathogen reduction requirements and site restrictions. All Class B sewage sludges also must meet one of the requirements for vector attraction reduction (see Section 6).

The Class B pathogen requirements for sewage sludge can be met in three different ways. The implicit objective of all three alternatives is to ensure that pathogenic bacteria and enteric viruses are adequately reduced in density. Farrell et al. (1985) have shown that, if treated sewage sludge has a fecal coliform density of 2 million or less MPN or CFU per gram of total sewage sludge solids, pathogenic bacteria and enteric viruses are reduced. Comparing pathogenic densities in the influent of a treatment works to pathogenic densities in treated sewage sludge solids, the 2 million MPN or CFU value represents a reduction of over 2 logs (a factor of 100) in fecal coliform densities, and is expected to result in a reduction of approximately 1.5 logs in Salmonella sp. bacteria densities and 1.3 logs in enteric virus densities. The three alternatives for meeting the Class B pathogen requirements are discussed in Sections 5.2 and 5.3. Site restrictions are presented in Section 5.4, and pathogen requirements for domestic septage are discussed in Section 5.5.

5.2 CLASS B, ALTERNATIVE 1—MONITORING OF INDICATOR ORGANISMS [503.32(b)(2)]

5.2.1 Explanation of Requirement

Class B, Alternative 1 requires that seven samples of sewage sludge that is used or disposed be collected, and that the geometric mean fecal coliform density of these samples be less than 2,000,000 CFU or MPN per gram of sewage sludge solids. As noted in Section 5.2.2 below, the absolute value of the fecal coliform density of a sewage sludge treated in processes typically used to achieve Class B pathogen reduction is expected to correlate well with average density of bacterial and viral pathogens in the sewage sludge. Because methods used to determine fecal coliform density (membrane filter method and the MPN dilution method) have poor precision and sewage sludge quality varies, at least seven separate samples must be analyzed to reduce the standard error.

When the Class B fecal coliform value is met (a log mean of 6.3, which is equivalent to a geometric mean of 2,000,000), the true mean value lies within a confidence interval that depends on the experimentally determined log standard deviation (i.e., s) of the fecal coliform determinations. If $s = 0.3$, which is what would be expected for measurements taken over a 2-week period using the membrane filter method, the 95-percent confidence interval of the true log mean is 6.08 (1,200,000 CFU/g) to 6.52 (3,300,000 CFU/g). If $s > 0.3$, the confidence interval is larger and there is less assurance that the sewage sludge meets the criterion.

5.2.2 Fecal Coliform Density as an Indicator of Pathogen Reduction

The 503.32(b)(2) requirement assumes that the absolute value of the fecal coliform density correlates well with the average density of bacterial and viral pathogens. This section provides the rationale for that assumption. Farrell et al. (1990) showed that the incoming wastewater solids from several Midwestern treatment works had almost the same indicator organism densities. This finding was verified by Oliveri et al. (1989) for several treatment works in the vicinity of Philadelphia. Fecal indicator organisms in raw wastewater are one-to-one indicators of fecal matter in untreated wastewater. As such, they should be accurate indicators of pathogen densities over the long term. It turns out that all wastewater solids, rather than all sewage sludges, are about equal (in the long term) in pathogen content.

Assuming that fecal indicators after sewage sludge is treated are good indicators of pathogens, their absolute density after treatment should be a good indicator of pathogen density. Examination of the data (Farrell et al., 1985, 1990) showed that if the treated sewage sludge had a fecal coliform density of 2 million MPN or CFU per gram, pathogenic enteric viruses and bacteria would be reduced. The data also showed that most treatment works practicing conventional stabilization processes could reach this goal. Comparing densities in suspended solids in the entering wastewater to densities in solids in treated sewage sludge, there is a fecal coliform reduction of over a factor of 100, and an expected reduction in salmonellae and enteric virus densities of about 1.5 logs and 1.3 logs, respectively.

The assumption that fecal coliform densities after processing are good indicators of pathogen densities needs to be examined. For conventional biological sewage sludge treatment processes such mesophilic aerobic and anaerobic digestion, information is available that shows that pathogenic bacteria and virus densities fall in proportion to the relative reduction in fecal indicator organism densities. Martin et al. (1990) obtained data on the relative declines in fecal indicators and animal viruses for aerobic digestion at temperatures from 8 to 40°C. In the temperature range of 15 to 31°C, the reductions did not show marked trends with temperature. Ratios of log reductions for fecal indicators relative to log reductions for viruses were calculated for seven temperatures in this temperature range. Average ratios and standard error of the mean are shown in Table 5-1, and are compared with Farrell et al.'s (1985) data for anaerobic digestion at 35°C. The differences in the effects on virus and indicator organism densities between anaerobic and aerobic processes are not great. Fecal coliform densities decline about 1.5 times more rapidly than viral densities. The agreement between declines in fecal streptococcus and viral densities is very good. These results demonstrate that, for aerobic and anaerobic processes in the commonly used temperature ranges, a decline in fecal indicator densities can be used to indicate declines in enteric viruses. Results of investigations by Farrah et al. (1986) for aerobic digestion and by Farrell et al. (1985) for anaerobic digestion show approximately a 1.2-log decline for fecal coliform to 1.0-log decline for salmonellae, indicating that for this representative bacterial pathogen, a decline in fecal indicator densities can be used to indicate declines in bacterial pathogen densities.

For treatment processes operated at temperatures higher than 35°C, available information (Martin et al., 1990; Berg and Berman, 1980) indicates that viruses fall faster than indicators fall. However, bacterial and viral reductions are much greater than 2 logs at thermophilic temperatures.

TABLE 5-1

COMPARISON OF REDUCTIONS IN FECAL INDICATOR DENSITIES TO REDUCTIONS IN VIRAL DENSITIES DURING AEROBIC DIGESTION AND MESOPHILIC ANAEROBIC DIGESTION

Organism	Ratio of log density of indicator organism to log density of viruses	
	Aerobic Digestion (15-31°C)[1]	Anaerobic Digestion (35°C)[2]
Total coliform	1.31 ± 0.17	2.01
Fecal coliform	1.17 ± 0.15	1.92
Fecal streptococci	0.96 ± 0.12	1.07

[1]Calculated from results by Martin et al. (1990).

[2]Calculated from results reported by Farrell et al. (1985).

Chemicals such as lime, chlorine or ozone are sometimes used to treat sewage sludge, generally to produce a combined result of pathogen reduction and vector attraction reduction. The chemical doses required to reduce vector attraction also produce great reductions in pathogen and indicator densities. For example, for lime treatment, results by Counts and Shuckrow (1975) and Strauch (1982) show that bacterial and viral densities are greatly reduced when pH exceeds 12.

5.3 CLASS B, ALTERNATIVES 2 AND 3—USE OF PSRP AND EQUIVALENT PROCESSES [503.32(b)(3) and (4)]

Under Alternatives 2 and 3, sewage sludge treated by one of the Processes to Significantly Reduce Pathogens (PSRPs) listed in Appendix B of Part 503 or an equivalent process is considered to be Class B. No microbiological monitoring is required. The permitting authority is responsible for determining PSRP equivalency.

These requirements are similar to the requirements in Part 257 that allowed use of listed PSRPs or equivalent processes. The PSRPs listed in Appendix B of Part 503 are essentially identical to those listed in Part 257 except that all requirements that address reduction of vector attraction have been removed (all Class B sludges must meet separate vector attraction reduction requirements—see Section 6).

Though not specified in Part 257, the operating conditions of the PSRP processes were set to reduce the densities of pathogenic bacteria and enteric viruses in the untreated sewage sludge by approximately 1.0 log. This value was based on work by Berg and Berman (1980) and Farrell et al. (1985), who showed that conventional anaerobic digestion produced reductions of this magnitude. Background information supporting the choice of conditions for the PSRP processes was given by Farrell (1980).

Unlike the comparable Class A requirements (see Sections 4.7 and 4.8), Class B Alternatives 2 and 3 do not require monitoring for fecal coliform or Salmonella sp. Monitoring for those organisms is extremely important for a Class A sewage sludge to demonstrate pathogen reduction and to ensure that regrowth has not occurred. Disease risk is not as high for Class B sewage sludge, because site restrictions prevent the public from coming in direct contact with the sewage sludge for a certain period of time. The Class B site restrictions, such as restriction of access and harvesting of crops, provide important barriers separating the public from risk of disease. Additionally, the presence in sewage sludge treated by PSRPs of competitive organisms and/or other conditions that inhibit growth prevents the type of regrowth to high densities of pathogenic bacteria that could occur with Class A sewage sludges.

5.4 SITE RESTRICTIONS [503.32(b)(5)]

Sewage sludge classified as Class B with respect to pathogens may still contain significant densities of pathogenic bacteria, enteric viruses, and viable helminth eggs. Thus, site restrictions are needed to reduce exposure to the sewage sludge. Site restrictions are discussed in this section.

5.4.1 Food Crops That Touch the Sewage Sludge [503.32(b)(5)(i)]

Food crops with harvested parts that are totally above the land surface and likely to touch the soil/sewage sludge mixture cannot be harvested for 14 months after application of the sewage sludge. For clarity, the term "harvested" has replaced the term "grown" used in Part 257.

Assuming that crops are harvested about 2 months after they are "grown" (i.e., planted), the Part 257 regulation effectively required 20 months before these crops could be harvested. The Part 503 regulation requires only 14 months. Based on data on the relatively high rate of die-off of viable helminth ova on the soil surface (Jakubowski, 1988), the Agency concluded that the 14-month period is adequate to protect public health and the environment.

5.4.2 Food Crops Below the Soil Surface [503.32(b)(5)(ii) and (iii)]

Part 503 requires that food crops with harvested parts below the soil surface not be harvested for 20 months after sewage sludge application provided that the sewage sludge remains on the soil surface for 4 months prior to incorporation in the soil. If the sewage sludge does not remain on the soil surface for 4 months, food crops with harvested parts below the soil surface cannot be harvested for 38 months after sewage sludge application. These site restrictions are based on results reported by Jakubowski (1988) which show that viable helminth eggs on the soil surface die off after 4 months' exposure on the soil surface, whereas their viability is prolonged to several years if they are deeper in the soil.

The requirement of 20 months is 6 months longer for root crops than for crops that grow above the surface. This additional time is required because the conditions of growth are so radically different for root crops. The above-ground environment is harsh for all pathogens, whereas the below-ground environment is benign by comparison. Additionally, the root crop is literally bathed in the soil, which may contain pathogens, whereas the above-ground crops only occasionally contact dust or are splattered by rain-splash containing soil particles. The extra 4 months provides additional time to overcome the anticipated slower decline in pathogen densities below ground and the increased exposure created by the intimate contact of the crop with the soil.

If 4 months of surface exposure is provided, the period between application and harvest is 20 months. For a September 1994 harvest, sewage sludge could be applied to the soil surface up to the end of December 1992, plowed or dished into the soil in the spring of 1993, and the crop could be harvested in September 1994.

If surface exposure is less than 4 months, the period between sewage sludge application and harvest is 38 months. Jakubowski's results indicate that survival of viable helminth eggs could be 50 percent after 4 years in the soil in some cases. Long exposure is needed to reduce risk. The Agency concluded that the 38-month period allows a long enough exposure to reduce viable helminth ova to below detectable limits.

5.4.3 Food Crops, Feed Crops, and Fiber Crops [503.32(b)(5)(iv)]

Food, feed, and fiber crops cannot be harvested for 30 days after application of sewage sludge. Crops become contaminated with sewage sludge when it is applied to the land. If these crops are harvested in less than 30 days, they carry contamination into the outside environment. As mentioned previously, 30 days is long enough for environmental factors such as sunshine, rain, and desiccation to reduce the density of pathogens in sewage sludge adhering to the crops to minimal levels. Hay is an example of a feed crop covered by this restriction.

5.4.4 Grazing of Animals [503.32(b)(5)(v)]

Animals are not allowed to graze on the land for 30 days after application of sewage sludge. Sewage sludge can adhere to animals that walk on sewage sludge-amended land shortly after sewage sludge application and can then be brought to humans who come in contact with the animals (for example, riding horses allowed to graze on sewage sludge-amended pasture).

The purposes of this requirement are prevention of disease in animals, prevention of transmission of animals' disease to humans, and prevention of direct transmission of disease organisms in sewage sludge to humans.

Grazing animals are primarily exposed to sewage sludge that has adhered to vegetation. They would not be grazed on barren or muddy surfaces. As Kowal and others have noted (see Section 2.2.2), pathogens adhering to vegetation typically are reduced in densities to low values within about 30 days of exposure of the surface of the vegetation.

5.4.5 Growing of Turf [503.32(b)(5)(vi)]

Turf grown on land to which sewage sludge has been applied cannot be harvested for 1 year after application if the turf is placed either on a lawn or on land with high potential for public exposure. Such uses involve a high potential for human contact with the turf's soil layer.

The 1-year period allows the environment to reduce the pathogens in the sewage sludge (see Section 5.4.6 below).

5.4.6 Public Access to Sites on Which Sewage Sludge Is Applied [503.32(b)(5)(vii) and (viii)]

Access is restricted for 1 year after sewage sludge application to land with a high potential for public exposure. This period of restricted access is the same as in the Part 257 regulation. It protects against exposure to the hardiest pathogens (i.e., the viable helminth eggs, which might survive for long periods on the land surface). If the land has a low potential for public exposure, the period of restricted access is 30 days.

The difference between high and low potential for public exposure is generally evident. A farm field used to grow corn or soybeans is an example of a low potential for public exposure. Even the farm family itself walks about very little on such fields. On the other hand, a baseball diamond or a soccer field gets heavy use, and contact with the soil is substantial (players fall on it and dust is raised which is inhaled and ingested).

5.5 DOMESTIC SEPTAGE [503.32(c)(1) and (2)]

Under Part 503.32(c), the potential public health risk associated with pathogens in domestic septage applied to agricultural land, forest, or a reclamation site may be controlled in one of two ways:

- *Either* site restrictions under 503.32(b)(5)—see Section 5.4, above—have to be met,
- *Or* pH of the domestic septage has to be raised to 12 and maintained at 12 for 30 minutes *and* the site restrictions discussed above in Sections 5.4.1 to 5.4.3 concerning harvesting of crops have to be met.

When domestic septage is applied to other types of land, the pathogen requirements for sewage sludge have to be met.

5.5.1 Site Restrictions

For untreated domestic septage, pathogen control is accomplished through the site restrictions. Site restrictions prevent exposure to the domestic septage for a certain period of time so that the environment can reduce the pathogens in sewage sludge. The site restrictions that have to be met are the same site restrictions that have to be met when a Class B sewage sludge is applied to the land.

5.5.2 pH Adjustment with Site Restrictions for Crop Harvesting

A pH adjustment reduces pathogenic bacteria and enteric virus densities to low levels. Although the time required by Part 503 for the pH of domestic septage to remain at 12 is less than the 2 hours required for the lime stabilization PSRP, the lower time (i.e., 30 minutes) produces pathogen reduction that exceeds the pathogen reduction requirements for a Class B sewage sludge. Data obtained by Farrell et al. (1974) and literature cited by them indicate that 0.5-hour contact at pH 12 produces a much greater reduction in bacterial and enteric viral densities than is achieved by conventional anaerobic digestion, which is a PSRP in Appendix B of Part 503. Research at the University of Wisconsin (Ronner and Cliver, 1987) on destruction of viruses by lime treatment of sewage sludge strongly supports this conclusion.

Restrictions on harvesting of crops are part of this requirement because the Agency concluded that pH adjustment alone does not reduce pathogens to the level required under Class A that would allow crops to be harvested immediately after applying domestic septage to the land. Site restrictions are imposed to provide the environment time to reduce the pathogens in the domestic septage.

SECTION SIX

VECTOR ATTRACTION REDUCTION REQUIREMENTS

6.1 INTRODUCTION

Part 503.33 contains the requirements for vector attraction reduction in sewage sludge applied to the land or placed on a surface disposal site. These requirements are designed to ensure reduction of vector attraction either through some form of treatment [503.33(b)(1-8)], or by creating a physical barrier that prevents vectors from coming in contact with the sewage sludge [503.33(b)(9-11)].

Which requirements are applicable depends on the nature of the sewage sludge (e.g., bulk sewage sludge, sewage sludge sold or given away in a bag or other container, or domestic septage) and the use or disposal practice. In every case, only one of a range of allowable options for demonstrating vector attraction reduction has to be selected.

This section describes and justifies the various vector attraction reduction requirements in Part 503.33 of the regulation. The section is organized according to the specific paragraphs in Subpart D, and uses the same numbering as the Part 503 paragraphs.

6.2 REDUCTION IN VOLATILE SOLIDS CONTENT [503.33(b)(1)]

Under 503.33(b)(1), vector attraction reduction is achieved if the mass of the volatile solids in the sewage sludge is reduced by at least 38 percent. (This requirement is the same as it was in Part 257.) The percent reduction is measured from the stabilization process influent to the sewage sludge that is used or disposed. This includes any additional volatile solids reduction that occurs before the sewage sludge is used or disposed, such as might occur when the sewage sludge is processed on drying beds.

The method of volatile solids reduction is not specified by Part 503 but is typically achieved by anaerobic or aerobic digestion. These processes degrade most of the biodegradable material to lower activity forms. Any biodegradable material that remains characteristically degrades slowly—so slowly that the vectors that would be attracted to unprocessed sewage sludge are not drawn to it.

This requirement was drawn from the Water Pollution Control Federation's Manual of Practice No. 8 (Water Pollution Control Federation, 1967). This amount of volatile solids reduction could be attained at the "good practice" recommended conditions for anaerobic digestion of 15 days residence time at 35°C in a completely mixed high-rate digester. Volatile solids reduction is calculated by a volatile solids balance around the digester or by the Van Kleek formula (Fisher, 1984). EPA has provided guidance on methods of calculation (1992b).

6.3 ADDITIONAL DIGESTION OF ANAEROBICALLY DIGESTED SEWAGE SLUDGE [503.33(b)(2)]

Under Part 503.33(b)(2), an anaerobically digested sewage sludge can be shown to have achieved satisfactory vector attraction reduction if it loses less than 17 percent volatile solids when it is batch-digested further at 30 to 37°C for an additional 40 days.

Frequently, sewage sludges are recycled through the biological wastewater processes of a treatment works or reside for long periods of time in the wastewater collection system. During this time, they undergo substantial biological degradation. If they are subsequently treated by anaerobic digestion for an adequate period of time, they achieve vector attraction reduction but, because they entered the digester already partially stabilized, the volatile solids reduction is frequently less than 38 percent. The additional digestion test is extremely useful in demonstrating that these sewage sludges are indeed satisfactorily reduced in vector attraction.

This requirement is based on information obtained by Jeris et al. (1985). These investigators demonstrated that most of their anaerobically digested sewage sludges could be further digested to a modest degree, while a few of the sewage sludges showed much more ability to digest further. This "ability to digest further" is used as an index of ability to putrefy further and attract vectors. Twenty to 40 days are needed to complete the determination. The time requirement makes the alternative infeasible if a sewage sludge must be immediately used or disposed, but is no obstacle to evaluating an operating process. The test must simply be started 20-40 days before the result is needed.

Jeris et al.'s data showed the following additional percent volatile solids reduction after 40 days of additional digestion for six digested sewage sludges samples taken from full-scale treatment works: 9, 10, 13, 22, 36, and 38 percent. The three sewage sludges with the lowest volatile solids (VS) reduction showed low volatile acid concentrations before the additional digestion period commenced; the other three showed higher volatile acids, indicating poorer digestion. The percent VS versus time curves essentially flattened out at 40 days, indicating the samples were completely digested by this time. For purposes of the Part 503 regulation, a VS reduction of 17 percent or less on additional batch digestion for 40 days was selected as adequate evidence of satisfactory vector attraction reduction. The 17-percent value is midway between the upper limit of well-digested samples and the lower limit of the poorly digested samples. This reduction is equivalent to the 38-percent volatile solids reduction, based on volatile solids entering and leaving the digester. Research in progress by Farrell and Bhide (1992) using sewage sludges digested for 10, 15, and 20 days nominal residence time supports this selection. Procedures for the test suggested by Farrell and Bhide are presented in EPA (1992b). The use of the additional volatile solids reduction to demonstrate vector attraction reduction is allowable for sewage sludges from anaerobic digestion that are unable to demonstrate 38-percent volatile solids reduction.

6.4 ADDITIONAL DIGESTION OF AEROBICALLY DIGESTED SEWAGE SLUDGE [503.33(b)(3)]

Under 503.33(b)(3), an aerobically digested sewage sludge of 2 percent or less solids achieves satisfactory vector attraction reduction if it loses less than 15-percent volatile solids when it is batch-digested at 20°C for an additional 30 days.

The circumstance in which a sewage sludge has been substantially reduced in biological degradability before it is aerobically digested is very common, because aerobic digestion is the stabilization process most frequently chosen for sewage sludges from extended aeration plants. In these treatment works, nominal residence time of sewage sludges leaving the wastewater treatment process generally exceeds 20 days. Consequently, it is difficult to demonstrate 38-percent volatile solids reduction after aerobic digestion. The additional digestion test is valuable in demonstrating adequate vector attraction reduction in these cases. The test can be run on sewage sludges up to 2-percent solids. It does not require a temperature correction for sewage sludges not initially digested at 20°C. Details on the most desirable way to run the test are provided in EPA (1992b).

This requirement is based on data from batch digestion tests on aerobically digested sewage sludges (Jeris et al. [1985]). These tests showed that after about 30 additional days of digestion, there was no longer any appreciable loss in volatile solids content. As with anaerobic digestion (see Section 6.3 above), the loss in volatile solids content was related to the amount of initial digestion. Farrell and Bhide (1992) have established that a sewage sludge with an initial solids content of 2-percent or less, when batch aerobically digested for 15 days at 20°C, typically will show under 15-percent additional volatile solids destruction when batch digested for an additional 30 days. The use of additional volatile solids reduction to demonstrate vector attraction reduction is allowable only for sewage sludges from aerobic digesters that are unable to demonstrate the 38-percent volatile solids reduction.

6.5 SPECIFIC OXYGEN UPTAKE RATE (SOUR) FOR AEROBIC SEWAGE SLUDGES [503.33(b)(4)]

The vector attraction potential of an aerobically digested sewage sludge also can be shown to be reduced if the SOUR determined at 20°C is equal to or less than 1.5 mg of oxygen per hour per gram of total sewage sludge solids. (See Section 4.2.2 for a definition of SOUR.)

Frequently, aerobically digested sewage sludges are circulated through the aerobic biological wastewater treatment stage for as long as 30 days. In these cases, the sewage sludge entering the aerobic digester is already partially aerobically digested. It is difficult then to demonstrate an additional 38-percent volatile solids reduction. The SOUR method for determining vector attraction reduction in this type of sewage sludge has been developed. This method depends on the rate of oxygen uptake of the sewage sludge.

If a sewage sludge has been treated aerobically to the point at which the biological organisms present are consuming very little oxygen, the value of the sewage sludge as a food source for microorganisms is very low. The likelihood that such a sewage sludge will attract vectors when applied to the land surface is likewise low. Eikum and Paulsrud (1977) have shown that both the odor index of aerobically digested sewage sludges and the oxygen uptake level decline at about the same rate with increasing nominal residence time in a continuous flow (fed once a day) digester. The relationship between odor intensity and oxygen uptake rate is approximately a direct proportion. Eikum and Paulsrud's results indicate that at 20°C, an oxygen uptake rate of 1.5 g/hr/g total volatile suspended solids (VSS) or less indicates a well-stabilized sewage sludge. The oxygen uptake rate depends on the temperature of digestion (i.e., t). Within a range of $\pm$ 5°C, the oxygen uptake rate obtained at another temperature can be converted to the uptake rate of 20°C by the following relationship:

$$\text{SOUR}\ (20°\text{C}) = \text{SOUR}\ (t°\text{C}) \times 1.10^{(20-t)}$$

The oxygen uptake rate depends on the conditions of the test and, to some degree, on the nature of the original sewage sludge before aerobic treatment. Similarly the temperature correction also depends on the nature of the sewage sludge. Research (Farrell and Bhide, 1992) has shown that the SOUR method may be unreliable at solids content above 2 percent and requires a poorly defined temperature correction at temperatures differing substantially from 20°C. Information on test procedures and sewage sludge-dependent factors are provided in EPA (1992b).

6.6 AEROBIC PROCESSES AT GREATER THAN 40°C [503.33(b)(5)]

Vector attraction is considered to be adequately reduced if sewage sludge is aerobically treated for 14 days or longer at a temperature over 40°C and an average temperature higher than 45°C. This vector attraction reduction method relates primarily to composted sewage sludge. The adequacy of this method to reduce vector attraction is demonstrated by field observation. These conditions are used at numerous within-vessel facilities (e.g., the plant at Fairfield, Connecticut), and the final compost produced does not attract vectors. (Aerated static pile composting facilities typically compost sewage sludge for longer periods than 14 days. This is not needed for vector attraction reduction but is used to produce a final product of superior agricultural utility.)

6.7 ADDITION OF ALKALI [503.33(b)(6)]

Sewage sludge may be reduced in vector attraction by adding sufficient alkali to: (1) raise the pH to at least 12; (2) remain at pH of at least 12 without addition of more alkali for 2 hours; and (3) remain at a pH of at least 11.5 for an additional 22 hours.

The vector attraction reduction achieved by adding alkali to produce a sufficiently high pH is not permanent. Alkali addition does not significantly change the nature of the substances in the sewage sludge, but instead causes stasis in biological activity. If the pH should drop, the surviving bacterial spores would become biologically active, and the sewage sludge would putrefy and attract vectors. The target conditions provided by the 503.33(b)(6) requirement are designed to ensure that the sewage sludge can be stored for at least several days at the treatment works, transported, and applied to the soil without the pH falling to a point where putrefaction occurs and vectors are attracted.

Noland et al. (1978) have shown that with addition of quicklime or slaked lime, sewage sludge pH remains high for extended periods. His Figure 9 shows that for a sewage sludge raised to pH 12.5, pH did not fall to below 12 for 25 days. One reason the pH stays high for such a long period is that a substantial portion of the lime is still not dissolved; this excess lime dissolves as the pH starts to drop below 12.5. Other alkalis, such as cement kiln dust or wood ash, may be more soluble, so at pH 12 or above little undissolved alkali may be present to help maintain the pH as it starts to fall. The Part 503 requirement for pH to exceed 11.5 for 22 hours after alkali addition is to ensure that it will be high long enough to use or dispose the sewage sludge even if a large proportion of the alkali is soluble.

In research in progress, Farrell and Bhide (1992) have shown that if chemical equivalents of hydroxyl ion are added using sodium hydroxide or calcium hydroxide, the pH stays above 11.5 for at least as long for the sodium hydroxide as for the calcium hydroxide. However, if the addition of hydroxyl ion is controlled by pH rather than by chemical equivalency, much less sodium hydroxide than calcium hydroxide is needed to reach a pH of 12. A more rapid drop in pH with time would be expected in this case. Thus, the Part 503 requirement that pH remain above 11.5 for an additional 22 hours after the first 2 hours following alkali addition is prudent when more soluble alkalies than lime are used.

The vector attraction reduction method in this requirement is similar to the vector attraction reduction method by lime addition described in Part 257, except for the additional requirement in Part 503 that the pH remain above 11.5 for another 22 hours, which was added to guard against insufficient addition of alkali when soluble alkalis are used as described above. This requirement does not mean that more lime is now needed to achieve reduced vector attraction. Typically, if enough lime has been added so that the pH is above 12 after 2 hours, the pH stays above 11.5 for an additional 22 hours.

6.8 MOISTURE REDUCTION OF SEWAGE SLUDGE CONTAINING NO UNSTABILIZED SOLIDS [503.33(b)(7)]

Under Part 503.33(b)(7), vector attraction reduction of sewage sludge that does not contain unstabilized solids generated in primary treatment processes can be achieved by increasing the solids content to at least 75 percent before mixing with other materials. Thus, the reduction is achieved by removing water, not by adding inert materials. The reduction may be obtained by adding active materials that remove water by reaction [for example, CaO reacting with water to form $Ca(OH)_2$], by adsorption, or as water of crystallization (for example, formation of $CaSO_4$). Because the objective is to determine available water, the best way to determine whether the material added is "active" or "inert" is to subject the sewage sludge/solid mixture to a drying determination at mild conditions. Method 2540B in "Standard Methods" (APHA, 1989) is appropriate. The sewage sludge or mixture is dried at 103-105°C. Drying time should be more than 1 but less than 2 hours.

Drying sewage sludge to near total dryness causes a stasis in biological activity. Yeager and Ward's (1981) data show that bacterial densities in sterilized raw sewage sludge inoculated with several bacterial species declined rapidly when the solids contents were over 75-percent, indicating diminished bacterial activity. Thus, it can be concluded that significant biological activity will not occur if sewage sludge is maintained above 75-percent solids.

A solids content of 75 percent indicates little likelihood that a sewage sludge will putrefy, but whether it can attract vectors depends on the nature of the sewage sludge and the manner in which it was processed. It is important that the sewage sludge not contain unstabilized sewage sludge as from a primary clarifier, because raw food scraps likely to be present in such a sewage sludge would attract birds, some mammals, and possibly insects, even if the solids content of the sewage sludge exceeded 75 percent. The requirement is therefore restricted to sewage sludges that do not contain unstabilized solids, such as sewage sludges treated by an aerobic or anaerobic biological process. These processes degrade the more easily decomposed portions of these particles and, when combined with a reduced moisture content (75-percent solids or greater), adequately reduce vector attraction.

6.9 MOISTURE REDUCTION OF SEWAGE SLUDGE CONTAINING UNSTABILIZED SOLIDS [503.33(b)(8)]

Under Part 503.33(b)(8), vector attraction of any sewage sludge is adequately reduced if solids content is increased to 90 percent or greater. This extreme desiccation deters vectors in all but the most unusual situations. As noted in Section 6.8 above, the solids increase is achieved by removal of water and not by dilution with inert solids.

For sewage sludges containing unstabilized solids, drying to 90 percent or greater solids—probably by heat drying—further limits biological activity and strips off or decomposes volatile compounds that attract vectors. This solids content is typical of heat drying processes, which reach 90-95-percent solids content and have no reported difficulty with vector attraction to the dried material.

6.10 SEWAGE SLUDGE INJECTION [503.33(b)(9)]

Vector attraction reduction may be achieved by injecting the sewage sludge below the land surface. Part 503.33(b)(9) requires that no significant amount of sewage sludge be present on the land surface within 1 hour after injection. If the sewage sludge is Class A with respect to pathogens, it must be injected within 8 hours after discharge from the pathogen-reducing process.

Injection of sewage sludge beneath the soil places a barrier of soil between the sewage sludge and vectors. The soil quickly removes water from the sewage sludge, which reduces its mobility and its odor. Odor is usually present at the site during the injection process, but it quickly dissipates when injection is complete.

The following considerations show that sewage sludge presents a negligible disease risk from salmonellae regrowth if injection is complete in 8 hours. Salmonellae doubling time is estimated from Hussong et al. (1985) to be more than 1 hour. In 8 hours there would be eight doublings. Density would increase to at most 256 MPN per gram ($2^8 = 256$). This density level is far below the usually mentioned levels for infective dose. Also, the sewage sludge is underground, rapidly drying out, and out of contact with vectors and humans. Subsequent environmental stresses also are expected to gradually lower densities to negligible levels.

6.11 INCORPORATION INTO THE SOIL [503.33(b)(10)]

Sewage sludge applied to the land surface or placed on a surface disposal site must be incorporated into the soil within 6 hours after application or placement. When land applied at agronomic rates, the loading of sewage sludge solids is about 1/200 of the mass of soil in the plow layer. If incorporation is reasonably good, the dilution of sewage sludge in the soil surface can be as high as is typically achieved with soil injection. Odor will be present and vectors will be attracted temporarily. As the soil dewaters on the soil surface, this attraction will diminish when the sewage sludge is mixed with the soil.

The potential for regrowth in 8 hours is the same as for injection, except that instead of being underground the sewage sludge is on the land surface ready to be incorporated in 6 hours. The likelihood of additional regrowth during the maximum of 6 hours allowed for incorporation is small so no reduction in the time between processing and application to the soil is necessary. The reasons that risk of regrowth is not increased by this additional time on the soil surface are:

- Regrowth is inhibited by the desiccation that starts as soon as the sewage sludge is applied to the land surface.
- The soil bacteria that invade the sewage sludge as soon as it is applied are effective inhibitors to rapid regrowth.

6.12 COVER OF SEWAGE SLUDGE ON AN ACTIVE SEWAGE SLUDGE UNIT [503.33(b)(11)]

Sewage sludge placed on an active sewage sludge unit must be covered daily to control vector attraction. Daily covering with soil or other suitable material reduces vector attraction by creating a physical barrier between the sewage sludge and vectors.

6.13 ELEVATION OF pH FOR DOMESTIC SEPTAGE [503.33(b)(12)]

For domestic septage, raising the pH to at least 12 and maintaining pH at 12 or higher for 30 minutes without adding more alkali satisfactorily reduces vector attraction. (These conditions also accomplish Class B pathogen reduction.)

This vector attraction reduction requirement is slightly less stringent than the alkali ıddition method for sewage sludge. Time between treatment and disposal is much shorter than 'or sewage sludge, so there is less need to ensure that pH is maintained at a high value for a ong time.

This vector attraction reduction option reduces pathogens at least as well as anaerobic ligestion (see Farrell et al., 1974, and Ronner and Cliver, 1987). Experience indicates that if pH s above 10.5, vector attraction will not occur. It is expected that, in the short time between ıpplication of alkali and application of the treated domestic septage, pH will not have fallen. Ronner and Cliver indicate that this is practiced in the State of Wisconsin, with no reports of nadequate vector attraction.

SECTION SEVEN

COMPARISON OF THE TYPE OF PATHOGEN AND VECTOR ATTRACTION REDUCTION REQUIREMENTS IN PARTS 257 AND 503

7.1 INTRODUCTION

The current pathogen and vector attraction reduction requirements for sewage sludge disposed on the land are in **40 CFR Part 257** (Criteria For Classification of Solid Waste Disposal Facilities and Practices). These requirements are being replaced by the pathogen and vector attraction reduction requirements for land application of sewage sludge and for placement of sewage sludge on a surface disposal site in **40 CFR Part 503** (Standards for the Use or Disposal of Sewage Sludge).

This section compares the type of pathogen and vector attraction reduction requirements in Part 257 to those in Part 503. This comparison does not address the requirements themselves (e.g., which processes are a Process to Further Reduce Pathogens). Further information on the actual requirements is provided in Part 257, Part 503, and (for the Part 503 requirements) in the other sections of this technical support document.

The Part 257 pathogen and vector attraction reduction requirements found in **40 CFR 257.3-6** apply to a facility or practice. A facility is "any land and appurtenances thereto used for the disposal of solid wastes" and a practice is "the act of disposal of solid waste." Neither a facility nor a practice can exist unless the Part 257 pathogen and vector attraction reduction requirements are met.

The term "disposed" in Part 257 is equivalent to the terms "applied" and "placed" in Part 503. Thus, the Part 257 requirements applied to both land application of sewage sludge and surface disposal of sewage sludge. Similarly, Part 257 also applied to land application and surface disposal of septic tank pumpings.

There was one case when the Part 257 disease requirements did not apply when sewage sludge or septic tank pumpings were disposed on the land. This was when sewage sludge or septic tank pumpings were disposed by a trenching or burial operation. A trenching or burial operation is "the placement of sewage sludge or septic tank pumpings in a trench or other natural or man-made depression and the covering with soil or other suitable material at the end of each operating day such that the wastes do not migrate to the surface." Thus, an additional Part 257 disease requirement did not have to be met when the sewage sludge or septic tank pumpings were covered at the end of each operating day. This approach also is reflected in the Part 503 pathogen requirements.

7.2 PART 257

7.2.1 Pathogens—Sewage Sludge

Part 257 requires that sewage sludge that is applied to the land or incorporated into the soil be treated in a Process to Significantly Reduce Pathogens (PSRP). Processes designated as PSRP are listed in Appendix II of Part 257. In addition, public access has to be restricted to the facility for 12 months and animals whose products are consumed by humans cannot be grazed for at least 1 month. Note that both requirements (i.e., treatment in a PSRP and site restrictions) have to be met when sewage sludge is applied to the land surface or incorporated into the soil.

Part 257 also requires that sewage sludge be treated in a Process to Further Reduce Pathogens (PFRP) when the edible portion of a crop for direct human consumption touches the soil and is grown within 18 months after the sewage sludge is applied or incorporated. When the edible portion of a crop for direct human consumption does not touch the sewage sludge (e.g., corn), the above requirements (i.e., treat in PSRP and site restrictions) have to be met. When crops for direct human consumption are not grown on the land, the above treatment and site restriction requirements also have to be met.

As mentioned previously, when the sewage sludge is covered at the end of each operating day, the Part 257 disease requirements do not apply. In this case, neither the requirement to treat the sewage sludge nor the site restrictions have to be met.

7.2.2 Pathogens—Septic Tank Pumpings

Part 257 requires that septic tank pumpings applied to the land or incorporated into the soil be treated in one of the PSRPs listed in Appendix II in Part 257 or that the site restrictions mentioned above (i.e. restrict public access for 12 months and do not graze animals whose products are consumed by humans for at least 1 month) be met. The difference between the Part 257 pathogen requirements for sewage sludge and for septic tank pumpings is that the site restrictions must be met when sewage sludge is applied or incorporated, but are an alternative to the treatment requirement for septic tank pumpings. This is reflected in the Part 503 pathogen requirements discussed in Section 7.3 below.

The Part 257 pathogen requirements for septic tank pumpings applied to land surface or incorporated into the soil when crops whose edible portion touch the soil are grown within 18 months are the same as the pathogen requirements for sewage sludge. In this case, the septic tank pumpings have to be treated in a PFRP. When the period before crops with edible portions that touch the soil are grown is longer than 18 months or when the edible portion of the crop does not touch the soil, the above pathogen requirements (i.e., treat the septic tank pumpings in a PSRP or meet the site restrictions) have to be met. When no crops with edible portions are grown on the land, either the above treatment requirements or site restrictions have to be met.

The Part 257 pathogen requirements for septic tank pumpings do not apply when the septic tank pumpings are covered at the end of each operation day (i.e., disposed in a burial or trenching operation). Neither the requirement to treat the septic tank pumpings nor the site restrictions have to be met in this case.

7.2.3 Vector Attraction Reduction—Sewage Sludge and Septic Tank Pumpings

Part 257 requires that "the facility or practice shall not exist or occur unless the on-site population of disease vectors is minimized through the periodic application of cover matĕrial or other techniques as appropriate so as to protect public health." This requirement applies to the disposal of both sewage sludge and septic tank pumpings.

Periodic application of cover is the application and compaction of soil or other suitable material over disposed solid waste (e.g., sewage sludge or septic tank pumpings) at the end of each operating day or at such frequencies and in such a manner as to reduce the risk of fire and to impede vector's access to the waste. In this case, the cover material keeps the vectors away from the sewage sludge or septic tank pumpings.

"Other techniques" for vector attraction reduction are not identified in Part 257. However, many of the process descriptions for a PSRP and a PFRP in Appendix II contain "other techniques" for vector attraction reduction. For example, the description of anaerobic digestion indicates that a minimum of 38 percent volatile solids reduction must be achieved. The purpose of this requirement is to reduce the attraction of vectors to the sewage sludge treated in this process. For other processes, such as lime stabilization, the treatment requirements for the process achieve both pathogen and vector attraction reduction.

7.3 PART 503

7.3.1 Pathogens—Sewage Sludge (Land Application)

The Part 503 pathogen requirements for sewage sludge applied to the land are similar to the Part 257 pathogen requirements. The sewage sludge has to be treated to reduce pathogens or a combination of treatment and restrictions on the site where the sewage sludge is applied is used to reduce pathogens.

When the Class A pathogen requirements in Part 503 are met, sewage sludge can be applied to the land without any restrictions being imposed on the site. In this case, the pathogen density levels that a Class A sewage sludge has to meet are equivalent those achieved by treating the sewage sludge in a PFRP (i.e., density levels are below the detection limit). Sewage sludge generated at each treatment works must meet the appropriate requirements for that sewage sludge to be considered Class A with respect to pathogens.

For a process to classified a PFRP, the process must reduce pathogens to the levels required for the sewage sludge to be classified Class A under Part 503. However, the PFRP demonstration does not have to be made at every treatment works. The demonstration can be made at one location and the results verified by EPA. After that initial demonstration, the PFRP process can be used at other locations without a further pathogen reduction demonstration as long as the process is operated in the same manner it was operated to achieve a PFRP designation.

In certain cases, only the Class A pathogen requirements can be met when sewage sludge is applied to the land. These cases are when bulk sewage sludge is applied to a lawn or a home garden, or when sewage sludge is sold or given away in a bag or other container for application to the land. In these two cases, it is not feasible to impose site restrictions on the land where the sewage sludge is applied. Consequently, the Class A pathogen requirements have to be met.

When the combination of treatment and site restrictions are used to reduce pathogens, the Class B pathogen requirements must be met for each sewage sludge. In addition, restrictions concerning harvesting of crops, grazing of animals, and public access must be met at each land application site. The site restrictions prohibit certain activities at the site for certain times so that the environment can further reduce the pathogens in the sewage sludge.

7.3.2 Pathogens—Domestic Septage (Land Application)

The Part 503 pathogen requirements for domestic septage applied to the agricultural land, forest, or a reclamation site are similar to the Part 257 pathogen requirements for septic tank pumpings disposed on the land. Part 503 has two alternative pathogen requirements for domestic septage applied to those types of land.

The first alternative is to impose restrictions on the site where the domestic septage is applied. In this case, the restrictions prevent exposure to the domestic septage until the environment has the opportunity to reduce the pathogens in the domestic septage. The site restrictions that have to be met are the same as the site restrictions when a Class B sewage sludge is applied to the land.

The second alternative is that the pH of the domestic septage be adjusted (i.e., raised to 12 or above and remain at 12 or above for 30 minutes) and that site restriction concerning harvesting of crops be met. The site restrictions are part of this alternative because it is not feasible for each load (e.g., each tank truck load) of domestic septage to be treated to meet the Class A pathogen requirements (i.e., raising the pH of the domestic septage to 12 or above and keeping the pH 12 or above for 30 minutes does not meet the Class A pathogen requirements). For this reason, crops cannot be harvested within a certain period after the domestic septage is applied to the land. The combination of pH adjustment and the site restrictions concerning harvesting crops are equivalent to treating the domestic septage in a PFRP and having no site restrictions.

7.3.3 Pathogens—Sewage Sludge (Surface Disposal)

Part 503 requires that either the Class A or Class B pathogen requirements be met when sewage sludge is placed on an active sewage sludge unit. In this case, site restrictions are not imposed for pathogen reduction when a Class B sewage sludge is placed on an active sewage sludge unit because site restrictions are already required for all surface disposal sites for other than pathogen reasons.

The exposure assessment used to develop the surface disposal pollutant limits only addressed certain pathways of exposure. For this reason, site restrictions are imposed on each surface disposal site to prevent exposure to pollutants in the sewage sludge after placement on an active sewage sludge unit. These restrictions address growing of crops, grazing of animals, and restricting public access to the surface disposal site. They are more stringent than the site restrictions that have to be met when a Class B sewage sludge is applied to the land.

There is one case when neither the Class A nor Class B pathogen requirements have to be met when sewage sludge is placed on an active sewage sludge unit. In this case, the sewage sludge has to be covered at the end of each operating day. This is equivalent to a burial or trenching operation as defined in Part 257. The Part 257 pathogen requirements did not apply when sewage sludge was disposed in a trenching or burial operation. This also is the case in Part 503.

7.3.4 Pathogens—Domestic Septage (Surface Disposal)

There are no pathogen requirements in Part 503 for domestic septage placed on an active sewage sludge unit because of the site restrictions that apply to all surface disposal sites. As mentioned previously, site restrictions are imposed on all surface disposal sites to prevent exposure to the pollutants in sewage sludge placed on an active sewage sludge unit.

7.3.5 Vector Attraction Reduction—Sewage Sludge (Land Application)

As mentioned previously, Part 257 requires that sewage sludge applied to the land be covered at the end of each operating day to reduce the attraction of vectors or that other techniques be used to reduce vector attraction. The Part 503 vector attraction reduction requirements recognize that daily cover is not a feasible vector attraction reduction alternative for land application of sewage sludge. Instead, Part 503 has "other techniques" for vector attraction reduction.

There are 10 alternative vector attraction reduction requirements in Part 503 for land application of sewage sludge (see Section 6). The first eight of these alternatives require treatment of the sewage sludge (e.g., pH adjustment). The other two alternative address how the sewage sludge is applied (i.e., injection below the land surface or incorporation into the soil).

When bulk sewage sludge is applied to agricultural land, forest, a public contact site, or a reclamation site, any 1 of the 10 vector attraction reduction requirements can be met. However, when bulk sewage sludge is applied to a lawn or a home garden, one of the eight treatment-related alternatives has to be met. In these cases, injection and incorporation are not considered feasible alternatives for vector attraction reduction.

When sewage sludge is sold or given away in a bag or other container for application to the land, one of the eight treatment-related vector attraction reduction requirements has to be met. Injection and incorporation also are not feasible in this case.

7.3.6 Vector Attraction Reduction—Domestic Septage (Land Application)

Part 503 requires that one of three alternative vector attraction reduction requirements be met when domestic septage is applied to agricultural land, forest, or a reclamation site. Vector attraction reduction can be achieved by injecting the domestic septage below the land surface, by incorporating the domestic septage into the soil, or by treating the domestic septage.

When domestic septage is injected below the land surface or incorporated into the soil, vectors do not have access to the domestic septage. For this reason, the attraction of vectors to the domestic septage is reduced.

To achieve vector attraction reduction by treatment, pH adjustment of the domestic septage is required. In this case, the pH of each container (e.g., each tank truck load) of domestic septage has to be adjusted prior to applying the domestic septage to agricultural land, forest, or a reclamation site.

The domestic septage pH adjustment requirement only applies to domestic septage applied to agricultural land, forest, or a reclamation site. If domestic septage is applied to other types of land, one of the alternative vector attraction reduction requirements for sewage sludge must be met.

7.3.7 Vector Attraction Reduction—Sewage Sludge (Surface Disposal)

When sewage sludge is placed on an active sewage sludge unit, Part 503 requires that 1 of 11 alternative vector attraction reduction requirements be met. The first 10 of these requirements are the same as the alternative vector attraction reduction requirements for sewage sludge applied to the land. These "other techniques" include eight treatment alternatives and two alternatives concerning how the sewage sludge is placed on the land (i.e., injection or incorporation).

The last alternative vector attraction reduction requirement is to cover sewage sludge placed on an active sewage sludge unit at the end of each operating day. When this alternative is met, no additional requirements are imposed for vector attraction reduction.

7.3.8 Vector Attraction Reduction—Domestic Septage (Surface Disposal)

Part 503 contains four alternative vector attraction reduction requirements for domestic septage placed on an active sewage sludge unit. These include injection below the land surface, incorporation into the soil, daily cover, and pH adjustment.

When domestic septage is injected below the land surface, incorporated into the soil, or covered at the end of each operating day, access to the domestic septage by vectors is prevented. This reduces the attraction of vectors to the domestic septage.

Adjusting the pH of domestic septage also reduces the attraction of vectors. The high pH affects the properties of domestic septage that attract vectors.

7.4 SUMMARY

The types of Part 257 and Part 503 pathogen and vector attraction reduction requirements are summarized below by use or disposal practice. Requirements are presented both for sewage sludge and domestic septage applied to the land or placed on a surface disposal site.

7.4.1 Land Application—Sewage Sludge

Pathogens:

Type of land	Part 257 Requirements	Part 503 Requirements
Agricultural land, forest, public contact site, or reclamation site	PSRP with site restrictions or PFRP when crops that touch soil are grown with 18 months	Class A or Class B with site restrictions
Lawn or home garden	Same as above	Class A

Vector attraction reduction:

Type of land	Part 257 Requirements	Part 503 Requirements
Agricultural land, forest, public contact site, or reclamation site	Cover at the end of each operating day or other techniques	One of 10 alternative techniques (daily cover not included)
Lawn or home garden	Same as above	One of eight alternatives techniques (daily cover not included)

7.4.2 Land Application—Domestic Septage

Pathogens:

Type of land	Part 257 Requirements	Part 503 Requirements
Agricultural land, forest, or reclamation site	PSRP or site restrictions; or PFRP when crops that touch the soil are grown within 18 months	Site restrictions pH adjustment restrictions on harvesting crops
Other types	Same as above	Meet the requirements for sewage sludge applied to the land

Vector attraction reduction:

Type of land	Part 257 Requirements	Part 503 Requirements
Agricultural land, forest, or reclamation site	Cover at the end of each operating day or other techniques	Injection, incorporation, or pH adjustment
Other types	Same as above	Meet the requirements for sewage sludge applied to the land

7.4.3 Surface Disposal—Sewage Sludge

Pathogens:

Type of land	Part 257 Requirements	Part 503 Requirements
Surface disposal site	PSRP with site restrictions or PFRP when crops that touch the soil are grown within 18 months	Class A, Class B, or cover at the end of each operating day

Vector attraction reduction:

Type of land	Part 257 Requirements	Part 503 Requirements
Surface disposal site	Cover at the end of each operating day or other techniques	One of 10 alternative techniques or cover at the end of each operating day

7.4.4 Surface Disposal—Domestic Septage

Pathogens:

Type of land	Part 257 Requirements	Part 503 Requirements
Surface disposal site	PSRP or site restrictions; or PFRP when crops that touch the soil are grown within 18 months	None. Site restrictions imposed for other than pathogen reasons

Vector attraction reduction:

Type of land	Part 257 Requirements	Part 503 Requirements
Surface disposal site	Cover at the end operating day or other techniques	Injection, incorporation, pH adjustment, or cover at the end of each operating day

SECTION EIGHT

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APPENDIX

Subpart D of the Part 503 Regulation

ıction requirements in § 503.33(b)(1) ugh § 503.33(b)(8) when one of those ıirements is met] have been met. This rmination has been made under my ction and supervision in accordance with system designed to ensure that qualified onnel properly gather and evaluate the rmation used to determine the [pathogen ırements and vector attraction reduction ırements if appropriate] have been met. aware that there are significant penalties alse certification including the ibility of fine and imprisonment."

ii) A description of how the ıogen requirements in § 503.32 (a), 2), (b)(3), or (b)(4) are met when one ıose requirements is met.

v) A description of how one of the or attraction reduction requirements 503.33 (b)(1) through (b)(8) is met n one of those requirements is met.

) The owner/operator of the surface ıosal site, shall develop the ›wing information and shall retain information for five years.

The concentration of each utant listed in Table 2 of § 503.23 in sewage sludge when the pollutant centrations in Table 2 of § 503.23 are or when site-specific pollutant ts in § 503.23(b) are met.

) The following certification ment:

certify, under penalty of law, that the ıgement practices in § 503.24 and the ›r attraction reduction requirement in rt one of the requirements in § 503.33) through (b)(11) if one of those ırements is met] have been met. This rmination has been made under my tion and supervision in accordance with ystem designed to ensure that qualified ›nnel properly gather and evaluate the mation used to determine that the ıgement practices [and the vector ction reduction requirements if ›priate] have been met. I am aware that are significant penalties for false ication including the possibility of fine mprisonment."

i) A description of how the agement practices in § 503.24 are

·) A description of how the vector ction reduction requirements in 3.33 (b)(9) through (b)(11) are met if of those requirements is met.

· When domestic septage is placed surface disposal site:

If the vector attraction reduction irements in § 503.33(b)(12) are met, ›erson who places the domestic ıge on the surface disposal site shall lop the following information and retain the information for five ::

The following certification ment:

certify, under penalty of law, that the r attraction reduction requirements in § 503.33(b)(12) have been met. This determination has been made under my direction and supervision in accordance with the system designed to ensure that qualified personnel properly gather and evaluate the information used to determine that the vector attraction requirements have been met. I am aware that there are significant penalties for false certification including the possibility of fine and imprisonment."

(ii) A description of how the vector attraction reduction requirements in § 503.33(b)(12) are met.

(2) The owner/operator of the surface disposal site shall develop the following information and shall retain that information for five years:

(i) The following certification statement:

"I certify, under penalty of law, that the management practices in § 503.24 and the vector attraction reduction requirements in [insert § 503.33(b)(9) through § 503.33(b)(11) when one of those requirements is met] have been met. This determination has been made under my direction and supervision in accordance with the system designed to ensure that qualified personnel properly gather and evaluate the information used to determine that the management practices [and the vector attraction reduction requirements if appropriate] have been met. I am aware that there are significant penalties for false certification including the possibility of fine or imprisonment."

(ii) A description of how the management practices in § 503.24 are met.

(iii) A description how the vector attraction reduction requirements in § 503.33(b)(9) through § 503.33(b)(11) are met if one of those requirements is met.

(Approved by the Office of Management and Budget under control number 2040–0157)

§ 503.28 Reporting.

Class I sludge management facilities, POTWs (as defined in 40 CFR 501.2) with a design flow rate equal to or greater than one million gallons per day, and POTWs that serve 10,000 people or more shall submit the information in § 503.27(a) to the permitting authority on February 19 of each year.

(Approved by the Office of Management and Budget under control number 2040–0157)

Subpart D—Pathogens and Vector Attraction Reduction

§ 503.30 Scope.

(a) This subpart contains the requirements for a sewage sludge to be classified either Class A or Class B with respect to pathogens.

(b) This subpart contains the site restrictions for land on which a Class B sewage sludge is applied.

(c) This subpart contains the pathogen requirements for domestic septage applied to agricultural land, forest, or a reclamation site.

(d) This subpart contains alternati vector attraction reduction requirem for sewage sludge that is applied to the land or placed on a surface disposal site.

§ 503.31 Special definitions.

(a) *Aerobic digestion* is the biochemical decomposition of organic matter in sewage sludge into carbon dioxide and water by microorganisms in the presence of air.

(b) *Anaerobic digestion* is the biochemical decomposition of organic matter in sewage sludge into methane gas and carbon dioxide by microorganisms in the absence of air.

(c) *Density of microorganisms* is the number of microorganisms per unit mass of total solids (dry weight) in the sewage sludge.

(d) *Land with a high potential for public exposure* is land that the public uses frequently. This includes, but is not limited to, a public contact site and a reclamation site located in a populated area (e.g, a construction site located in a city).

(e) *Land with a low potential for public exposure* is land that the public uses infrequently. This includes, but is not limited to, agricultural land, forest, and a reclamation site located in an unpopulated area (e.g., a strip mine located in a rural area).

(f) *Pathogenic organisms* are disease-causing organisms. These include, but are not limited to, certain bacteria, protozoa, viruses, and viable helminth ova.

(g) *pH* means the logarithm of the reciprocal of the hydrogen ion concentration.

(h) *Specific oxygen uptake rate (SOUR)* is the mass of oxygen consumed per unit time per unit mass of total solids (dry weight basis) in the sewage sludge.

(i) *Total solids* are the materials in sewage sludge that remain as residue when the sewage sludge is dried at 103 to 105 degrees Celsius.

(j) *Unstabilized solids* are organic materials in sewage sludge that have not been treated in either an aerobic or anaerobic treatment process.

(k) *Vector attraction* is the characteristic of sewage sludge that attracts rodents, flies, mosquitos, or other organisms capable of transporting infectious agents.

(l) *Volatile solids* is the amount of the total solids in sewage sludge lost when the sewage sludge is combusted at 550 degrees Celsius in the presence of excess air.

)3.32 Pathogens.

a) *Sewage sludge—Class A.* (1) The
uirement in § 503.32(a)(2) and the
uirements in either § 503.32(a)(3),
4), (a)(5), (a)(6), (a)(7), or (a)(8) shall
met for a sewage sludge to be
ssified Class A with respect to
hogens.

2) The Class A pathogen
uirements in § 503.32 (a)(3) through
8) shall be met either prior to
eting or at the same time the vector
action reduction requirements in
)3.33, except the vector attraction
uction requirements in § 503.33
5) through (b)(8), are met.

3) *Class A—Alternative 1.* (i) Either
density of fecal coliform in the
age sludge shall be less than 1000
st Probable Number per gram of total
ds (dry weight basis), or the density
almonella sp. bacteria in the sewage
lge shall be less than three Most
bable Number per four grams of total
ds (dry weight basis) at the time the
age sludge is used or disposed; at
time the sewage sludge is prepared
sale or give away in a bag or other
tainer for application to the land; or
e time the sewage sludge or
erial derived from sewage sludge is
pared to meet the requirements in
3.10 (b), (c), (e), or (f).

i) The temperature of the sewage
lge that is used or disposed shall be
ntained at a specific value for a
od of time.

A) When the percent solids of the
age sludge is seven percent or
er, the temperature of the sewage
lge shall be 50 degrees Celsius or
er; the time period shall be 20
utes or longer; and the temperature
time period shall be determined
g equation (2), except when small
icles of sewage sludge are heated by
er warmed gases or an immiscible
id.

$$\frac{131{,}700{,}000}{10^{0.1400t}} \quad \text{Eq. (2)}$$

re,
me in days.
nperature in degrees Celsius.

) When the percent solids of the
age sludge is seven percent or higher
small particles of sewage sludge are
ed by either warmed gases or an
iscible liquid, the temperature of
sewage sludge shall be 50 degrees
ius or higher; the time period shall
5 seconds or longer; and the
perature and time period shall be
rmined using equation (2).

) When the percent solids of the
ge sludge is less than seven percent
the time period is at least 15 seconds, but less than 30 minutes, the temperature and time period shall be determined using equation (2).

(D) When the percent solids of the sewage sludge is less than seven percent; the temperature of the sewage sludge is 50 degrees Celsius or higher; and the time period is 30 minutes or longer, the temperature and time period shall be determined using equation (3).

$$D=\frac{50{,}070{,}000}{10^{0.1400t}} \quad \text{Eq. (3)}$$

Where,
D=time in days.
t=temperature in degrees Celsius.

(4) *Class A—Alternative 2.* (i) Either the density of fecal coliform in the sewage sludge shall be less than 1000 Most Probable Number per gram of total solids (dry weight basis), or the density of *Salmonella* sp. bacteria in the sewage sludge shall be less than three Most Probable Number per four grams of total solids (dry weight basis) at the time the sewage sludge is used or disposed; at the time the sewage sludge is prepared for sale or give away in a bag or other container for application to the land; or at the time the sewage sludge or material derived from sewage sludge is prepared to meet the requirements in § 503.10 (b), (c), (e), or (f).

(ii) (A) The pH of the sewage sludge that is used or disposed shall be raised to above 12 and shall remain above 12 for 72 hours.

(B) The temperature of the sewage sludge shall be above 52 degrees Celsius for 12 hours or longer during the period that the pH of the sewage sludge is above 12.

(C) At the end of the 72 hour period during which the pH of the sewage sludge is above 12, the sewage sludge shall be air dried to achieve a percent solids in the sewage sludge greater than 50 percent.

(5) *Class A—Alternative 3.* (i) Either the density of fecal coliform in the sewage sludge shall be less than 1000 Most Probable Number per gram of total solids (dry weight basis), or the density of *Salmonella* sp. bacteria in sewage sludge shall be less than three Most Probable Number per four grams of total solids (dry weight basis) at the time the sewage sludge is used or disposed; at the time the sewage sludge is prepared for sale or give away in a bag or other container for application to the land; or at the time the sewage sludge or material derived from sewage sludge is prepared to meet the requirements in § 503.10 (b), (c), (e), or (f).

(ii) (A) The sewage sludge shall be analyzed prior to pathogen treatment to determine whether the sewage sludge contains enteric viruses.

(B) When the density of enteric viruses in the sewage sludge prior to pathogen treatment is less than one Plaque-forming Unit per four grams of total solids (dry weight basis), the sewage sludge is Class A with respect to enteric viruses until the next monitoring episode for the sewage sludge.

(C) When the density of enteric viruses in the sewage sludge prior to pathogen treatment is equal to or greater than one Plaque-forming Unit per four grams of total solids (dry weight basis), the sewage sludge is Class A with respect to enteric viruses when the density of enteric viruses in the sewage sludge after pathogen treatment is less than one Plaque-forming Unit per four grams of total solids (dry weight basis) and when the values or ranges of values for the operating parameters for the pathogen treatment process that produces the sewage sludge that meets the enteric virus density requirement are documented.

(D) After the enteric virus reduction in paragraph (a)(5)(ii)(C) of this section is demonstrated for the pathogen treatment process, the sewage sludge continues to be Class A with respect to enteric viruses when the values for the pathogen treatment process operating parameters are consistent with the values or ranges of values documented in paragraph (a)(5)(ii)(C) of this section.

(iii)(A) The sewage sludge shall be analyzed prior to pathogen treatment to determine whether the sewage sludge contains viable helminth ova.

(B) When the density of viable helminth ova in the sewage sludge prior to pathogen treatment is less than one per four grams of total solids (dry weight basis), the sewage sludge is Class A with respect to viable helminth ova until the next monitoring episode for the sewage sludge.

(C) When the density of viable helminth ova in the sewage sludge prior to pathogen treatment is equal to or greater than one per four grams of total solids (dry weight basis), the sewage sludge is Class A with respect to viable helminth ova when the density of viable helminth ova in the sewage sludge after pathogen treatment is less than one per four grams of total solids (dry weight basis) and when the values or ranges of values for the operating parameters for the pathogen treatment process that produces the sewage sludge that meets the viable helminth ova density requirement are documented.

(D) After the viable helminth ova reduction in paragraph (a)(5)(iii)(C) of this section is demonstrated for the pathogen treatment process, the sewage ge continues to be Class A with ect to viable helminth ova when the es for the pathogen treatment ess operating parameters are istent with the values or ranges of es documented in paragraph)(iii)(C) of this section.

) *Class A—Alternative 4.* (i) Either lensity of fecal coliform in the ıge sludge shall be less than 1000 t Probable Number per gram of total ls (dry weight basis), or the density ılmonella sp. bacteria in the sewage ge shall be less than three Most able Number per four grams of total ls (dry weight basis) at the time the ıge sludge is used or disposed; at ime the sewage sludge is prepared ale or give away in a bag or other ainer for application to the land; or e time the sewage sludge or ırial derived from sewage sludge is ared to meet the requirements in 3.10 (b), (c), (e), or (f).

) The density of enteric viruses in sewage sludge shall be less than one ue-forming Unit per four grams of solids (dry weight basis) at the time sewage sludge is used or disposed; e time the sewage sludge is ared for sale or give away in a bag her container for application to the ; or at the time the sewage sludge aterial derived from sewage sludge epared to meet the requirements in 3.10 (b), (c), (e), or (f), unless rwise specified by the permitting ority.

i) The density of viable helminth n the sewage sludge shall be less one per four grams of total solids weight basis) at the time the sewage ge is used or disposed; at the time ewage sludge is prepared for sale or away in a bag or other container for ication to the land; or at the time sewage sludge or material derived . sewage sludge is prepared to meet equirements in § 503.10 (b), (c), (e),), unless otherwise specified by the iitting authority.

) *Class A—Alternative 5.* (i) Either iensity of fecal coliform in the ıge sludge shall be less than 1000 t Probable Number per gram of total ls (dry weight basis), or the density ılmonella, sp. bacteria in the sewage ge shall be less than three Most able Number per four grams of total ls (dry weight basis) at the time the ıge sludge is used or disposed; at ime the sewage sludge is prepared ale or given away in a bag or other ainer for application to the land; or e time the sewage sludge or ırial derived from sewage sludge is ared to meet the requirements in 3.10(b), (c), (e), or (f).

(ii) Sewage sludge that is used or disposed shall be treated in one of the Processes to Further Reduce Pathogens described in appendix B of this part.

(8) *Class A—Alternative 6.* (i) Either the density of fecal coliform in the sewage sludge shall be less than 1000 Most Probable Number per gram of total solids (dry weight basis), or the density of *Salmonella*, sp. bacteria in the sewage sludge shall be less than three Most Probable Number per four grams of total solids (dry weight basis) at the time the sewage sludge is used or disposed; at the time the sewage sludge is prepared for sale or given away in a bag or other container for application to the land; or at the time the sewage sludge or material derived from sewage sludge is prepared to meet the requirements in § 503.10(b), (c), (e), or (f).

(ii) Sewage sludge that is used or disposed shall be treated in a process that is equivalent to a Process to Further Reduce Pathogens, as determined by the permitting authority.

(b) *Sewage sludge—Class B.* (1)(i) The requirements in either § 503.32(b)(2), (b)(3), or (b)(4) shall be met for a sewage sludge to be classified Class B with respect to pathogens.

(ii) The site restrictions in § 503.32(b)(5) shall be met when sewage sludge that meets the Class B pathogen requirements in § 503.32(b)(2), (b)(3), or (b)(4) is applied to the land.

(2) *Class B—Alternative 1.*

(i) Seven samples of the sewage sludge shall be collected at the time the sewage sludge is used or disposed.

(ii) The geometric mean of the density of fecal coliform in the samples collected in paragraph (b)(2)(i) of this section shall be less than either 2,000,000 Most Probable Number per gram of total solids (dry weight basis) or 2,000,000 Colony Forming Units per gram of total solids (dry weight basis).

(3) *Class B—Alternative 2.* Sewage sludge that is used or disposed shall be treated in one of the Processes to Significantly Reduce Pathogens described in appendix B of this part.

(4) *Class B—Alternative 3.* Sewage sludge that is used or disposed shall be treated in a process that is equivalent to a Process to Significantly Reduce Pathogens, as determined by the permitting authority.

(5) *Site Restrictions.* (i) Food crops with harvested parts that touch the sewage sludge/soil mixture and are totally above the land surface shall not be harvested for 14 months after application of sewage sludge.

(ii) Food crops with harvested parts below the surface of the land shall not be harvested for 20 months after application of sewage sludge when the sewage sludge remains on the land surface for four months or longer prior to incorporation into the soil.

(iii) Food crops with harvested parts below the surface of the land shall not be harvested for 38 months after application of sewage sludge when the sewage sludge remains on the land surface for less than four months prior to incorporation into the soil.

(iv) Food crops, feed crops, and fiber crops shall not be harvested for 30 days after application of sewage sludge.

(v) Animals shall not be allowed to graze on the land for 30 days after application of sewage sludge.

(vi) Turf grown on land where sewage sludge is applied shall not be harvested for one year after application of the sewage sludge when the harvested turf is placed on either land with a high potential for public exposure or a lawn, unless otherwise specified by the permitting authority.

(vii) Public access to land with a high potential for public exposure shall be restricted for one year after application of sewage sludge.

(viii) Public access to land with a low potential for public exposure shall be restricted for 30 days after application of sewage sludge.

(c) *Domestic septage.* (1) The site restrictions in § 503.32(b)(5) shall be met when domestic septage is appliec agricultural land, forest, or a reclamation site; or

(2) The pH of domestic septage applied to agricultural land, forest, or a reclamation site shall be raised to 12 or higher by alkali addition and, without the addition of more alkali, shall remain at 12 or higher for 30 minutes and the site restrictions in § 503.32 (b)(5)(i) through (b)(5)(iv) shall be met.

§ 503.33 Vector attraction reduction.

(a)(1) One of the vector attraction reduction requirements in § 503.33 (b)(1) through (b)(10) shall be met when bulk sewage sludge is applied to agricultural land, forest, a public contact site, or a reclamation site.

(2) One of the vector attraction reduction requirements in § 503.33 (b)(1) through (b)(8) shall be met when bulk sewage sludge is applied to a lawn or a home garden.

(3) One of the vector attraction reduction requirements in § 503.33 (b)(1) through (b)(8) shall be met when sewage sludge is sold or given away in a bag or other container for application to the land.

(4) One of the vector attraction reduction requirements in § 503.33 (b)(1) through (b)(11) shall be met whe sewage sludge (other than domestic

·ptage) is placed on an active sewage udge unit.

(5) One of the vector attraction duction requirements in § 503.33)(9), (b)(10), or (b)(12) shall be met hen domestic septage is applied to ricultural land, forest, or a clamation site and one of the vector traction reduction requirements in 503.33 (b)(9) through (b)(12) shall be et when domestic septage is placed on active sewage sludge unit.

(b)(1) The mass of volatile solids in e sewage sludge shall be reduced by ninimum of 38 percent (see lculation procedures in :nvironmental Regulations and chnology—Control of Pathogens and ctor Attraction in Sewage Sludge", 'A–625/R–92/013, 1992, U.S. vironmental Protection Agency, ıcinnati, Ohio 45268).

:2) When the 38 percent volatile ids reduction requirement in 03.33(b)(1) cannot be met for an aerobically digested sewage sludge, ctor attraction reduction can be monstrated by digesting a portion of previously digested sewage sludge aerobically in the laboratory in a ich-scale unit for 40 additional days a temperature between 30 and 37 grees Celsius. When at the end of the days, the volatile solids in the vage sludge at the beginning of that iod is reduced by less than 17 cent, vector attraction reduction is lieved.

3) When the 38 percent volatile ids reduction requirement in 03.33(b)(1) cannot be met for an obically digested sewage sludge, ctor attraction reduction can be nonstrated by digesting a portion of previously digested sewage sludge t has a percent solids of two percent ess aerobically in the laboratory in ench-scale unit for 30 additional days :0 degrees Celsius. When at the end he 30 days, the volatile solids in the vage sludge at the beginning of that iod is reduced by less than 15 cent, vector attraction reduction is ieved.

4) The specific oxygen uptake rate)UR) for sewage sludge treated in an obic process shall be equal to or less n 1.5 milligrams of oxygen per hour gram of total solids (dry weight is) at a temperature of 20 degrees sius.

5) Sewage sludge shall be treated in ierobic process for 14 days or longer. ing that time, the temperature of the age sludge shall be higher than 40 rees Celsius and the average perature of the sewage sludge shall higher than 45 degrees Celsius.

(6) The pH of sewage sludge shall be raised to 12 or higher by alkali addition and, without the addition of more alkali, shall remain at 12 or higher for two hours and then at 11.5 or higher for an additional 22 hours.

(7) The percent solids of sewage sludge that does not contain unstabilized solids generated in a primary wastewater treatment process shall be equal to or greater than 75 percent based on the moisture content and total solids prior to mixing with other materials.

(8) The percent solids of sewage sludge that contains unstabilized solids generated in a primary wastewater treatment process shall be equal to or greater than 90 percent based on the moisture content and total solids prior to mixing with other materials.

(9)(i) Sewage sludge shall be injected below the surface of the land.

(ii) No significant amount of the sewage sludge shall be present on the land surface within one hour after the sewage sludge is injected.

(iii) When the sewage sludge that is injected below the surface of the land is Class A with respect to pathogens, the sewage sludge shall be injected below the land surface within eight hours after being discharged from the pathogen treatment process.

(10)(i) Sewage sludge applied to the land surface or placed on a surface disposal site shall be incorporated into the soil within six hours after application to or placement on the land.

(ii) When sewage sludge that is incorporated into the soil is Class A with respect to pathogens, the sewage sludge shall be applied to or placed on the land within eight hours after being discharged from the pathogen treatment process.

(11) Sewage sludge placed on an active sewage sludge unit shall be covered with soil or other material at the end of each operating day.

(12) The pH of domestic septage shall be raised to 12 or higher by alkali addition and, without the addition of more alkali, shall remain at 12 or higher for 30 minutes.

Subpart E—Incineration

§ 503.40 Applicability.

(a) This subpart applies to a person who fires sewage sludge in a sewage sludge incinerator, to a sewage sludge incinerator, and to sewage sludge fired in a sewage sludge incinerator.

(b) This subpart applies to the exit gas from a sewage sludge incinerator stack.

§ 503.41 Special definitions.

(a) *Air pollution control device* is one or more processes used to treat the exit gas from a sewage sludge incinerator stack.

(b) *Auxiliary fuel* is fuel used to augment the fuel value of sewage sludge. This includes, but is not limited to, natural gas, fuel oil, coal, gas generated during anaerobic digestion of sewage sludge, and municipal solid waste (not to exceed 30 percent of the dry weight of sewage sludge and auxiliary fuel together). Hazardous wastes are not auxiliary fuel.

(c) *Control efficiency* is the mass of a pollutant in the sewage sludge fed to an incinerator minus the mass of that pollutant in the exit gas from the incinerator stack divided by the mass of the pollutant in the sewage sludge fed to the incinerator.

(d) *Dispersion factor* is the ratio of the increase in the ground level ambient air concentration for a pollutant at or beyond the property line of the site where the sewage sludge incinerator is located to the mass emission rate for the pollutant from the incinerator stack.

(e) *Fluidized bed incinerator* is an enclosed device in which organic matter and inorganic matter in sewage sludge are combusted in a bed of particles suspended in the combustion chamber gas.

(f) *Hourly average* is the arithmetic mean of all measurements, taken during an hour. At least two measurements must be taken during the hour.

(g) *Incineration* is the combustion of organic matter and inorganic matter in sewage sludge by high temperatures in an enclosed device.

(h) *Monthly average* is the arithmetic mean of the hourly averages for the hours a sewage sludge incinerator operates during the month.

(i) *Risk specific concentration* is the allowable increase in the average daily ground level ambient air concentration for a pollutant from the incineration of sewage sludge at or beyond the property line of the site where the sewage sludge incinerator is located.

(j) *Sewage sludge feed rate* is either the average daily amount of sewage sludge fired in all sewage sludge incinerators within the property line of the site where the sewage sludge incinerators are located for the number of days in a 365 day period that each sewage sludge incinerator operates, or the average daily design capacity for all sewage sludge incinerators within the property line of the site where the sewage sludge incinerators are located.

(k) *Sewage sludge incinerator* is an enclosed device in which only sewage sludge and auxiliary fuel are fired.

(l) *Stack height* is the difference between the elevation of the top of a sewage sludge incinerator stack and the

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TECHNICAL SUPPORT DOCUMENT FOR PATHOGENS AND VECTOR ATTRACTION REDUCTION

Federal Register Version	Final Version	Difference	Explanation
No Acknowledgement page	Acknowledgement page added.	Yes	Gives credit to Dr. Farrell for preparing the report and to others for reviewing the report.
Table of Contents 2.1.4 Page 2-9 2.2.2 Page 2-12 2.3.1 Page 2-15 2.3.5 Page 2-19 2.6.2 Page 2-26 4.4 Page 4-6 4.4.1 Page 4-8 4.4.2 Page 4-10 4.4.3 Page 4-13 4.4.4 Page 4-14 4.4.5 Page 4-15 4.5 Page 4-17 4.6 Page 4-18 4.7 Page 4-19 4.8 Page 4-19 4.9 Page 4-21 5.4.3 Page 5-7 5.4.6 Page 5-8 5.5.1 Page 5-9 5.5.2 Page 5-9 6.11 Page 6-10 6.13 Page 6-11	Table of Contents 2.1.4 Page 2-10 2.2.2 Page 2-13 2.3.1 Page 2-16 2.3.5 Page 2-20 2.6.2 Page 2-27 4.4 Page 4-8 4.4.1 Page 4-9 4.4.2 Page 4-11 4.4.3 Page 4-14 4.4.4 Page 4-15 4.4.5 Page 4-17 4.5 Page 4-18 4.6 Page 4-19 4.7 Page 4-20 4.8 Page 4-20 4.9 Page 4-22 5.4.3 Page 5-8 5.4.6 Page 5-9 5.5.1 Page 5-10 5.5.2 Page 5-10 6.11 Page 6-9 6.13 Page 6-10	Yes	Page numbers changed after "pen and ink" changes were incorporated into the final draft of the report.

Federal Register Version	Final Version	Difference	Explanation
Table of Contents Appendix	Table of Contents Appendix Subpart D of the Part 503 Regulation	Yes	Title of appendix added to the table of contents.
Page 1-4 No discussion of the appendix.	Page 1-4 Added the following sentence: "An appendix to the document provides a copy of Subpart D of the Part 503 regulation."	Yes	Sentence added to be consistent with the listing of the appendix in the table of contents.
Page 2-11 Sentence at the bottom of the page starts with "Large sewage sludge ..."	Page 2-12 The corresponding sentence in the final draft starts with: "The large sewage sludge ..."	Yes	Editorial
Page 4-5 Second full paragraph contains the following sentence: "On the other hand, Yanko (1988) found high frequency of detection of salmonellae, ..."	Page 4-5 Second full paragraph contains the following sentence: "On the other hand, Yanko (1988) found high frequent occurrence of salmonellae, ..."	Yes	Editorial

Federal Register Version	Final Version	Difference	Explanation
Insert A, Page 4-6 First sentence in the last paragraph of the insert reads: "Both estimates show that if the fecal coliform densities are below 1000 MPN per gram, the likelihood of salmonella detection will be rare."	Page 4-6 First sentence in the third paragraph reads: "Both estimates show that if fecal coliform densities are below 1000 MPN per gram, the likelihood of salmonella detection is low."	Yes	Editorial
Page 4-6 Last sentence in first full paragraph reads: "Under conditions favorable for regrowth, the fecal coliforms can regrow to levels higher than 1000 MPN per gram, but salmonellae, once reduced totally, could never regrow."	Page 4-8 The first full sentence at the top of the page reads: "Under conditions favorable for regrowth, the fecal coliforms can regrow to levels higher than 1000 MPN per gram, but salmonellae, once totally eliminated, can never regrow."	Yes	Editorial
Page 4-9 Paragraphs 4.4.1.1 and 4.4.1.2 refer to enteric viruses.	Pages 4-9 and 4-10 Paragraphs 4.4.1.1 and 4.4.1.2 refer to viruses.	Yes	Change reflects the organism discussed in the referenced reports. The word "viruses" was used originally.

Federal Register Version	Final Version	Difference	Explanation
Page 4-13 Second sentence in the second full paragraph reads: "For example, Brannen et al. (1975) report that <u>Ascaris</u> ova are reduced . . ."	Page 4-14 Second sentence in the first full paragraph reads: "For example, Brannen et al. (1975) report that <u>Ascaris</u> ova are destroyed . . ."	Yes	Change reflects the discussion in the referenced report. The work "destroyed" was used originally.
Page 4-17 Third sentence in the last paragraph reads: "The hostile conditions of high pH and high temperature allow a variance to a less severe time-temperature regime than EPA's above . . ."	Page 4-18 Third sentence in the last paragraph reads: "The hostile conditions of high pH and high temperature allow a variance to a less severe time-temperature regime EPA's . . ." The word "above" was deleted.	Yes	Editorial
Page 4-21 Last sentence in first full paragraph reads: "If the dose is being delivered, the pathogens will be reduced."	Page 4-22 Last sentence in first full paragraph reads: "If the dose is being delivered, the pathogens will be reduced to below detectable levels."	Yes	Editorial to indicate how well a treatment process reduces enteric viruses.

Federal Register Version	Final Version	Difference	Explanation
Page 5-3 First full paragraph on this page. In two places, enteric virus is used. Extraneous phrase "pathogens from these studies" was included at the end of this paragraph.	Page 5-3 First full paragraph on this page. In two places, virus is used instead of enteric virus. Extraneous phrase was deleted.	Yes	Change reflects the organism discussed in the referenced reports. The original discussion indicated virus before the "pen and ink" changes were made. Extraneous phrase was not needed.
Page 5-8 Last paragraph on this page. Reference is made to an "Insert C" on the back of this page.	Page 5-9 Second full paragraph on this page. "Insert C" was not included because there was no "Insert C".	Yes	During the review of this section, an "Insert C" was to be added. However, a decision was made not to add an "Insert C". For this reason, no additional information was added to this paragraph. A different "Insert C" was added on Page 6-6. Had we intended to add "Insert C" on Page 5-9, the insert on Page 6-6 would have been "Insert D" instead of "Insert C".

Federal Register Version	Final Version	Difference	Explanation
Page 6-6, Insert C. The last paragraph of Insert C discussed aerated static pile composting.	Page 6-6 First full paragraph. The paragraph on aerated static pile composting from Insert C was placed in parenthesis and the last sentence of that paragraph was deleted.	Yes	Editorial.
Page 6-9 The directions for the "pen and ink" changes for the last paragraph on this page were to delete the third sentence and retain the remainder of the paragraph.	Page 6-9. Fourth full paragraph. "Pen and ink" changes were edited when they were incorporated into the final report.	Yes	Editorial.
Page 6-11 Last sentence in last paragraph reads: "Ronner et al. indicate that this option is actually in practice in the State of Wisconsin, with no reports of vector attraction."	Page 6-11 Last sentence in last paragraph reads: "Ronner and Cliver indicate that this is practiced in the State of Wisconsin, with no reports of inadequate vector attraction."	Yes	Editorial

Federal Register Version	Final Version	Difference	Explanation
Appendix Included Subparts A and D from the Part 503 regulation.	Apperdix Only included Subpart D from the Part 503 regulation.	Yes	Editorial. This report discusses the Subpart D requirements, not the Subpart A requirements.

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