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U.S. Army Toxic and Hazardous Materials Agency

COMPOSTING OF EXPLOSIVE-CONTAMINATED SOIL TECHNOLOGY

October 1989

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Prepared For:

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A conceptual level development of the use of composting technology for the treatment of explosives-contaminated logoon sediments has been conducted. Previous investigations of the technical aspects of explosives composting, including recent USATHAMA field demonstrations, have indicated that composting can significatly reduce explosives contaminant levels. Conceptual level facilety design, construction and operating requirements for implementation of composting have been developed based on the current level of knowledge with respect to the technical and regulatory aspects of the process. The economics of the process has been evaluated to include the economic sensitivity of the process to various design and operating variables. This evaluation is based on the areated static pile method. It does not include mechanical or in-vessel composting since they have not been tested with explosive-contaminated soil. Based upon present field demonstation data, implementation of composting for explosive-contaminated soil would likely prove to be expensive. However, further evaluation of compost mixture soil ratio, amendment costs, process kinetics, and performance criteria may result in significant economic improvements.

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COMPOSTING OF EXPLOSIVES-CONTAMINATED SOIL TECHNOLOGY

FINAL REPORT

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Prepared for:

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EXECUTIVE SUMMARY

A conceptual level development of the use of composting technology for the treatment of explosives-contaminated lagoon sediments has been conducted. Such sediments exist at a variety of Army Ammunition Plants (AAPs) and Army Depots (ADs) as a result of past industrial activities associated with the production of munitions. Previous investigations of the technical aspects of explosives composting, including recent USATHAMA field demonstrations, have indicated that composting can result in significant reductions in explosives contaminant levels in these lagoon sediments.

In this project conceptual level facility design, construction, and operating requirements for the potential implementation of composting as a remedial technology have been developed. These analyses reflect the current level of knowledge with respect to both the technical and regulatory aspects of the process. The potential economics of such systems has been evaluated. In addition the economic sensitivity of the process to various design and operating variables has been considered.

At the present state of development, the aerated static pile method of composting is considered to be the most viable approach to explosives composting with a possibility for achieving the necessary level of performance and process control at an acceptable cost. Other composting processes such as mechanical or in-vessel composting have not, as yet, been tested for composting of such wastes. Demonstration of their potential advantages over the aerated static pile system (most notably the potential for better process control through continuous mixing) would be necessary for their ultimate selection over the aerated static pile.

Based upon the present definition of process operating parameters as evaluated in USATHAMA field demonstrations, direct implementation of composting would likely prove expensive. However, further evaluation of several process design and operating parameters may result in significant economic improvements. In particular, additional investigations into the compost mixture soil ratio, amendment costs, process kinetics, and performance criteria (as determined in part by regulatory requirements) are warranted. With favorable findings from such investigations, composting may prove to be an economically viable alternative technology.

1. INTRODUCTION

1.1 Problem statement. The contamination of soils and sediments at Army Ammunition Plants (AAPs) and Army Depots (ADs) has occurred in areas where explosives and propellants were produced and handled. A major source of explosives-contaminated soils is from lagoons and sedimentation basins used to settle out the explosives from washout operations at the AAPs. These practices resulted in contamination of sediments with various explosives, including 2,4,6-trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), and octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), and N-methyl-N-2,4,6-tetranitroaniline (tetryl).

Soils and sediments contaminated with explosives may require treatment to prevent possible contaminant migration. Several treatment technologies have been investigated by USATHAMA for possible application during remediation of soils and sediments contaminated with explosives.

One such potential treatment technology for explosives and propellant-contaminated material is composting. There are several potential advantages associated with composting, which may encourage its development as a remedial technology. It generally requires a relatively low level of manpower and energy for operation and therefore may prove an economical alternative to other destructive treatment technologies. Furthermore, emissions from the process are relatively minimal (so long as odors and leachate are controlled) and the product (finished compost) is aesthetically acceptable.

The primary use for this technology has been the disposal of municipal solid wastes and wastewater treatment plant sludges. However, more recent interest has developed on its potential use for treatment of industrial wastes.

Composting of explosives-contaminated soils has been investigated by USATHAMA, with promising initial results. Several of these previous composting studies were performed on a bench scale. Critical parameters affecting microbial activity can vary significantly, depending upon the scale of the compost system. Consequently, WESTON initiated a field demonstration study with TNT, HMX, RDX, and tetryl contaminated soil. The primary objectives of the field demonstration were to address the final fate of the parent explosives and decomposition products (such as diaminonitrotoluenes and amino dinitrotoluenes) and to evaluate the influence of temperature upon composting effectiveness. This study demonstrated that the bioconversion of explosives under composting conditions was technically possible at the field scale level [1].

The intent of the present task was to evaluate possible system configurations for full scale implementation of explosives-composting as a remedial technology.

1.2 Objectives of study. The objective of this project was to develop, at the conceptual level, a system or approach for composting of explosives-contaminated soils at Army facilities. The information resulting from this effort would then be used both in planning full scale implementation and in evaluating the need for additional process development and optimization.

To accomplish the desired results, several tasks were required:

- A review of recent literature of potential application to composting operations for industrial wastes.
- Consideration of potential regulatory requirements for explosives composting operations.
- Development of conceptual level facility descriptions, including process flow and materials balances, conceptual facility layouts, and operating requirements.
- Development of general construction requirements and major equipment lists.
- Conceptual level economic analysis, including capital costs estimates, and operating and maintenance (O&M) cost estimates.
- Sensitivity evaluation to determine dominant economic factors and identify areas in which further development or refinement is warranted.

1.3 Analytical approach. In order to develop a generalized conceptual composting system for comparative or analytical purposes, a definition of certain design requirements and objectives is necessary. Primary among these requirements is the materials throughput (or processing rate) of the system, as determined by, in part, the amount of contaminated soils requiring treatment. The required process throughput will also be largely determined by the timeframe within which the cleanup operation must be completed. This aspect will in turn be largely determined by regulatory requirements.

At the present state of development, a compost system may have application on a range of different scales, corresponding to a range of soil quantities and cleanup schedules. For purposes of this conceptual technology development, USATHAMA has defined a range of potential cleanup project sizes. This range has been established as 20,000 to 200,000 tons of contaminated soils to be treated within a 5-year remedial operating period.

Implementation of composting at any particular Army facility would require identification of the total quantity of sediments at that facility.

In order to allow for a wide range of potential system sizes, a "modular" approach was used in this analysis. This approach depended upon a standardized compost pad size and configuration with the option of using varying numbers of pads (with appropriately scaled site facilities) to achieve varying processing rates. While altering the scale of the constructed facility in this fashion would be the one way of tailoring capacity to site specific requirements, additional flexibility may be obtainable by other relatively minor reconfigurations of the pads and/or facility. Likewise, the modular approach facilitates economic and sensitivity analysis of the process. However, optimization of the design in response to a particular, site-specific cleanup scenario will likely result in greater economy.

This conceptual evaluation is based largely upon process performance and kinetics as determined in the LAAP field demonstration [1] in which the concurrent removal of a particular mixture of contaminants was evaluated. Previous literature on the composting of explosives, as well as municipal and industrial composting literature, has also been considered. The actual operating characteristics of the system may depend in part upon the specific contaminant profile (with respect to relative concentrations of all target constituents) at a given site. The possible effects of changes in the contaminant mixture cannot be addressed in a generalized approach. However, the general sensitivity of process economics to variation in the required compost mixture (as might result from specific contaminant reduction requirements) has been recognized and is addressed in Section 4.

The conceptual facility descriptions developed in this study are also based upon, in part, recent literature and visits to recently developed municipal sludge composting facilities. Site visits were made to the Sussex County (NJ) Municipal Utilities Authorities enclosed sludge composting facility and to the Philadelphia (PA) Sludge Processing and Distribution Center. The cooperation of personnel at these facilities is appreciated.

2. BACKGROUND INVESTIGATION

2.1 General background on composting technologies. This section provides a discussion of composting as presently used for nonhazardous wastes and is based in large part upon EPA guidance on composting, as presented in Reference 2. Composting is a process by which organic materials are biodegraded by microorganisms under controlled conditions. Microbial activity results in the production of organic and/or inorganic byproducts and energy in the form of heat, which can generate and maintain thermophilic conditions in the compost mixture. Disposal of organic wastes under conditions now called composting has been practiced for many years. The advent of composting as an engineered (controlled) process is more recent, with most interest in the composting of municipal and industrial sludges in the U.S. dating to the early '70s [2].

Composting can be initiated by mixing biodegradable organic matter with bulking agents and, possibly, other amendments [1]. In conventional composting systems, the bulking agents are added primarily to enhance the porosity of the mixture to be composted, but may provide additional carbon for the microorganisms. Materials of relatively low total organic content may be composted through the addition of other high organic carbon sources. In such cases the added organic carbon fraction, in addition to being degraded or stabilized itself, serves to maintain the necessary microbial population in the compost mixture, and to provide for the generation of thermophilic conditions.

Several parameters have been shown to affect the efficiency of the composting process:

- Compost pile temperature.
- Compost pile moisture content.
- Type and concentration of organic constituents.
- Inorganic nutrients.
  - Nitrogen.
  - Phosphorous.
- Compost pile oxygen content.

These parameters can be at least partially controlled or manipulated with the compost system design or operating scheme.

There are several general categories of composting technologies currently used for composting of solid wastes:

- Windrow.
- Aerated static pile.
- Mechanical (in vessel).

The windrow and aerated static pile processes have been used most frequently for municipal sludge composting. The basic steps to be followed in these two processes are similar [2]. In the windrow method, oxygen is drawn into the pile by natural convection and mechanical turning of the compost. In the static pile method, aeration is induced by forced air circulation [2].

In the windrow composting process, the compost mixture is placed in long parallel rows called windrows. The windrow is mechanically turned, using specially designed equipment, to reintroduce air to the compost mixture. Typical pile dimensions may be 15 feet wide at the base, with a triangular cross section 3 to 7 feet high [2]. As with other composting systems, heat is provided by aerobic microbial metabolism. Since temperature control is effected primarily by mechanical turning of the compost, closely regulated temperature regimes in such a system may be difficult to achieve.

In aerated static pile composting, the material to be composted is mixed with a bulking agent (commonly woodchips) and formed into a pile. The pile is placed over an aeration system comprised of blowers and piping, and air is forced or drawn through the pile to provide oxygen and to regulate temperature. Depending upon the design and operating parameters of the aeration system, more precise temperature control may be possible with this approach, as compared to windrow composting.

One common configuration for aerated static pile sludge composting is known as the Beltsville method [2]. In this approach, a section of perforated, flexible plastic tubing is set within a layer of bulking agent (typically woodchips) on the compost pad. The perforated tubing is connected to the blower (or blower manifold) by a section of nonperforated pipe. The compost mixture is placed upon the prepared base, forming a pile of roughly triangular cross section (dimensions approximately 15 feet wide at the base and 7.5 feet high). The pile may then be covered by a layer of finished compost. The blower can then be used to control pile temperature by varying the rate (or frequency) of heat removal by ventilation.

Mechanical composting is accomplished inside an enclosed vessel. This system is intended to provide a higher degree of process control, and better odor control, as compared to open windrow or aerated static pile systems.

The primary differences among various mechanical composting systems are in the methods of process control. Some provide aeration by tumbling or dropping the material from one level to another. Others use devices such as augers to stir the composting mass, or rotating drums which enhance mixing and aeration.

Mechanical composting systems typically have shorter retention times in the reactor vessel which allow them greater materials throughput. However, this increased materials throughput does not necessarily improve the overall process throughput or economics. All present mechanical composting systems rely to some extent upon a second, "curing" step following treatment in the reactor. Therefore, the amount of operating time required can approach that of windrows or static piles. Several mechanical composting systems currently in use are described in Section 4.

As implied in the above description, a major factor in the operation of a compost system is the method of aerating the compost mixture. Controlling aeration is important both from the standpoint of providing oxygen to the microbial community and for controlling the removal of metabolically generated heat and therefore controlling the temperature of the process. Some research suggests that the latter factor may be the controlling parameter in operating the aeration system. It might be noted that the use of alternate oxygen sources (such as hydrogen peroxide) has been employed in other bioremediation processes, particularly when conducted in situ. The applicability of such concepts to composting has apparently not been determined.

2.2 Explosives/industrial waste composting. Composting has been suggested as a candidate process for biological treatment of a variety of organic and organics-contaminated industrial solid wastes, including sludges, soils, and sediments. At least part of the impetus for such suggestions derives from the extensive historical experience with composting of domestic and municipal wastes and from recognition, based upon past experience, of its potential advantages. These advantages include its low energy intensity; relatively low capital and operating costs; and the production of a biologically stable, humus-like, nonobjectionable product.

Most existing experience, however, derives from composting of conventional (generally municipal, and almost exclusively nonhazardous) wastes. Certain basic differences between such materials and industrial or hazardous wastes should be recognized in the evaluation and development of this technology for treatment of the latter categories.

2.2.1 Approaches to composting of industrial wastes. Suler has discussed the general differences inherent in composting of industrial materials [3]. He defines two arbitrary categories of industrial wastes. The first category (Type 1) includes nontoxic, readily degradable industrial residues, such as food processing wastes. The goals of composting such materials include general destruction of existing organic material; possibly pathogen destruction; production of a stable, readily disposable product; and reduction in waste volume. Therefore, this process is generally similar to the composting of municipal treatment plant sludges. Composting of food processing wastes has been considered for such materials as seafood wastes [4] and cannery wastes [5].

The second type of waste (Type 2) defined by Suler includes wastes that contain "toxic, hazardous, and generally recalcitrant compounds," which restrict other use or disposal of the waste [3]. The general objective of composting such wastes is the destruction of the toxic contaminants of concern so that the waste can be disposed as a nonhazardous material. Thus, the requisite conditions, possible kinetics, and resulting products of microbial transformation of the hazardous constituents become primary issues in evaluating composting technology for these types of wastes.

This difference is also manifested in terms of basic mass balance and materials handling considerations. In the case of municipal wastes and many Type 1 industrial wastes, the organic fraction is relatively high. In fact, the process is largely defined in terms of reduction of the organic material. Although in certain cases the addition of amendments (such as nutrients) may be needed, sufficient organic carbon generally exists to support the biological process (both in terms of the thermophilic environment and the size of the microbial population). Depending upon the efficiency with which any required bulking agent can be recovered, some net reduction in waste volume can be derived as a benefit.

In the case of Type 2 wastes, the target organics may often be present in relatively low concentrations in a largely inorganic or nondegradable matrix, such that the organic fraction is too low to support and propagate the biological process. Consequently, the addition of significant quantities of supplemental organic material (such as plant material) as well as nutrient supplementation may be required. This fact implies that the biological destruction of the target compounds may be basically different mechanistically than their use as a source of carbon and energy. From the standpoint of materials handling, the requirement for an external carbonaceous substrate means that sources and supply adequacy (and cost) of supplemental organic materials, as well as their storage, handling, and mixing in the compost facility, become significant factors. Furthermore, the addition of significant quantities of such supplemental organic materials means that the net volume of waste after composting, although nonhazardous, may be significantly increased. Therefore, the importance of establishing adequate redisposal arrangements should also be considered.

Based upon the above distinctions, explosives-contaminated soils and sediments would be classified as Type 2 wastes. They contain toxic and/or possibly recalcitrant organics, generally at sufficiently low concentrations that supplemental carbon sources would likely be required, and the destruction of those specific organics is the fundamental process requirement.

Development of a commercial or field-scale composting system for Type 2 wastes would require, in its early stages, experimental investigation in two broad areas:

- Preliminary, feasibility-level testing to determine whether the proposed process is scientifically and technologically valid.

- Engineering-level investigations with the goal of determining actual design and operational parameters.

A significant portion of process development, following successful initial demonstrations, involves the investigation of various process variables and control parameters for their possible effects on process performance and economics. Among the process related variables that might be evaluated at either the feasibility or engineering level are the following:

- Growth and cultural characteristics of the microbial populations which develop in the compost pile, and whether those naturally-developing populations could be augmented by the addition of bacterial supplements.

- The amendment and nutrient mixtures and types that best promote microbial activity.

- Specific operating parameters such as mixing requirements, aeration rates and cycles, and leachate generation/water consumption rates.

2.2.2 Composting of explosives-contaminated wastes. The composting of explosives-contaminated solid wastes has been studied at both laboratory and field scales, and early literature has recently been reviewed [1]. These initial investigations have generally focused upon the first of the above categories of investigation, i.e., a demonstration that reduction in explosives concentrations through composting is technically feasible.

USATHAMA has conducted previous research into the composting of sediments contaminated with explosives or propellants. Laboratory scale and pilot scale tests were conducted at Louisiana

Army Ammunition Plant (LAAP) and Badger Army Ammunition Plant (BAAP) by Atlantic Research Corporation for USATHAMA [6]. The experiments on LAAP sediments examined the potential for treatment of TNT, RDX, HMX, and tetryl, while the work at BAAP focused upon nitrocellulose. Two types of compost materials were examined in the laboratory, including an alfalfa hay/horse feed mixture and a sewage sludge/wood chip mixture. External temperature control (incubation) was used to maintain thermophilic conditions.

Three different sediment ratios (10, 18, and 25 percent soil by weight) were tested. Laboratory results indicated that all of the target compounds (TNT, RDX, HMX, tetryl, and nitrocellulose) were susceptible to destruction by composting under one or more of the sets of reaction conditions (combinations of compost material and soil fraction). Based upon these results, pilot scale tests were conducted for composting of LAAP and BAAP sediments. The scale of these tests were sufficiently large (500 gallons each) to allow observation of the self-sustaining properties of the compost mixture (with respect to temperature). LAAP sediments were mixed with hay/horse feed (11 percent sediment by weight) and sewage sludge (16 percent sediment by weight). BAAP's nitrocellulose contaminated sediments were composted with the hay/horse feed mixture at the rate of 15 percent sediment by weight. Degradation of TNT, RDX, HMX, and tetryl was demonstrated in self sustaining composts using the hay/horse feed and the manure/hay/sawdust mixtures. Degradation was not observed in the sewage sludge compost, in direct contrast to the laboratory results. It was postulated that adequate compost conditions (temperature) could not be sustained for sufficiently long periods on the residual carbon content of sewage sludge. Degradation of explosives in laboratory scale sewage sludge composts was apparently facilitated by the external temperature control.

The pilot scale test of nitrocellulose contaminated sediments, in combination with alfalfa/horsefeed, demonstrated rapid and essentially complete degradation of this constituent under self-sustaining conditions.

A field-scale demonstration of composting was conducted by WESTON for USATHAMA, using LAAP sediments contaminated with TNT, RDX, HMX, and tetryl [1]. This demonstration employed the aerated static pile composting configuration, with total compost volumes of 34 to 39 cubic yards in each pile. Temperature was the primary variable examined in this study with comparative evaluation of piles maintained at mesophilic (35°C) and thermophilic (55°C) temperatures.

Initial tests during this project composted sediments with a mixture of straw/manure and sawdust, using a higher sediment ratio than had previously been attempted (36% sediment by volume, or 79% by mass). Although the compost in these piles generated sufficient heat in the early stages to achieve temperatures of approximately 45 to 50°C, both test piles cooled down within approximately 33 days. Reductions in TNT concentrations in the two test piles were 64 and 84 percent, and no significant change in RDX or HMX concentrations were found.

It was postulated that the lack of adequate heat production was attributable to a low moisture content and the high proportion of soil compared to degradable carbon in the compost mixture. Consequently, two additional piles were constructed using a modified mixture so that moisture and organic content would not limit microbial activity. The new compost preparation incorporated contaminated sediment at 3 percent by volume, 24 percent by mass in a mixture of alfalfa hay, straw manure, and horse feed. The compost mixture was moistened with water during pile construction.

Under these conditions it was found that average compost temperatures could be maintained in the desired ranges (approximately 35°C and 55°C respectively in the mesophilic and thermophilic piles) by controlling operation of the aeration system. The piles were operated in this fashion for 153 days. Excellent destruction of the target compounds was achieved during this period, with the reduction in total explosives content (sum of all target explosives) being 98 percent for the mesophilic pile and 99.6 percent for the thermophilic pile.

Based upon the results of these experimental efforts, the technical feasibility of composting explosives-contaminated soils can be summarized as follows:

- Substantial reduction in explosives concentrations through composting is possible under test conditions examined to date.

- Generally, the addition of supplemental carbon and energy sources, as well as nutrients, is necessary, suggesting that the reduction of explosives concentrations may be a cometabolic, or at least a partially nongrowth, event. (From the standpoint of materials balances, the volumetric fraction of the total composting material represented by explosives-contaminated wastes has generally been on the order of 10 percent by volume.)

- At the present level of knowledge, end products of the reaction that remain in the finished compost do not appear to be toxic.

- As with conventional composting, the process appears to be temperature related (with respect to degradation rate) with thermophilic conditions (approximately 55°C) providing better results than mesophilic temperatures (approximately 35°C) as measured by destruction efficiency [1].

2.2.3 Kinetics and reaction parameters. The pilot-scale experiments reported in the ARCs study and the field demonstration conducted by WESTON both determined that, under the conditions studied, the rate of disappearance of the target explosives could be described by first order reaction kinetics (i.e., a rate equation of the form $C = C_o e^{-kt}$ where C is the concentration at time t, C_o the concentration at time 0, and k the specific rate constant). Under such kinetics, the half life of the constituent, or the time required for half of the existing quantity or concentration to degrade, is constant.

Table 2-1 summarizes the experimental conditions from which kinetic data were obtained in each study, as well as the specific rate constants and half-lives estimated for each constituent.

Given the range of operating conditions in these experiments, the kinetic data obtained appear to be reasonably consistent. It should be recognized that the effects of explosives concentration, interactions among contaminants, and compost operating parameters on microbial kinetics have not been fully defined.

The data in Table 2-1 indicate that, of the four explosives present in these experiments, TNT is most rapidly degraded, while HMX is most slowly degraded. The single estimate of tetryl degradation rate presently available indicates that its degradation is approximately as rapid as TNT.

As with all waste treatment processes, the feasibility and economics of composting will be directly influenced by the length of time required for treatment. Treatment requirements may be specified in terms of final residual concentrations in the product or in terms of required treatment efficiency (i.e., as percentage removed), and may be developed on a site-specific basis. Once determined, the treatment period to reach such objectives will also be affected by the level of contamination in the soil/sediment as well as other factors.

Treatment standards for explosives-contaminated soils have not been fully developed. However, measured or estimated degradation kinetics can be used to evaluate potential design and operating requirements under various potential treatment scenarios.

As noted previously, the effect of initial explosives concentration on the rate and extent of reaction is not fully understood. It is well known that the rate of microbial oxidation of substrates is not always an increasing function of

Table 2-1

Kinetic Parameter Estimates For Explosives Composting

Study	Conditions	Soil Ratio (Mass %)	Constituent	k (d^{-1})	Half Life (days)
ARCs[6]	Pilot test, hay/horsefeed mixture (tank 1)	10.8	TNT	0.056	12.4
			RDX	0.035	19.8
			HMX	0.022	31.5
			Tetryl	NA	NA
	Pilot test, hay/horsefeed mixture (tank 2)	12.1	TNT	0.071	9.8
			RDX	0.030	23
			HMX	0.021	33.2
			Tetryl	NA	NA
ARCs[6]	Pilot test, sewage sludge wood chips (tank 4)			No loss of explosives	
	Pilot test, sewage sludge wood chips (tank 5)			No loss of explosives	
	Pilot test, sewage sludge wood chips (tank 6)			No loss of explosives	
ARCs[6]	Pilot test, manure mixture (tank 5)	11.0	TNT	0.097	7.2
			RDX	0.040	17.3
			HMX	0.030	23
			Tetryl	0.082	8.4
WESTON[1]	Field demonstration, hay, manure, horsefeed, fertilizer mixture, mesophilic (pile 3)	24.0	TNT	0.032	21.9
			RDX	0.023	30.1
			HMX	0.016	42.0
			Tetryl	NS	NS
			Total Explosives	0.026	26.6
WESTON[1]	Field demonstration, hay, manure, horsefeed, fertilizer mixture, thermophilic (pile 4)	24.0	TNT	0.058	11.9
			RDX	0.040	17.3
			HMX	0.030	22.8
			Tetryl	ND	ND
			Total Explosives	0.043	16.2

Notes: NA = Not applicable.
ND = Not determined. Contaminant was not present above detection limits in initial compost mixture.

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substrate concentration. For some organics a concentration may exist above which microbial oxidation may decrease due to inhibitory or toxic effects of the substrate. Even when not serving as a substrate, toxic organics may inhibit microbial activity. An upper concentration limit may exist for explosives composting, although its value has not yet been determined.

From the standpoint of field application, an important question involves the upper concentration limit that can exist in the prepared compost pile for the process to succeed. Previous work has indicated the need for the addition of supplemental carbon and nutrient sources in order to maintain the biological reaction.

In terms of the potential toxicity of the explosives in the composting process, the addition of carbon sources and bulking agents has the effect of diluting the bulk explosives concentration to lower levels, possibly lowering the liklihood of toxic effects. However, it should be noted that significantly higher localized concentrations are likely to persist to the extent that the mixture is not truly homogenous. The mixing ratios and resulting compost pile explosives concentrations at which previous studies have been conducted provide one estimate of the raw sediment explosives concentrations that can be successfully treated. The extent to which higher raw explosives concentrations would necessitate lower ratios of sediment to compost will directly affect engineering design and operating parameters. Even within the acceptable concentration range, the specific rate constant may vary with initial concentration.

It should also be noted that a variety of factors other than substrate concentration may limit the extent of reaction. Commonly cited examples include the accumulation of toxic or inhibitory reaction products, certain microbial population effects, and other changes in environmental conditions. To some extent such limitations are inherent in batch treatment processes, and the unavoidable heterogeneity of a compost mixture may also play a role. Whether such interactions actually determine the extent of reaction, and whether operational strategies exist that can mitigate such effects, is not yet known.

2.2.4 Process control. With an understanding of the effects of reaction conditions on rate, the possibility of controlling or manipulating these parameters in order to optimize performance can be considered. Operating variables that may be under engineering control in a compost system include mixing regime, nutrient conditions, moisture level, aeration, and temperature.

Several of these parameters are, of course, interrelated. Aeration will directly affect moisture levels by evaporation, and will affect temperature both through the direct removal of heat and by evaporative cooling. In fact, aeration may be the major process control parameter used.

Finstein et al. [7 to 10] argue that the most effective process control for composting operations generally centers upon temperature. (It should be noted that their discussion deals with composting of municipal wastewater treatment plant sludges, wherein neither nutrient and moisture limitation nor microbial inhibition and toxicity is a major problem.) The authors acknowledge that the ultimate goal of design and operation should be to maximize microbial rates, and that the rational method of achieving this condition is to control temperature within the compost pile, with a maximum operating temperature of 60°C [10]. The recommended method of achieving such control (assuming that the basic pile configuration is acceptable) involves ventilative heat removal using positive pressure forced air ventilation in conjunction with feedback temperature control systems (a combination the authors refer to as the Rutgers strategy after the university at which the concept was developed). The authors do not completely discount the potential contributions of factors such as bulking agents, moisture, and periodic remixing of the pile but consider their value to be in support of, and secondary to, the primary effort to control temperature.

The need for process control parameters leads to a discussion of composting system configuration. Many, if not most, new municipal compost facilities are of the aerated static pile configuration in which air is drawn or forced through a pile of composting material by mechanical aeration equipment. Many examples still exist of windrow composting in which large compost piles are periodically turned (by construction equipment or specially designed composting equipment) to reintroduce oxygen and re-establish composting conditions.

More recent developments involve mechanical, in-vessel (reactor) composting systems in which, generally, composting mixtures are mechanically agitated. In theory, the intent of such systems is to provide a higher degree of process control as compared to, for example, the aerated static pile system.

In order to be of practical value, an improvement in process control should translate into improvement in reaction rates or other performance criteria of sufficient magnitude to offset the generally higher capital cost and operating complexity of such systems. Based upon literature encountered to date, there does not appear to be any demonstrated experience with the use of mechanically agitated systems for composting explosives-contaminated wastes. With respect to sludge composting process temperature control, Finstein et al., as noted above, suggest that mechanical agitation by in-vessel composting systems neither ensures not precludes effective control. The authors discuss some mechanical composting systems which they feel would mitigate against effective temperature control due to unfavorable pile configurations [10]. Conversely, Finstein et al. present the possibility for conversion of existing aerated static pile systems to the "Rutgers strategy" by redesign of the ventilation to provide forced air, and the control systems, to provide a temperature feedback control loop.

It might be speculated that mechanically agitated systems may result in improved homogeneity in an explosives composting system and thus reduce limitations (if any) arising from high localized explosives concentrations or uneven distribution of substrate, nutrients, or microorganisms. Such speculation has not, as yet, been subjected to investigation.

As discussed above, the primary methods for controlling oxygenation and temperature in compost mixtures, given the presence of adequate carbon sources, are mechanical agitation and ventilation. Moisture addition when necessary is conceptually straightforward, so long as excess water addition and consequent leachate production are controlled.

Alternative methods of process control might be postulated particularly for temperature control. For example, the use of heat trapping enclosures, such as greenhouses, and waste heat from other processes might conceivably supplement microbial processes in maintaining compost temperatures. In municipal sludge or solid waste composting there is, of course, little incentive to pursue such concepts. In fact, removal of excess metabolic heat resulting from degradation of the carbon source is generally the necessary form of temperature control. However, in the composting of contaminated sediments, self heating will not occur in the absence of added carbon. As noted previously, supplemental carbon sources are added at potentially significant cost to enable the establishment and maintenance of cultural conditions that foster destruction of the target compounds. To the extent that the actual function of supplemental carbon is to provide for heat generation rather than maintenance of population density, it may be possible to consider economic tradeoffs between the cost of this carbon and the use of other heat sources. Thus, while there is no economic incentive for investigating such options in municipal composting, there may be for explosives composting. There are, however, important technical questions which would have to be addressed, in addition to economics. The true significance of the supplemental carbon for purposes other than heat generation should be considered in order to evaluate whether it can be partially replaced. Furthermore, the effectiveness of potential methods for applying heat to the pile would have to be demonstrated. Lastly, it might be noted that if supplemental carbon is required in excess of its use in heat production, then heat removal, by ventilation or possibly other means, would still be required.

It was noted at the beginning of this section that several of the process control parameters are interrelated. Therefore, efforts to alter and improve controls of one such parameter must consider the potential effects of such changes on the other interrelated parameters.

2.3 Regulatory issues. The sediments resulting from the accumulation of pink water from explosives manufacturing operations are classified as a listed hazardous waste from specific sources-K047 (pink/red water from TNT operations) as defined in 40 CFR 261.32. The RCRA classification of contaminated sediments should be reviewed on a site-specific basis for final determination. The treatment of explosives-contaminated (TNT, RDX, HMX, tetryl) sediments by aerated static pile composting involves piling up the compost mixtures (sediment-bulking agent) and aerating the compost pile. Therefore, from the regulatory standpoint a composting operation may be considered as a form of waste pile.

As defined in 40 CFR 260.10, "pile" means any noncontainerized accumulation of solid, nonflowing hazardous waste that is used for treatment or storage. On the basis of this definition, it seems probable that the regulations listed in 40 CFR 264 Subpart L (Waste Piles) would apply to the treatment of explosives-contaminated sediments (hazardous waste) in compost piles. The permit program for this category may, in some cases, be managed by the state in which the treatment facility is to be constructed and operated (subject to EPA approval of the state's program). Under Subpart L of 40 CFR 264, the treatment facility (waste piles) must meet RCRA facility design requirements that include a double liner system and a leachate collection system. In addition, 40 CFR 264 Subpart F regulates the groundwater monitoring requirements for treatment facilities that treat hazardous waste in waste piles.

However, exemptions from the requirements to install a liner and leachate collection system, and exemptions from the Subpart F groundwater monitoring requirements, may be possible if it is demonstrated that neither runoff nor leachate is generated from the pile. Specifically, the following should be demonstrated during construction of the compost piles (40 CFR 264.250(c)):

- Protection from Precipitation. Demonstrate that the pile is inside or under a structure that provides complete protection from precipitation.

- Free Liquids. Demonstrate that neither liquids nor materials containing free liquids are placed in the pile.

- Runon Protection. Demonstrate that the pile is protected from surface water runon by the structure or in some other manner.

- Wind Dispersal Control. Demonstrate how the pile design and operation controls wind dispersal of wastes.

- Leachate Generation. Demonstrate that the pile will not generate leachate through decomposition or other reactions.

It is possible that the compost pile would be exempted from the requirements of a liner system, a leachate collection system, and 40 CFR 264 Subpart F groundwater monitoring requirements [11]. Before granting these exemptions, the EPA and/or state agency would evaluate in detail the proposed design and construction of the compost pile system with regard to:

- Protection from precipitation.
- Free liquids.
- Runon protection.
- Wind dispersal control.
- Leachate generation.

A RCRA Part B Permit Application for Subpart L, containing the general information as described in 40 CFR 270.14 and the relevant specific information as presented in Appendix A, must be submitted to the state agency for approval. These information requirements are necessary in order for the state agency to determine whether the treatment facility is in compliance with 40 CFR 264 Subpart L standards.

Because the compost mixture is classified as hazardous, it is possible that the EPA and/or state agency may determine that the composting treatment facility must meet RCRA facility design requirements. Under these circumstances, the facility should comply with the regulations listed in 40 CFR 264.251 pertaining to design and operating requirements for waste piles (compost piles).

A list of specific items (40 CFR 264.251 and 40 CFR 270.18) with regard to liner system description, liner foundation design, a leachate collection and removal system, a runon control system, and a runoff control system, which should be discussed in detail in the RCRA Part B Application for Subpart L to demonstrate the compliance of the treatment facility with RCRA facility design requirements, is presented in Appendix A.

In addition to these general requirements, more specific facility regulations may apply in specific locations and situations. Examples of additional standards that warrant investigation on a case-specific basis include:

- RCRA facility closure requirements that will apply after the facility ceases operation.

- RCRA disposal requirements for redisposal of treated sediments. In this report, it is assumed that treated sediments can be delisted and disposed of on land, in a manner similar to conventional compost.

- RCRA manifest and transportation requirements if sediments must be moved offsite. As noted above it is assumed in this report that onsite disposal can be used.

- RCRA impoundment requirements and NPDES or pretreatment requirements if excess runoff or drainage is generated. It is assumed in this report that runoff/leachate will be recycled to the compost pile.

- State RCRA requirements (where approved by EPA) that may be more stringent than federal standards.

- State solid waste regulations, if the sediments are determined to be nonhazardous.

- Local erosion and sedimentation (E&S) plan requirements for facility construction and operation.

3. CONCEPTUAL PROCESS DEVELOPMENT

3.1 Objective. The primary objective of the conceptual process development section is to describe an aerated static pile composting system for the treatment of explosives-contaminated sediments. This process development section will discuss the primary equipment, facilities, materials, personnel, and regulatory requirements that comprise the conceptual treatment system.

This process development is based upon the use of an aerated static pile composting system, with general operating parameters derived from the previous field demonstration project [1]. Such an approach has been selected as best representing the current state of process development and therefore being most nearly ready for implementation. Some potential alternatives, modifications, and process sensitivities will be addressed in Section 4.

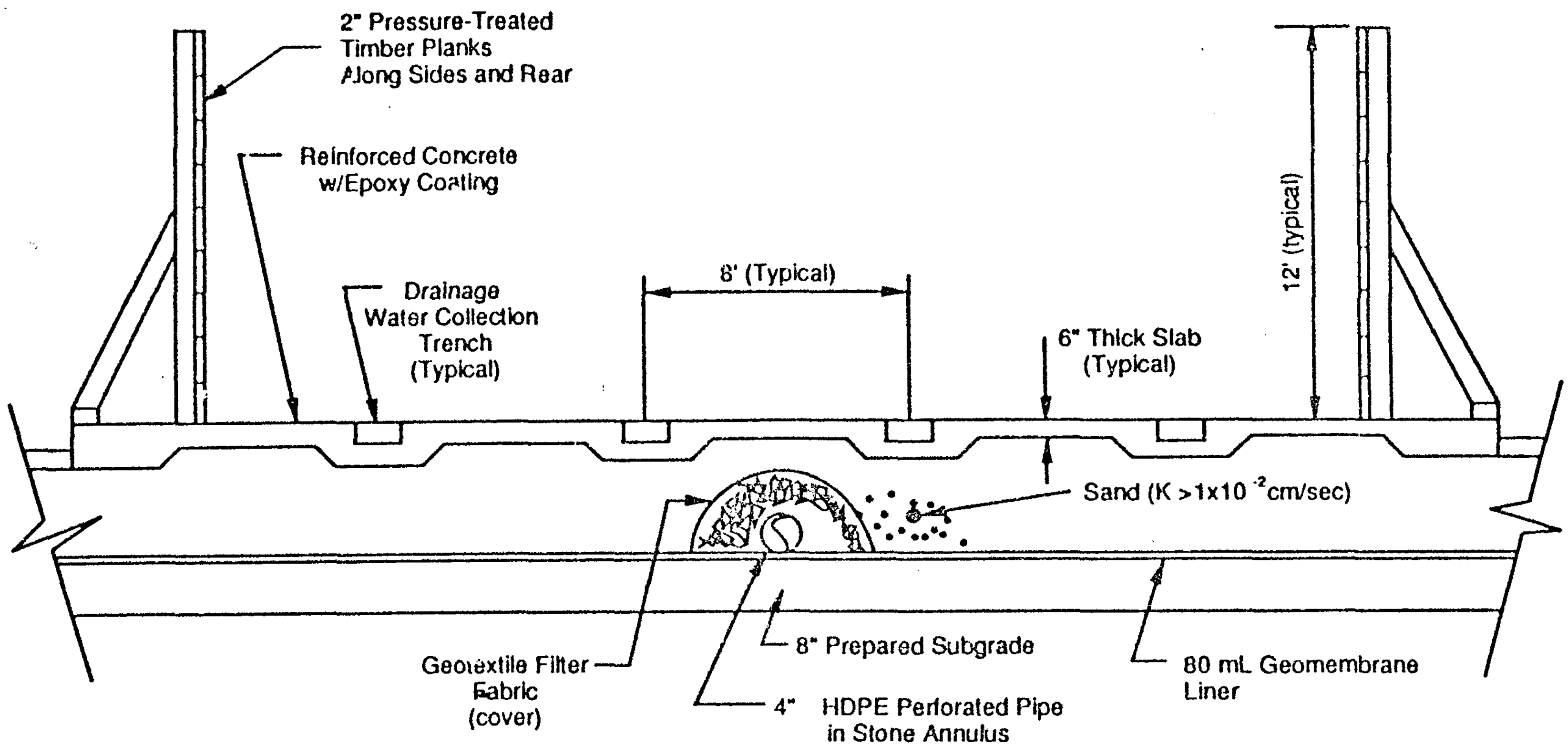
3.2 Design basis and assumptions. Based on data collected during the field demonstration project showing composting of explosives-contaminated sediments at the Louisiana Army Ammunition Plant (LAAP)[1], published literature for composting of municipal and industrial sludges (see Subsection 2.2), and visits to state of the art composting facilities, a design basis was developed.

3.2.1 Compost pad configuration. An aerated static pile system located in a bin-type structure (three wooden walls) was established for the design basis. This resulted in a rectangular pile configuration with dimensions of 60 feet long by 40 feet wide by 8 feet high, resulting in a total compost pile volume of 19,200 cubic feet (711 cubic yards). A cross section of the compost pad is provided in Figure 3-1.

This static pile system configuration with bin walls was selected because it offered the following advantages over non-bin type systems:

- The bins act as an insulating barrier for the compost pile allowing for better temperature control.
- The bins protect the compost pile from the elements (snow, rain, wind, etc.) and therefore help control runon/runoff.
- The bin walls help prevent short-circuiting of air as commonly happens in non-bin type systems.

The use of bin walls can also increase the total compost mixture volume in the pile by allowing a rectangular rather than trapezoidal cross section.



Note: A Tarpaulin or Equivalent Cover Will Be Placed Over the Pad

Drawing not to scale

G18-148

Figure 3-1. Typical compost pad cross section

3.2.2 Compost mixture. The compost pile mixture developed during WESTON's field demonstration at LAAP was used as a baseline and modified to reflect potential optimal conditions for the design basis. The design basis mixture is presented in Table 3-1.

The primary modification, as compared to the LAAP study, involved the elimination of the high protein horsefeed that was present in the test compost mixture at a volumetric ratio of 12 percent. This material is relatively expensive ($220 to $260 per ton) and, at the volume ratios used at LAAP, would present a significant operating cost to the facility. While the use of this rich supplement may be beneficial, its presence has not been sufficiently established as essential to the process to justify its cost.

The volumetric fractions of the straw/manure mixture and alfalfa were increased to compensate for the volume loss created from the deletion of horsefeed. The relative proportions of straw/manure to alfalfa were retained at approximately 1.09:1 [1].

3.2.3 Compost pile sediment fraction. The contaminated sediment fraction in the compost mixture is assumed for the baseline case to be 10 percent by volume. This fraction represents the best current estimate of the maximum sediment fraction that will achieve and maintain the requisite microbial environment. This estimate does not consider the maximum allowable bulk explosives concentration (with respect to microbial toxicity and/or process kinetics).

The previous study was conducted at a bulk explosives concentration in the compost mixture of 18,000 mg/kg [1]. Although it is possible that some sediments may exhibit explosives levels greater than 18,000 mg/kg and that these concentrations may determine the maximum compost mixture sediment fraction, this is not, at present, considered to be a likely scenario. It is assumed that for the purposes of this study explosives levels will not affect application of this process from either a microbial toxicity or a safety standpoint.

3.2.4 Composting treatment period. This conceptual development is based upon an assumed treatment requirement of 99.5% removal of TNT. Based upon kinetic data from the LAAP study (presented in Table 2-1), the half life of TNT under thermophilic conditions is approximately 11.9 days. Under these conditions, the minimum composting period for contaminated sediments to achieve approximately 99.5 percent removal of TNT would be 90 days. Therefore, for this study a compost pile cycle time of 90 days was assumed. The potential effects of varying the compost period, representing various treatment objectives, are discussed in Section 4.

TABLE 3-1. MODIFIED COMPOST PILE MIXTURE[a]

Component	Volume %	Volume[b] (yd^3)	Mass %	Mass[b] (lbs)	Mass[b] (tons)	Density[c] (lb/yd^3)
Sediment	10	71	69	163,584	82	2,300
Alfalfa	43	307	9	22,394	11	72
Straw/Manure	47	333	22	51,220	26	155
Total	100	711	100	237,198	119	~334

[a]Source: Reference [1].

[b]Assumes a rectangular compost pile with a total volume of 711 cubic yards (yd^3).

[c]Density based on information obtained from source [1].

3.2.5 Regulatory requirements. The composting system is assumed to be classified as a Resource Conservation and Recovery Act (RCRA) facility, and subsequently must meet or exceed the RCRA facility design standards (see Appendix A).

3.2.6 Facility size. Three different size composting facilities were evaluated, with each employing a different number of the base (modular) compost pads, as described in Subsection 3.2.1, to achieve various sediment processing rates. The smallest of the three facilities employs 12 composting pads, while the largest employs 124 pads. This size range was selected to encompass the required processing rates for completing cleanup projects (20,000 to 200,000 tons of sediment treated in 5 years) under the stated operating conditions with respect to the quantity of sediment in each pile (approximately 80 tons) and the required composting period (90 days). An intermediate size facility comprising 50 composting pads was also developed.

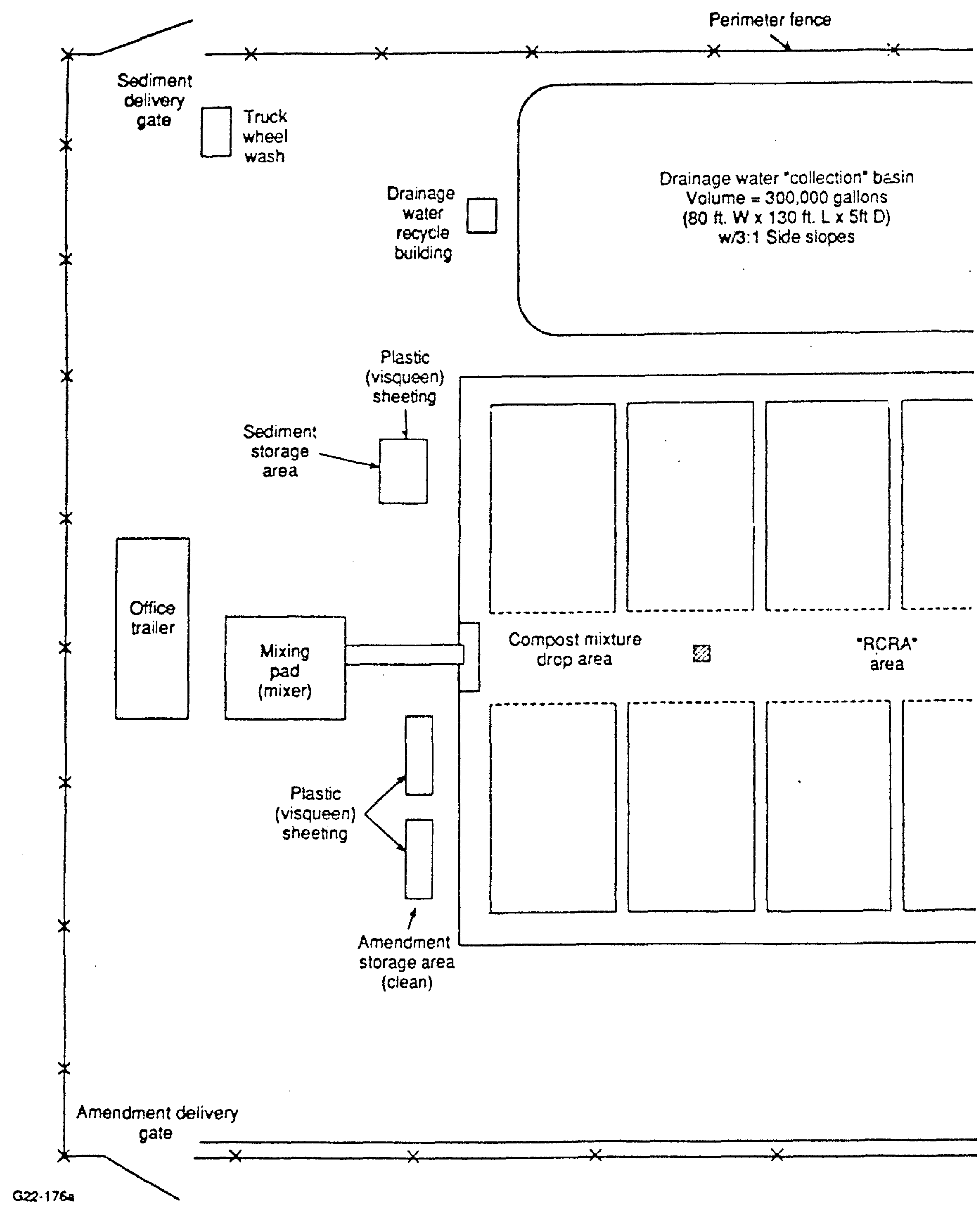
The materials balance for a single (modular) compost pile was used to develop appropriate support facilities and to meet the total materials handling requirements of each system.

The following sections present equipment requirements for the three systems. The detailed discussion of design and operating requirements uses the intermediate size facility (50 pads) as the illustrative example. Likewise, the economic sensitivity analysis presented in Section 4 uses the 50-pad facility as its baseline. For the facility sizes considered in this study, the total mass of sediment treated in 5 years (under the stated assumptions) would range from 18,000 tons for the 12-pad facility to 200,000 tons for the 124-pad facility.

Conceptual layouts for a 12-pad (3,600 tons of sediment per year), 50-pad (16,000 tons of sediment per year), and 124-pad (40,000 tons of sediment per year) composting facilities are shown in Figures 3-2 to 3-4, respectively.

3.2.7 Water (drainage) management. It is assumed that composting is essentially a water-consumptive process so that, if rainfall and runon is controlled, no net generation of drainage will occur from the compost pile. Rather, the addition of small quantities of makeup water (currently estimated at 610 gallons per pile per day) will be required [1].

Some quantities of runoff water are expected to be generated from high traffic areas of the compost pad area that are open to the weather. Good management practices will be used to keep this area as clean as possible. However, this runoff may still be considered to be potentially contaminated. A collection basin will be used to collect and hold runoff from this area for recycle to the compost piles.



Perimeter fence
Sediment delivery gate
Truck wheel wash
Drainage water recycle building
Drainage water "collection" basin
Volume = 300,000 gallons
(80 ft. W x 130 ft. L x 5ft D)
w/3:1 Side slopes
Plastic (visqueen) sheeting
Sediment storage area
Office trailer
Mixing pad (mixer)
Compost mixture drop area
"RCRA" area
Plastic (visqueen) sheeting
Amendment storage area (clean)
Amendment delivery gate

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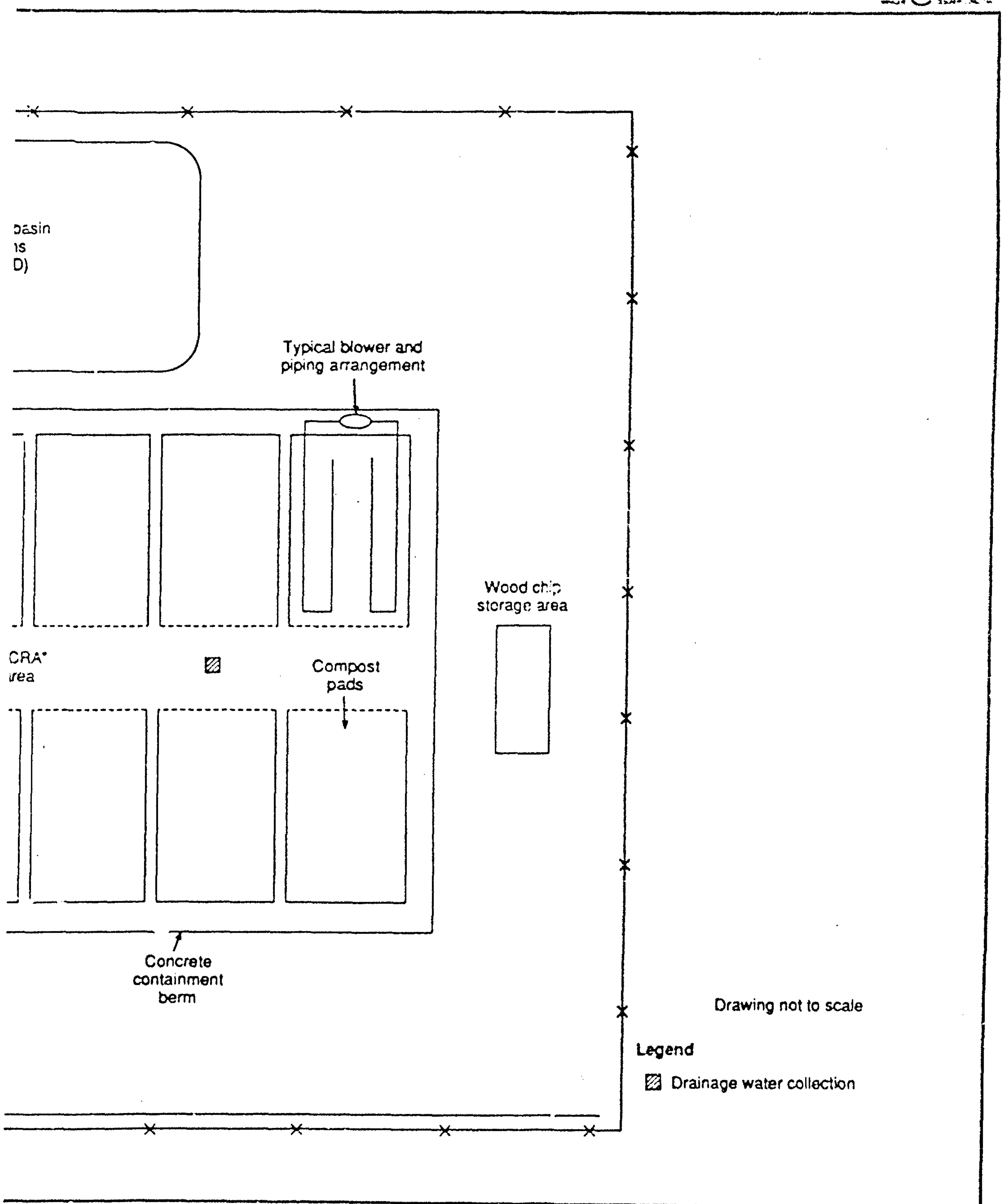
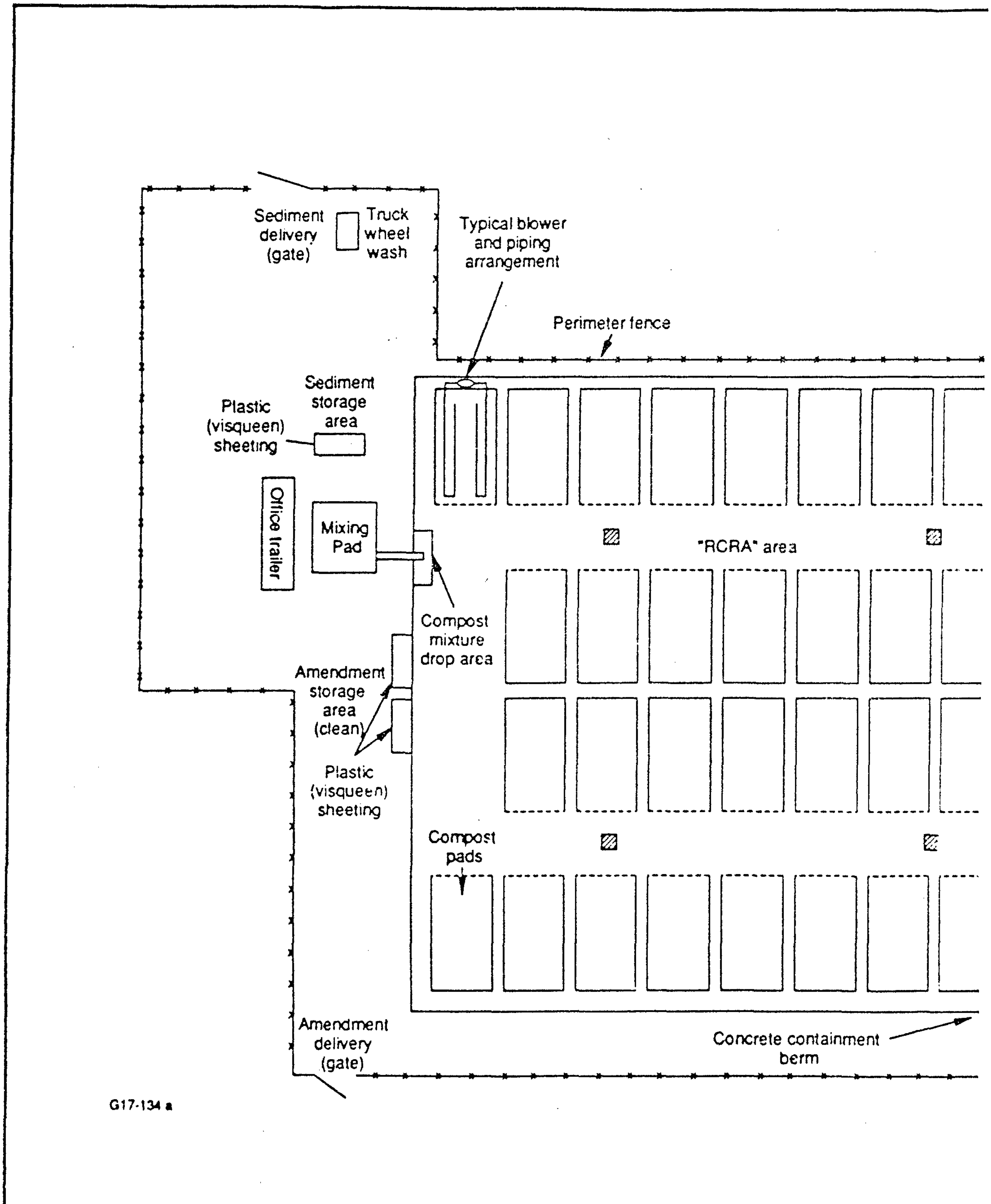


2.

Figure 3-2. Site layout for 12-pad facility.


Sediment delivery (gate)
Truck wheel wash
Typical blower and piping arrangement
Perimeter fence
Sediment storage area
Plastic (visqueen) sheeting
Office trailer
Mixing Pad
"RCRA" area
Compost mixture drop area
Amendment storage area (clean)
Plastic (visqueen) sheeting
Compost pads
Amendment delivery (gate)
Concrete containment berm
G17-134 a

1

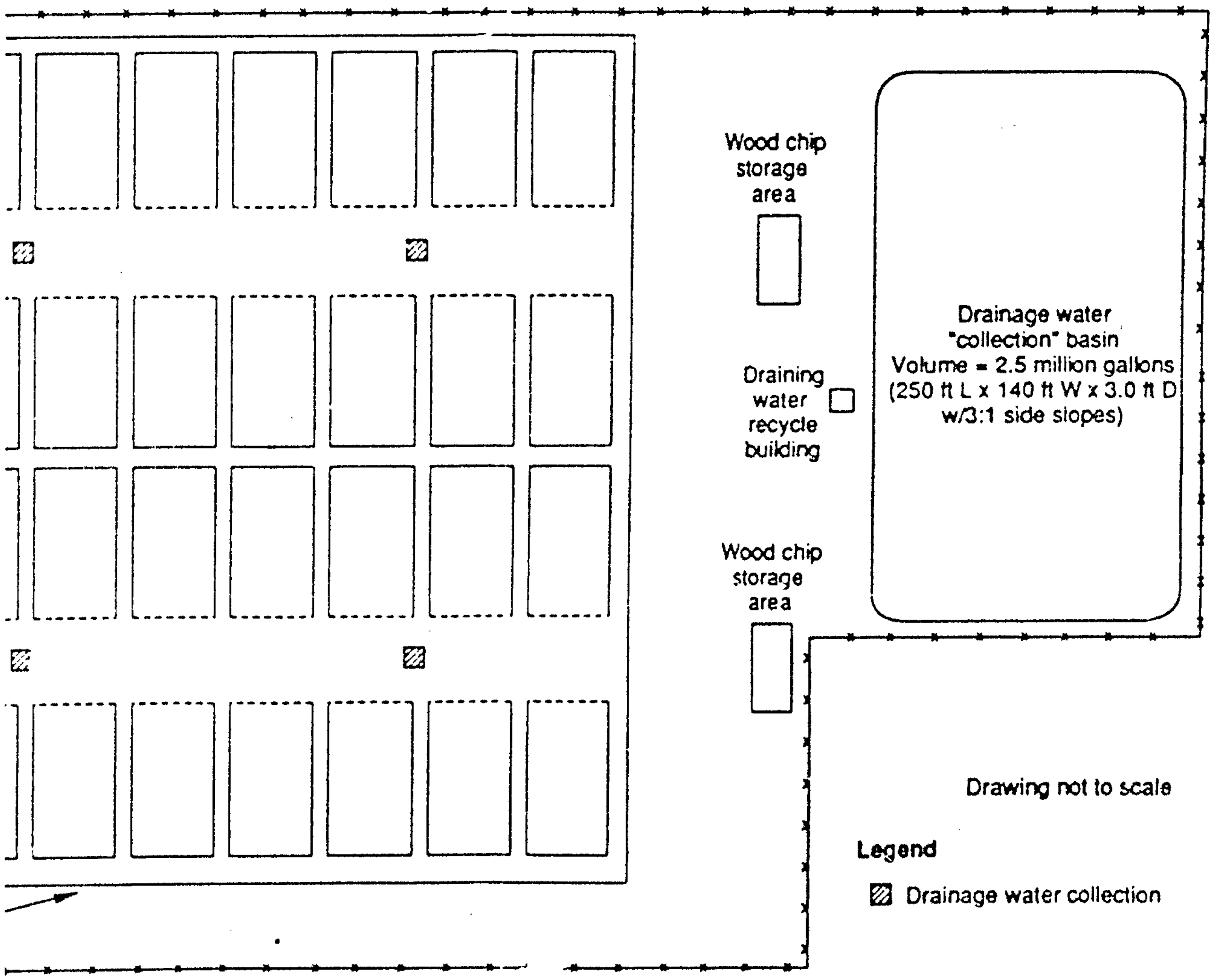
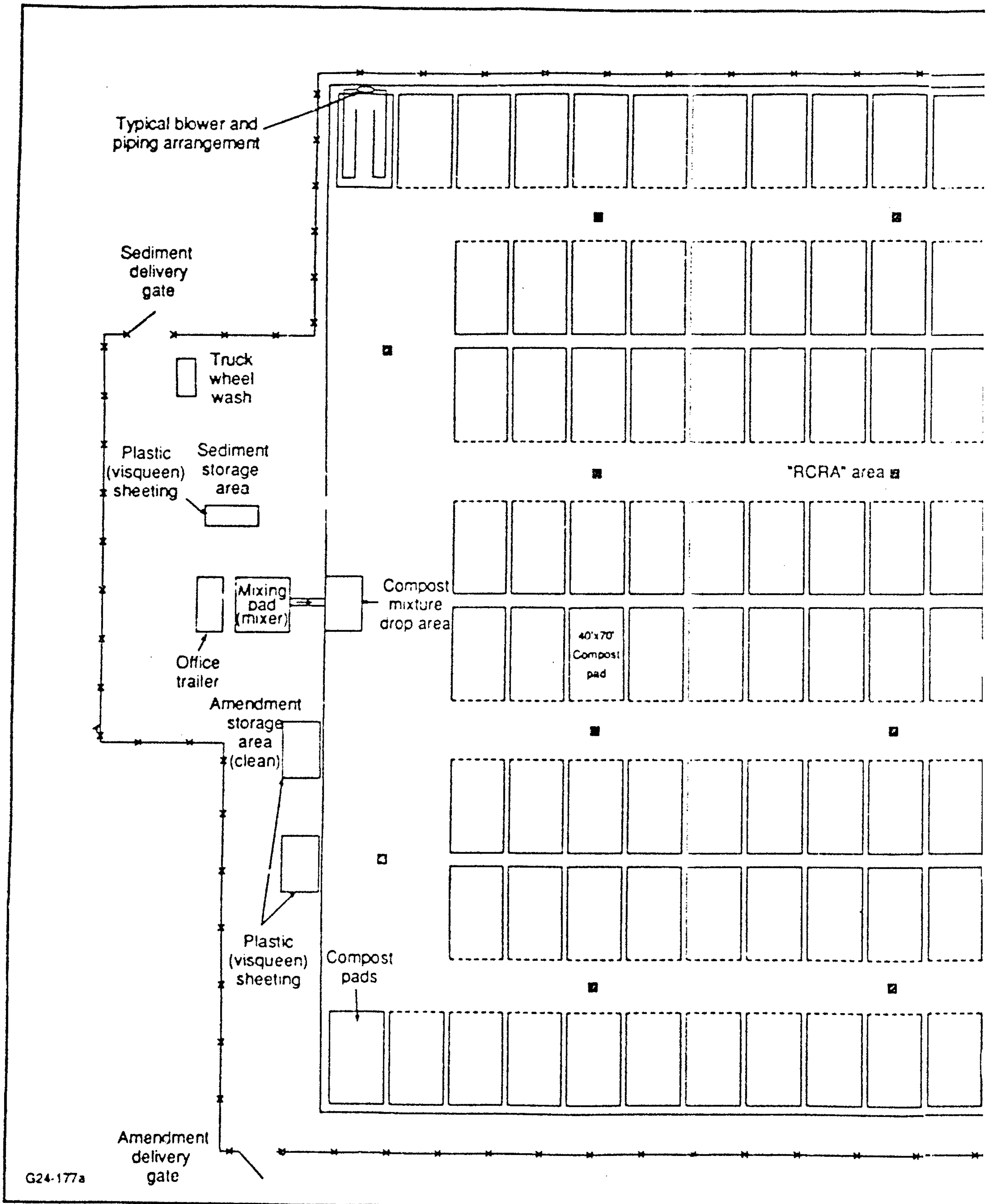


Figure 3-3. Site layout for 50-pad facility


Typical blower and piping arrangement
Sediment delivery gate
Truck wheel wash
Plastic (visqueen) sheeting
Sediment storage area
"RCRA" area
Mixing pad (mixer)
Compost mixture drop area
40'x70' Compost pad
Office trailer
Amendment storage area (clean)
Plastic (visqueen) sheeting
Compost pads
Amendment delivery gate
G24-177a

1

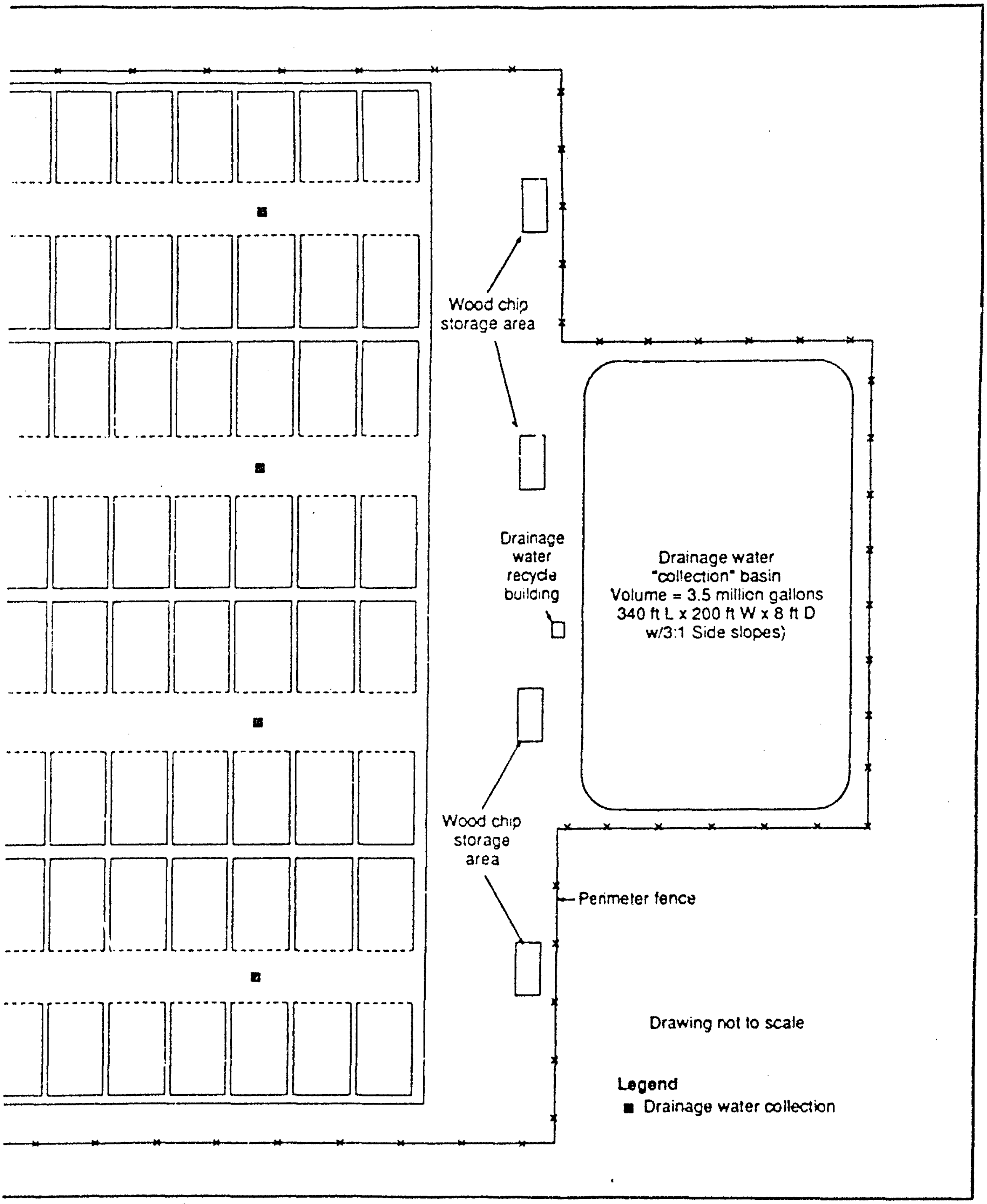


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Figure 3-4. Site layout for 124-pad facility.

3.2.8 Aeration requirements. Blowers were sized assuming the Rutgers method of control (i.e., forced ventilation).

3.3 Process Description and Materials Balance. By using this design basis, a process flow diagram and materials handling scenarios were developed (see Figure 3-5 and Tables 3-2, 3-3, and 3-4).

The process flow diagram applies to all three facility sizes that were analyzed. Each process stream and/or operation must be performed for each facility. However, the number and type of individual pieces of equipment will depend on the sediment treatment kinetics and facility size. For example, the 12-pad facility size following TNT kinetics requires one compost mixer while the 124-pad facility requires seven to maintain the four piles per year per pad processing rate desired. Therefore, the materials handling scenarios will vary for the three facility sizes. The materials handling scenarios for the 12-pad, 50-pad, and 124-pad facilities are presented in Tables 3-2, 3-3, and 3-4, respectively. The materials handling scenarios are based on an 8-hour work day for 5 days per week for 50 weeks per year or 2000 hours per year. All quantities given on a per day basis refer to the 8-hour per day operating schedule.

In terms of the actual materials flow through the system, system operations can be divided into three categories (pile construction, pile operation, and compost disposal), as indicated in Figure 3-5. Although for any single compost pile these phases are sequential, the routine operation of a multi-pad facility will involve differing proportions of activity in each phase at given points in time. For example, in a small facility of 12 pads, construction of the 12 piles may take approximately 20 operating days. Once 12 piles have been constructed, additional pile construction will not be needed again until the first of the original piles is finished. Likewise, it will probably be possible to dispose of 12 compost piles relatively quickly. Therefore, certain phases of the overall operation will actually operate in periodic fashion.

In Table 3-2, 3-3, and 3-4, therefore, the compost pile construction phase represents the materials balance during those periods of compost pile construction. The compost pile operation represents the daily operation of each individual pile with the assumption that the facility will operate the maximum number of piles on a year round basis. The materials balance for compost disposal again represents the disposal rate during the periodic disposal operation.

In the development of the equipment lists and operating requirements for the facilities described herein, the overall rates of the various phases have been matched with the overall

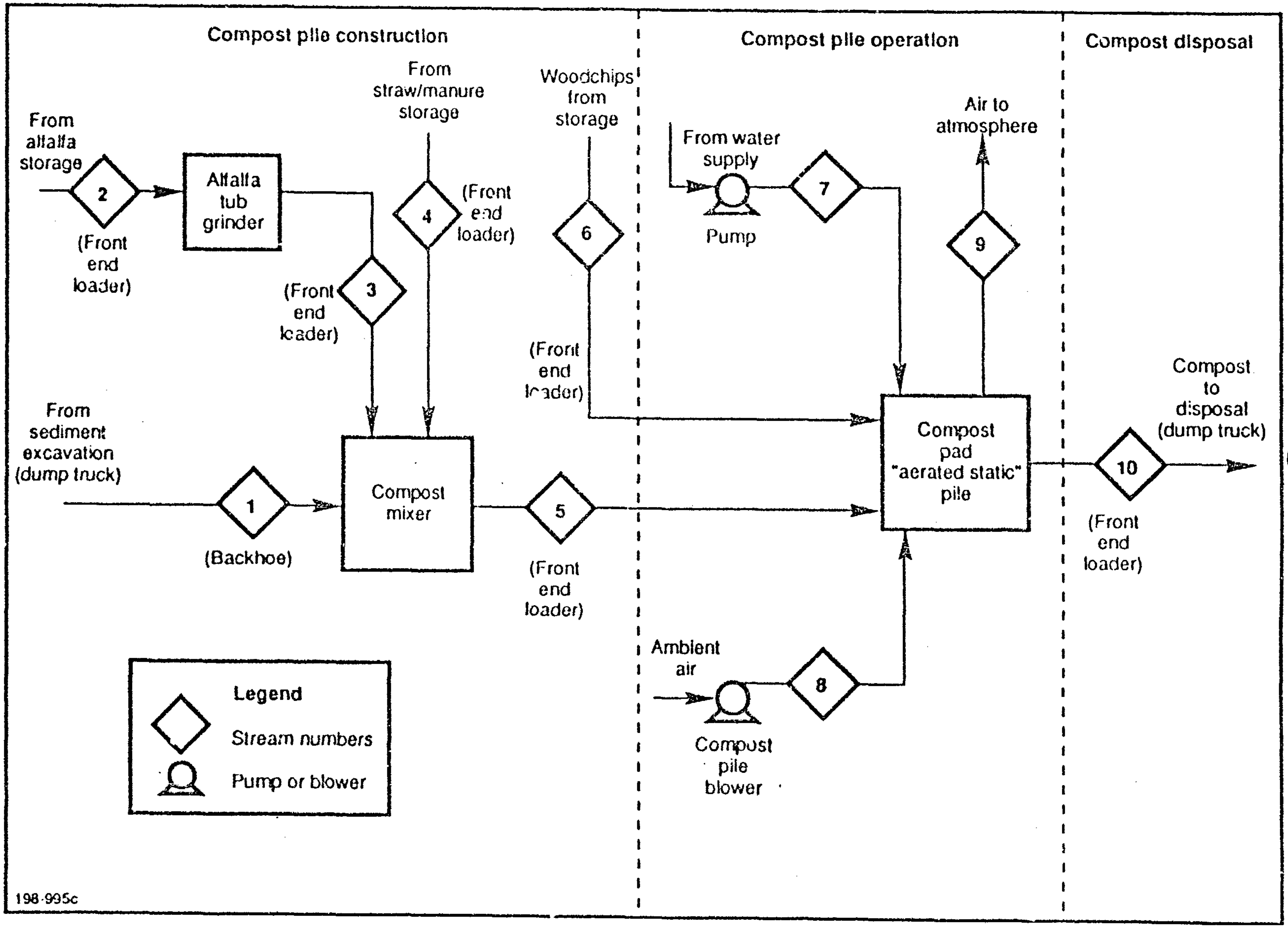

Figure 3-5. Process flow diagram for an aerated static pile composting system.

TABLE 3-2. MASS BALANCE FOR AN AERATED STATIC PILE COMPOSTING PROCESS[a]
(12-pad facility following an 8-hour work day)

Stream Component	Units	Materials Stream[a]: Compost Pile Construction 1	2	3	4	5	6[b]	Compost Pile Operation 7[c]	8[b]	9	Compost Disposal 10[c]
Total Mass Flow	tons/day	52	7	7	16	75	11	2.5	339	339	U
Total Mass Flow	lb/day	103,500	13,896	13,896	32,550	149,632	25,500	5,055	678,720[d]	678,720[d]	U
Density	lb/cy	2,300	72	72	155	334	500	1,685	2.2	2.2	U
Total Volume Flow	cy/day	45	193	193	210	448	45[b]	3	308,509[d]	308,509	U
Solids	lb/day	77,280	13,896	13,896	32,550	123,726	22,500	0	0	0	U
Total Explosions Concentration	mg/kg	42,000	0	0	0	28,924	0	0	0	0	289[e]
Total Explosives	lb/day	4,328[f]	0	0	0	4,328[f]	0	0	0	0	100[e,f]
Percent Water	%	25	NA	NA	NA	17	NA	100	0-100	0-100	U
Water	lb/day	25,760	NA	NA	NA	25,760	0	5,055	0	0-5,055	U
Water	gal/day	3,089	NA	NA	NA	3,089	NA	610[g]	NA	0-610	U
Air Flow	CFM	NA	NA	NA	NA	NA	NA	NA	35,000[d]	35,000[d]	NA

[a]Refer to Figure 3-5.
[b]Assumes one pile built per day.
[c]These columns apply to the operation of the system after the pile has been constructed. The quantities are for a 24-hour operating day per pile.
[d]Each blower operates 10 min/hr.
[e]The explosives are removed by composting and residuals leave the system as an inert part of the total mass.
[f]The total explosives in lbs/day are included in the solids flow.
[g]Once per day in one hour.
NA = Not applicable.
U = Undetermined.

Note: This table provides data on each process stream. The table also provides daily production rates for each stream which corresponds to a materials handling component listed in Figure 3-5.

TABLE 3-3. MASS BALANCE FOR AN AERATED STATIC PILE COMPOSTING PROCESS[a]
(50-pad facility following an 8 hour work day)

Stream Component	Units	Materials Stream[a]: Compost Pile Construction 1	2	3	4	5	6[b]	Compost Pile Operation 7[c]	8[c]	9	Compost Disposal 10[c]
Total Mass Flow	tons/day	154	21	21	49	224	11	2.5	339	339	339
Total Mass Flow	lb/day	308,200	41,616	41,616	97,960	448,896	22,500	5,055	678,720[d]	678,720[d]	U
Density	lb/cy	2,300	72	72	155	334	500	1,685	2.2	2.2	U
Total Volume Flow	cy/day	134	578	578	632	1,344	45[b]	3	308,509[d]	308,509	U
Solids	lb/day	231,150	41,616	41,616	97,960	370,726	NA	0	0	0	U
Total Explosions Concentration	mg/kg	42,000	0	0	0	28,835	0	0	0	0	288[e]
Total Explosives	lb/day	12,944[f]	0	0	0	12,944[f]	0	0	0	0	300[e,f]
Percent Water	%	25	NA	NA	NA	17	NA	100	0-100	0-100	U
Water	lb/day	77,050	NA	NA	NA	77,050	0	5,055	0	0-5,055	U
Water	gal/day	9,239	NA	NA	NA	9,239	NA	610[g]	NA	0-610	U
Air Flow	CFM	NA	NA	NA	NA	NA	NA	NA	35,000[d]	35,000[d]	NA

[a]Refer to Figure 3-5.
[b]Assumes one pile built per day.
[c]These columns apply to the operation of the system after the pile has been constructed. The quantities are for a 24-hour operating day per pile.
[d]Each blower operates 10 min/hr.
[e]The explosives are removed by composting and residuals leave the system as an inert part of the total mass.
[f]The total explosives in lbs/day are included in the solids flow.
[g]Once per day in one hour.
NA = Not applicable.
U = Undetermined.

Note: This table provides data on each process stream. The table also provides daily production rates for each stream which corresponds to a materials handling component listed in Figure 3-5.

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TABLE 3-4. MASS BALANCE FOR AN AERATED STATIC PILE COMPOSTING PROCESS[a]
(124-pad facility following an 8 hour work day)

Stream Component	Units	Materials Stream[a] — Compost Pile Construction 1	2	3	4	5	6[b]	Compost Pile Operation 7[c]	8[c]	9	Compost Disposal 10[c]
Total Mass Flow	tons/day	361	49	49	114	524	11	2.5	339	U	339
Total Mass Flow	lb/day	722,200	97,056	97,056	228,470	1,047,424	22,500	5,055	678,720[d]	678,720[d]	U
Density	lb/cy	2,300	72	72	155	334	500	1,685	2.2	2.2	U
Total Volume Flow	cy/day	314	1,348	1,348	1,474	3,136	45[b]	3	308,509[d]	308,509[d]	U
Solids	lb/day	541,650	97,056	97,056	228,740	867,176	NA	0	0	0	U
Total Explosions Concentration	mg/kg	42,000	0	0	0	28,959	0	0	0	0	290[e]
Total Explosives	lb/day	30,332[f]	0	0	0	30,332[f]	0	0	0	0	604[e,f]
Percent Water	%	25	NA	NA	NA	17	NA	100	0-100	0-100	U
Water	lb/day	180,550	NA	NA	NA	180,550	0	5,055	0	0-5,055	U
Water	gal/day	21,649	NA	NA	NA	21,649	NA	610[f]	NA	0-610	U
Air Flow	CFM	NA	NA	NA	NA	NA	NA	NA	35,000[d]	35,000[d]	NA

[a]Refer to Figure 3-5.
[b]Assumes one pile built per day.
[c]These columns apply to the operation of the system after the pile has been constructed. The quantities are for a 24-hour operating day per pile.
[d]Each blower operates 10 min/hr.
[e]The explosives are removed by composting and residuals leave the system as an inert part of the total mass.
[f]The total explosives in lbs/day are included in the solids flow.
[g]Once per day in one hour.
NA = Not applicable.
U = Undetermined.

Note: This table provides data on each process stream. The table also provides daily production rates for each stream which corresponds to a materials handling component listed in Figure 3-5.

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goal of keeping the overall facility at maximum capacity (maximum number of piles in continuous operation).

It is recognized that to some extent differences in processing rates among the various phases result from discrete operating rates for specific standard equipment sizes. It is possible that, in specific site applications, some additional optimization in equipment sizing may be achieved.

At present, several aspects of the system mass balance remain, to a large extent, indeterminate, particularly with respect to the fate of organic materials in the exit streams (indicated by "U" in the mass balance). In the absence of quantifiable information, the general concepts are noted with respect to compost mixture components:

- Soil fraction. The biologically inert soil mass is expected to be conservative and to exit the system completely in the final compost (Stream 9).

- Organic (amendment) mixture. The amendment mixture serves as a substrate for microbial growth and heat generation (as well as in its role as a bulking agent). Therefore, a portion of this material is metabolized during composting. Of the portion metabolized, a fraction is mineralized to end products, including carbon dioxide and water, expressed in the exit gases (Stream 9) and final compost mixture (Stream 10). The degradable portion not mineralized would be expressed as an increase in microbial mass in the final compost mixture. Finally, the amendment material not degraded, as well as its minor inorganic fraction, will be retained in the final compost mixture.

- Moisture. Moisture will leave the mixture primarily through evaporation in the exit gas (Stream 9) (so long as the moisture addition rate is controlled to prevent leachate generation).

The net effect of these factors on the final compost mass for disposal has not been fully determined. In the LAAP field demonstration, WESTON visually observed an approximate 20 to 30 percent volume reduction in the final compost as compared to the original compost mixture [1]. This loss of volume results not only from a loss of mass through microbial metabolism but also from settling and compaction of the compost mixture and any net water losses.

3.3.1 Process description. The aerated static pile composting process is made up of six basic materials handling steps:

1. Sediment Excavation/Staging.
2. Amendment Materials Preparation.
3. Compost Mixing.
4. Pile Construction.
5. Pile Operation and Remixing.
6. Pile Removal and Disposition of Treated Sediment Compost.

The following subsections provide a description of the major equipment and various materials handling steps that are included in the conceptual compost system and based upon the process flow and materials balance information provided in Figure 3-5 and Tables 3-2, 3-3, and 3-4. In the description that follows, equipment sizes and capacities are provided consistent with these requirements. References to specific equipment by manufacturer or model number are used only for illustrative purposes and do not exclude the use of other similar equipment.

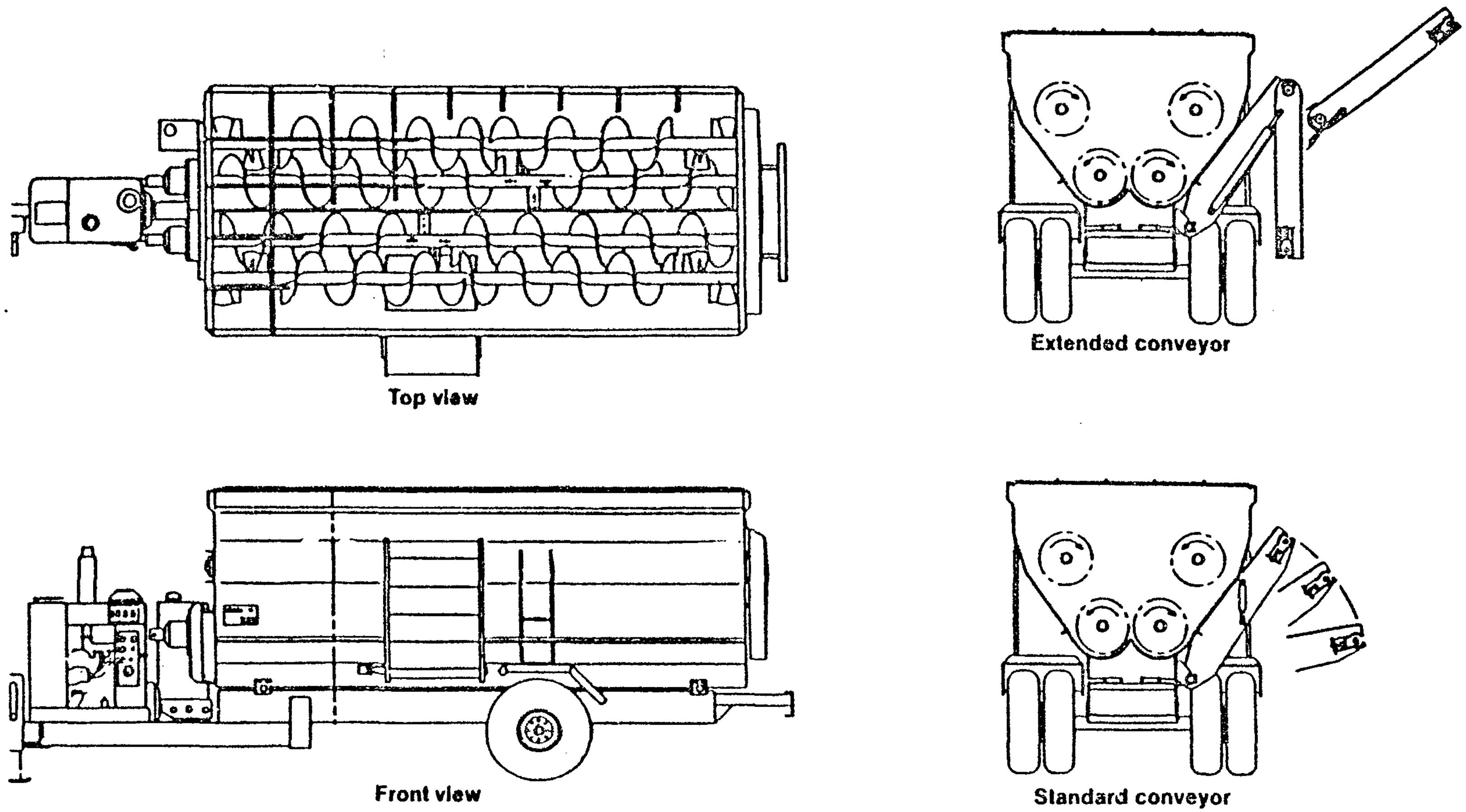
3.3.1.1 Sediment excavation/staging. Contaminated sediment would be excavated from the source area and loaded into a 12-cubic-yard dump truck. The dump truck bed could be slightly tilted toward the excavation to allow free standing water to drain from excavated sediment back into the excavated area. When the dump truck is filled with sediments, it will be moved to the mixing area. The dump truck will be parked or staged in the mixing area and utilized as a storage and/or feed container for the sediments prior to their incorporation into the compost mixing procedure. Upon completion of the use in the compost mixing area the dump truck will pass through a wheel wash to prevent contamination. For larger facilities, where the dump truck is more active, the sediments may be staged in the compost mixer area on plastic (visqueen) sheeting. This will result in a savings of operating time. For the baseline facility presented in previous sections, the estimated sediment volume to be excavated is 71 cubic yards per pile. Therefore, for a 50-pad system following TNT kinetics for 99.5 percent removal (90 days per pile and 196 piles per year), the annual processing rate is 14,000 cubic yards per year (16,000 tons of sediment per year). During pile construction operations, the mixing equipment will process 154 tons per day, and this operation will take place 104 days per year.

3.3.1.2 Amendment materials preparation. The amendment materials used during the composting process include alfalfa and a straw/manure mixture. These materials are delivered through the clean side of the facility (see Figure 3-3 and Subsection 3.4.1.1). This area is isolated from contact with the sediments in order to minimize costs and materials associated with decontaminating trucks and equipment. The amendment materials will be staged in the compost mixing area on plastic (visqueen) sheeting and covered with plastic sheeting when the facility is not mixing compost. The alfalfa is delivered in bales that require "pretreatment" before addition to the compost mixer. A tub grinder (such as that supplied by Jones Grinding in Beemer, Nebraska [12]) will be used to debale the alfalfa and reduce it to a 2 to 3-inch particle size. A front-end loader with a two-cubic-yard bucket capacity will be used to load and unload the alfalfa tub grinder. The straw/manure mixture will require no pretreatment before its use in the compost mixer and will be stored on plastic sheeting during nonactive periods. For the 50-pad facility the estimated volume of alfalfa and straw/manure required to process 14,000 cubic yards of sediment per year are 60,200 cubic yards per year and 65,300 cubic yards per year, respectively.

3.3.1.3 Compost mixing. In this step the amendment components are mixed with the contaminated sediment to form the actual compost mixture. The compost mixer is a batch-type mixer with a 15 to 20-cubic-yard working batch size. One such unit is manufactured by Sludge Systems, Inc., Eau Claire, Wisconsin [15], which has a 17-cubic-yard working batch size with a mixing time of 3 to 6 minutes (see Figure 3-6).

The sediments will be loaded into the open top batch mixer using the backhoe. The theoretical production rate of this 1-cubic-yard bucket capacity backhoe is 120 cubic yards per hour [13]. Amendments will be loaded into the mixer with a 1-cubic-yard front-end loader having a theoretical capacity of 65 cubic yards per hour. The materials will then be mixed for an estimated 5 minutes and then conveyed out of the mixer to the compost drop area. The compost is then transported from the drop area to the compost pads by means of another front-end loader. For larger size facilities the compost mixture can be conveyed to the bed of a dump truck for transport to the pads. This would decrease the travel distance of the front-end loader. It should be noted that the reasons for using the backhoe for sediments and the front-end loader for amendments are two-fold. First, the backhoe will handle the sediments from the contaminated side of the facility while the front-end loader remains on the clean side of the facility. Second, by using individual pieces of equipment, the materials handlers can keep pace with the compost mixer.

A production schedule for the overall compost mixture preparation step is presented in Figure 3-7. This schedule has been developed using estimates of actual equipment operating rates based upon their theoretical capacities derived from the literature [13]. Table 3-5 summarizes the theoretical and assumed actual operating rates for the pertinent equipment pieces. Based upon these assumptions, Figure 3-7 shows that four batches can be completed in 57.5 minutes beginning from sediment excavation and ending after the compost is mixed. The front-end loader that is used for compost transport and pile



Source: Sludge Systems Ind. Literature

Figure 3-6. Typical compost mixer.

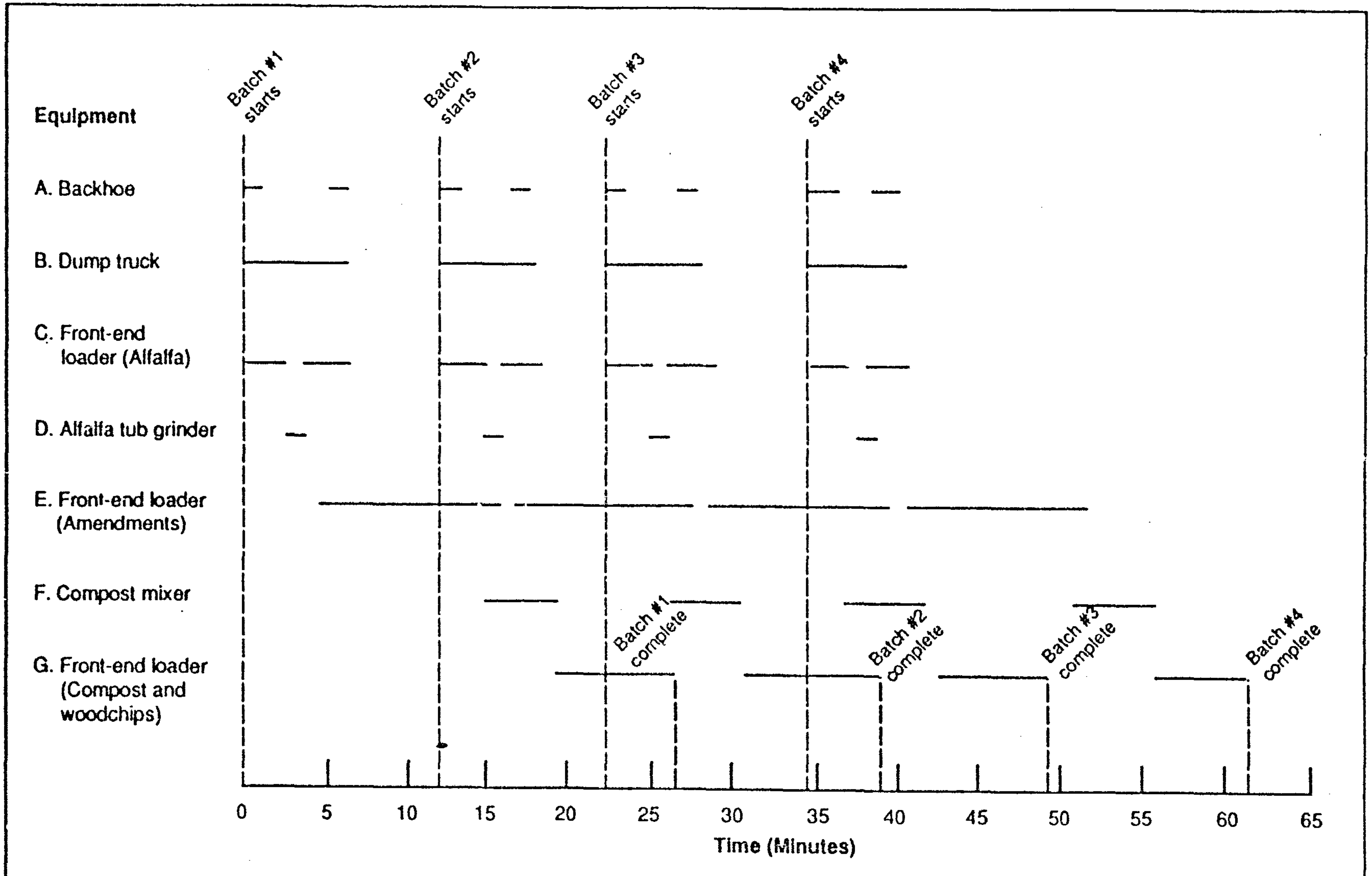


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Figure 3-7. Equipment operating schedule for a four-batch cycle for the 50-pad facility (19 tons per hour)

TABLE 3-5. THEORETICAL AND ASSUMED EQUIPMENT OPERATING RATES FOR COMPOST MIXTURE PRODUCTION

Equipment Item No.	Description	Theoretical Rate	Assumed Rate For Analysis	Reference
1	Backhoe	120 yd^3/hr	120 yd^3/hr	13
2	Dump Truck	12 yd^3	12 yd^3	13
3	Alfalfa Tub Grinder	830 yd^3/hr	415 yd^3/hr	12
4	Front-End Loader (Amendments)	66 yd^3/hr	65 yd^3/hr	13
5	Compost Mixer	68 yd^3/hr	56 yd^3/hr	15
6	Front-End Loader (Alfalfa)	132 yd^3/hr	130 yd^3/hr	13
7	Front-End Loader (Compost)	132 yd^3/hr	130 yd^3/hr	13

pile construction, has an operating time that exceeds the 1-hour time period on the operating schedule, but is active (start of use in Batch 1 until the completion of use in Batch 4) for only 42.5 minutes every hour. Therefore, a four batches per hour production rate can be maintained. Each production batch contains 4.8 tons of contaminated sediment, resulting in an hourly sediment processing rate of approximately 19.3 tons.

3.3.1.4 Pile construction. The 2-cubic-yard front-end loader is used to transport wood chips from the wood chip storage area to the compost pads. This compost area front-end loader has an assumed production capacity of 130 cubic yards per hour and will be used for wood chip handling as well as compost handling. A plant laborer will spread the wood chips evenly over the blower piping network, creating a 6-inch buffer zone for air distribution. The compost mixture is then loosely placed on top of the wood chips using the front-end loader until the desired pile configuration is achieved (8-foot height). The compost mixture will then be spread as evenly as possible by a plant laborer. The laborer will then place six thermocouples (each 6 feet long) into the compost pile. The thermocouples will be placed in one of six 20 feet by 20 feet areas into which the piles will theoretically be divided. The thermocouples are used to monitor pile temperature and will control the blower cycling based on the desired temperature range. (In this case, the blower cycling will help maintain a 55°C temperature for thermophilic conditions.) The addition of water to the pile will be accomplished by a sprinkler system using water collected from the onsite collection basin. The water is added at a rate of approximately 610 gallons per day per pile [1].

3.3.1.5 Pile remixing. It has been assumed for the conceptual design that the piles will require remixing one time (halfway through the composting cycle) during the compost period [1]. This will be accomplished using a 2-cubic-yard front-end loader to remove the compost mixture from the pad and to load this mixture into one of the trailer-mounted compost mixers. It is assumed that if a mixer is used for remixing and is required to mix fresh compost, it will be steam cleaned before its re-use. The facility will have one empty pad at all times so that when a pile is being remixed the material will be removed from one pad and placed on the adjacent pad after mixing. This will be accomplished with a second front-end loader that has a 2-cubic-yard bucket capacity.

3.3.1.6 Pile removal and disposition of treated sediments. Upon completion of the compost period, the pile will be sampled (composite) for analysis and verification of contaminant removal. The pile will be loaded into a 12-cubic-yard dump truck using a 2-cubic-yard front-end loader and transported to a previously selected area onsite for dedicated land disposal or for use as fill material.

3.3.2 Process flow diagram/materials balance. Figure 3-5 and Tables 3-2, 3-3, and 3-5 show the process flow diagram and material balances for an aerated static pile composting process operating under the above conditions. The material balance sheets show the daily (8 hour) production rates for each process flow stream. As previously discussed, some operating phases, such as pile construction and compost disposal, may not be required every operating day.

Sediments are excavated using a backhoe and transported from the excavation area to the compost mixing area by means of a dump truck at a rate of 45 cubic yards per day. The alfalfa is processed using a tub grinder to a particle size of 2 to 3 inches and added to the compost pile mixer using a front-end loader at a rate of 192 cubic yards per day. The straw/manure mixture is added to the compost mixer using a front-end loader at a rate of 211 cubic yards per day. After mixing the compost mixture is transferred from the mixer by means of an attached conveyor to the drop area at a rate of 448 cubic yards per day. At this rate, a single compost pile can be constructed in approximately 13 hours (1.6 operating days). The compost is picked up using a front-end loader and transported to the desired pad at a rate of 130 cubic yards per hour. For larger size facilities the compost mixture may be conveyed directly into a dump truck for transport to the pad currently under construction. After the pile is constructed, it remains on the pad for 45 days at which time it is remixed and moved to the adjacent and/or empty pad. During the composting period the following materials are added to each compost pile:

- Air at 35,000 cfm (average of 10 minutes per hour).
- Water at 610 gallons per day [1].

3.4 <u>Facility description</u>.

3.4.1 General. This subsection provides a description of the conceptualized compost facility which would be used to implement a composting treatment alternative for explosives contaminated sediments based upon the background review and regulatory issues discussed in Section 2, and the conceptual process development presented in Section 3.

These facilities have been developed as hazardous waste treatment facilities. This approach is based upon the possibility that, if sediments are excavated from the lagoon for treatment, the compost pile may be regulated as a waste pile. As discussed in Subsection 2.3, such an approach would require positive control of leachate generation and migration, including the use of a liner and leachate collection system. This is likely to be the most conservative (and most costly) approach to facility design and operation. There are several potential avenues by which less stringent requirements may be obtainable without compromising environmental protection:

- The final regulatory approach has not been definitively determined. If regulatory agencies determine that other regulatory categories are more appropriate than the waste pile classification, facility standards may change.

- As discussed in Subsection 2.3, exemptions from certain technical requirements (including the double liner and leachate collection system) may be possible if it can be demonstrated that the pile will not generate leachate or runoff.

- Alternative system design and management strategies, such as the possibility of conducting the composting directly in a cleared area of an existing contaminated lagoon, may result in a different regulatory status.

- In certain geographical areas, meteorological conditions may minimize the likelihood of runoff or leachate generation through precipitation.

In order to illustrate the effect of system size on facility layout, three different facilities (12 pad, 50 pad, and 124 pad) were developed. Basic facility layouts for each system are shown in Figures 3-2, 3-3, and 3-4. As with the process description above, the intermediate size (50 pad) facility was chosen as the illustrative example for the facility description which follows. The basic design and construction aspects, as well as general operating parameters, are similar for all three systems.

Following the overall facility description, major equipment lists are presented for all three conceptual treatment facilities. Estimated capital and operations and maintenance costs for each facility are presented in Section 4.

3.4.2 Site layout. The composting facility centers upon a compact arrangement of concrete pads on which the actual compost process is conducted. Compactness, consistent with equipment and materials handling requirements, is important in minimizing the total area, which might be subject to RCRA standards. The compost pad area includes a liner and leachate collection system and is surrounded by a berm all to control runon/runoff. A double-lined basin is provided to collect any leachate generated for recycle to the compost pile.

Facility support areas are segregated into "clean" and "potentially contaminated" areas to minimize areas subject to RCRA standards. Contaminated sediments are handled on one side of the plant, while "clean" materials (amendments and woodchips) enter the other side.

The compost pads employ bin walls and tarpaulins to minimize or prevent leachate generation, with clean runoff being diverted to an available sewer or to surface runoff along with drainage from clean areas.

The following subsections describe these facilities in detail.

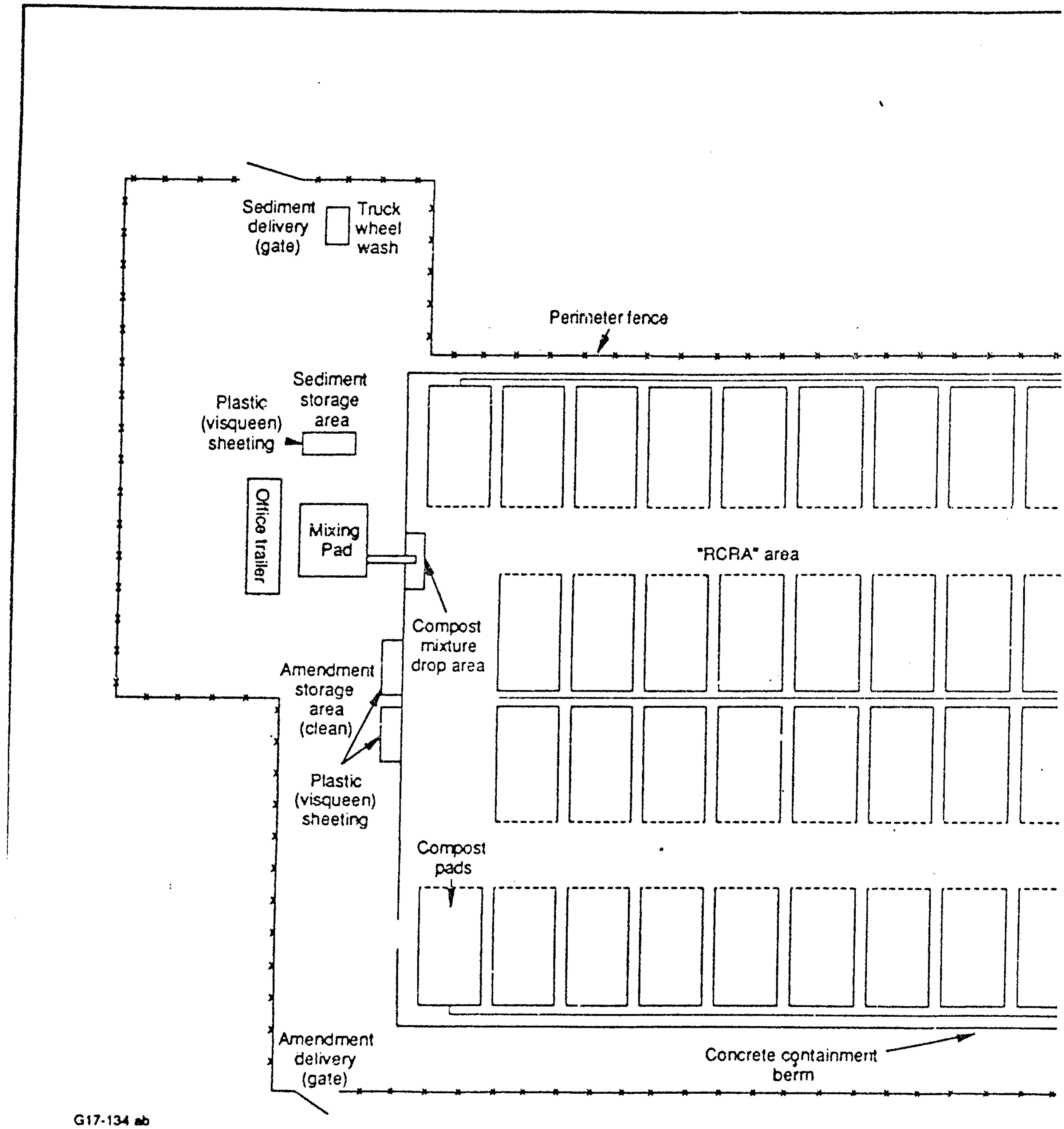
3.4.2.1 Materials preparation and handling. The materials preparation and handling consists of the alfalfa, straw/manure, and woodchips storage and/or handling. The alfalfa and straw/manure are staged in the designated clean area of the plant (no contact with sediment) on plastic sheeting (visqueen) and covered with plastic when not in use. These materials will be moved using a front-end loader or equivalent piece of equipment. The woodchips are staged in the pad area for easy access by the compost area front-end loader and will be covered with plastic sheeting to keep them dry when not in use.

The amendments and sediments will be mixed in a batch type mixer located on a concrete mixing pad that measures 40 feet by 40 feet. The concrete pad is sloped to allow for drainage collection, and the runoff is piped to the collection basin.

3.4.2.2 Compost area. The compost pads are epoxy-coated concrete (6-inch thick) with trenches for aeration piping. The concrete pads are epoxy coated to protect the rebar from corrosion caused by contact with the drainage water. Also, the epoxy coating is cheaper than an acid resistant type concrete. The pad dimensions are 40 feet wide by 70 feet long, allowing a 10-foot entrance area to the bins. Each pad will have one blower and an associated piping network to provide air (oxygen) to the compost pile and to control temperature.

The bins are constructed of pressure treated timber with an average height of 12 feet to encompass three sides of the compost pile. The front is open to access by materials handling equipment and plant operators. The bins are covered with a plastic tarp to prevent runon to the piles. The bins will be constructed to slope from front to rear to collect rain and/or snow runoff in gutters that will carry the water to the storm sewer. Figure 3-8 provides a diagram of this system for the 50-pad facility.

Figure 3-3 shows a containment berm that is designed to prevent runon or runoff from entering the compost pad area. The area encompassed by the containment berm will have a geomembrane liner with leak detection to satisfy the RCRA requirements discussed in Subsection 2.3.


Sediment delivery (gate)
Truck wheel wash
Perimeter fence
Sediment storage area
Plastic (visqueen) sheeting
Office trailer
Mixing Pad
"RCRA" area
Compost mixture drop area
Amendment storage area (clean)
Plastic (visqueen) sheeting
Compost pads
Amendment delivery (gate)
Concrete containment berm

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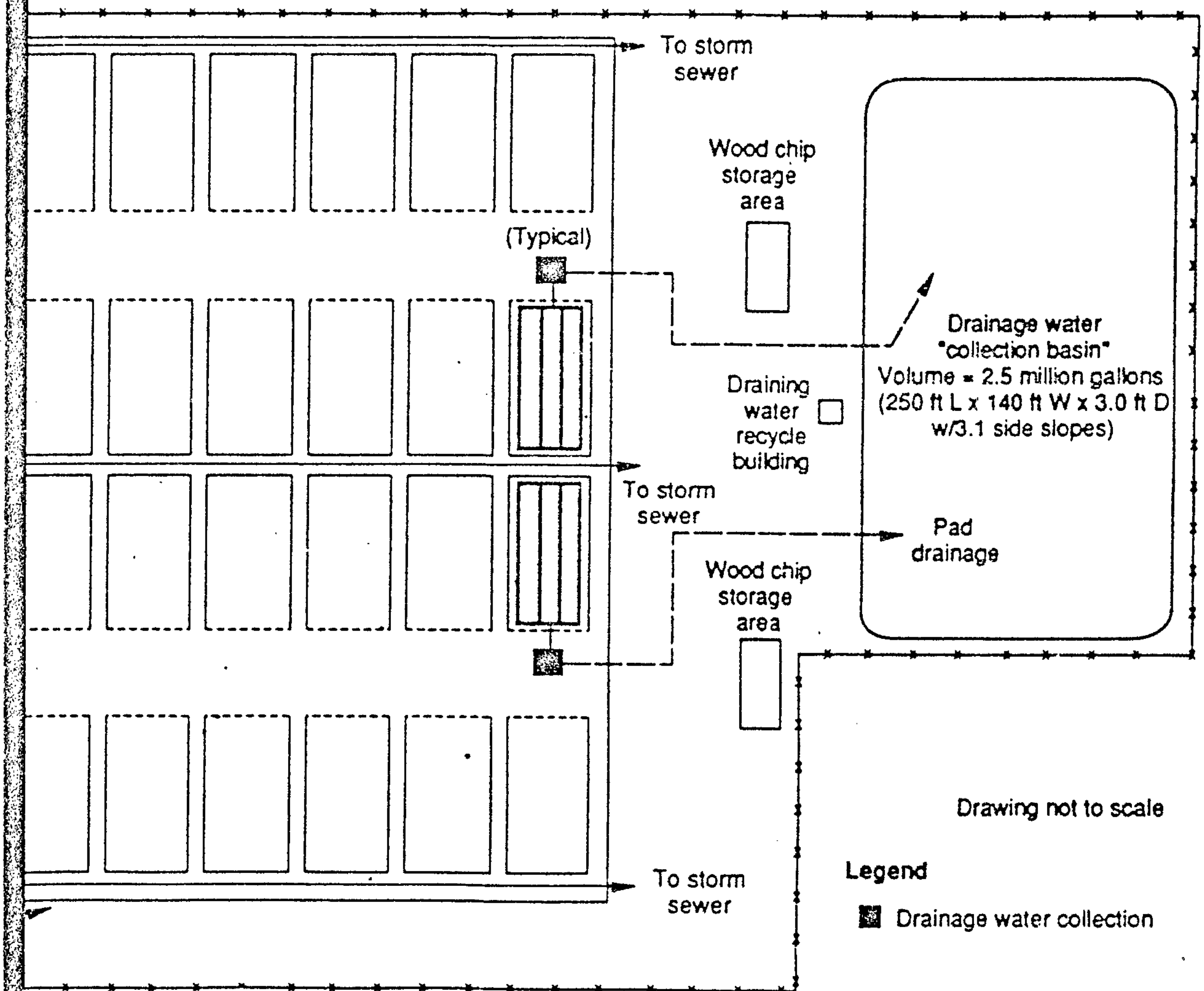

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Figure 3-8. Drainage plan for 50-pad facility

3.4.2.3 Site support facilities. The site support facilities have been minimized to reduce costs. The support facilities include an office trailer for plant personnel, a perimeter fence to maintain site security, and a portable toilet.

3.4.3 Site operation/management. The facility layout has been adopted to afford the optimum control of materials handling and composting operation. In the following subsections the compost pile operating cycle and water management plan will be presented.

3.4.3.1 Compost pile operating cycle. The compost mixture is transferred from the drop area to the pads by using a front-end loader. Once the pile has been constructed, thermocouples are placed in the pile (six per pile) to monitor compost pile temperature. By aerating the piles based on temperature, thermophilic conditions can be maintained and oxygen can be provided to the pile. Typical cycle times for blowers when composting municipal sludge are approximately 10 minutes per hour [14]. In addition to aerating the piles, water is provided through a sprinkler system to keep the piles moist.

Since remixing of the compost piles during the compost period is recommended [1], a provision to remix has been included. The remixing will be performed once (at the half way point) during the composting period. This is accomplished with two front-end loaders and the batch type mixer. The pile is broken down and dumped into the mixer by using a front-end loader. The second front-end loader then transfers the mixture from the mixer drop area to the open (adjacent) pad. The mixer has a conveyor attached (see Figure 3-6) to automatically transfer material to an adjacent area. This area next to the mixer is the above referenced drop area. Remixing of a pile is expected to take 18 hours. This includes breaking down the pile, remixing, and reconstruction. Since the compost mixer operates at a rate of 56 cubic yards per hour, it can remix the compost pile in 13.5 hours of operation. It was assumed that the front-end loaders can keep up with the mixer and will load and unload concurrently. A buffer of 4.5 hours has been assumed for lag time associated with the mixing of the material.

3.4.3.2 Water management. In order to control water runon and runoff from the site, a water management plan has been developed. Figure 3-8 illustrates a drainage plan for the 50-pad facility layout. A concrete containment berm has been provided to maintain separation between the clean and possibly contaminated areas. The berm will prevent runon and runoff to the RCRA area. Clean stormwater from the pad covers will be transferred using gutters to storm water drainage outside the berm, while any possibly contaminated water from pile watering will be collected and transferred to the collection basin through drainage piping.

3.5 Facility design and operating requirements.

3.5.1 Equipment lists. The major equipment list for the 12-pad, 50-pad, and 124-pad facilities are presented in Tables 3-6, 3-7, and 3-8, respectively. This list includes all major operating equipment required for sediment excavation, materials handling, compost mixing, compost pile construction, and compost pile monitoring and testing equipment.

These equipment lists (particularly with respect to materials handling equipment) are based upon the general approach of keeping the maximum number of pads in each site actively composting to achieve the maximum number of compost piles treated per year. Each of the materials handling phases can be evaluated in terms of this requirement. From this, the required rate of pile construction (and, where not required continuously throughout the year, the necessary construction periods) can be obtained. (Likewise, the frequency and rate of compost disposal can be estimated). Then, the excavation, transport, and mixing equipment needed to provide the necessary qualities of compost at the appropriate time can be estimated for each size facility.

3.5.2 Operating requirements.

3.5.2.1 Control parameters. The primary control parameters for aerated static pile composting are:

- Pile temperature/air addition.
- Water addition.

The temperature and oxygen (air) addition are controlled by forced aeration of the piles using blowers. An automatic temperature feedback system from thermocouples to the blower is typically operated for 10 minutes per hour. Water is added using a centrifugal pump to recycle drainage collected in the basin. Typically water is added for one hour every day. (Depending on facility location, makeup water may be required.)

3.5.2.2 Utilities requirements. The utilities required onsite for operation are:

- Makeup water for wetting piles.
- Diesel fuel for heavy equipment.
- Electric power for lighting and equipment.

3.5.2.3 Personnel. The facility labor can be categorized into plant operations personnel (plant supervisor, chemist, and shift laborer) and production personnel (equipment operators/ laborers). The production staff will require one operator for each piece of heavy equipment including the compost mixer. Each operator will be trained in the use of all equipment in order to

TABLE 3-6. MAJOR EQUIPMENT LIST FOR 12-PAD
(3,600 TONS PER YEAR) SCENARIO

Treatment System Components

1. Backhoe

Function:	To excavate sediments from lagoons or other source areas and load them into dump trucks. Also to load sediments from staging pad into the compost mixer.
Number Required:	One
Production Rate:	120 cubic yards per hour
Bucket Capacity:	One cubic yard
Type:	Caterpillar 225 backhoe or equivalent

2. Dump Truck

Function:	To transport the excavated sediments from source area to mixing area. Also, to transport treated compost from pads to fill location.
Number Required:	One
Capacity:	12 cubic yards

3. Alfalfa Tub Grinder

Function:	To shred the baled alfalfa to a size of 2 to 3 inches prior to addition to the compost mixer.
Number Required:	One
Production Rate:	15 tons per hour of alfalfa
Dimensions:	9 feet diameter by 11 feet high (typical)
Type:	Stationary; electric or equivalent

TABLE 3-6. MAJOR EQUIPMENT LIST FOR 12-PAD (3,600 TONS PER YEAR) SCENARIO (continued)

4. Front-End Loader (Amendment Materials)	
Function:	To transfer the amendment materials from the storage area into the compost mixer.
Number Required:	One
Production Rate:	65 cubic yards per hour
Bucket Capacity:	1 cubic yard
Dimensions:	A cycle time of 0.5 minute
Type:	Caterpillar 910 wheel loader or equivalent
5. Front-End Loader (Alfalfa Processing)	
Function:	To load and unload the alfalfa tub grinder.
Number Required:	One
Production Rate:	130 cubic yards per hour
Bucket Capacity:	2 cubic yards
Dimensions:	A cycle time of 0.5 minute
Type:	Caterpillar 926 wheel loader or equivalent.
6. Compost Mixer	
Function:	To thoroughly mix the amendment materials with the sediments to form the compost material.
Number Required:	One
Production Rate:	56 cubic yards per hour

TABLE 3-6. MAJOR EQUIPMENT LIST FOR 12-PAD
(3,600 TONS PER YEAR) SCENARIO
(continued)

	Capacity:	15 to 20 cubic yards per batch
	Dimensions:	24 feet long, 9 feet high, and 9 feet wide
	Type:	Batch mixer; carbon steel, diesel powered or equivalent.
7.	Front-End Loader (Compost)	
	Function:	To transfer woodchips and mixed compost to the compost pads and build the compost piles. Also to transfer compost from pads to dump trucks for disposal.
	Number Required:	One
	Production Rate:	130 cubic yards per hour
	Bucket Capacity:	2 cubic yards
	Dimensions:	A cycle time of 0.5 minutes
	Type:	Caterpillar 926 wheel loader or equivalent
8.	Compost Pile Blowers	
	Function	To provide air to the compost piles for oxygen, moisture and temperature control.
	Number Required:	12; one per pad
	Capacity:	46,900 cfm per blower at required discharge pressure.
	Type:	Centrifugal; radial-blade type, explosion proof.

TABLE 3-6. MAJOR EQUIPMENT LIST FOR 12-PAD
(3,600 TONS PER YEAR) SCENARIO
(continued)

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9. Compost Pile Water Pump

Function:	To recycle water from collection pond to the compost pile.
Number Required:	Two: one operating, one standby.
Capacity:	10 gpm at required TDH
Type:	Centrifugal; explosion proof.

10. Compost Pile Thermocouples

Function:	To monitor compost pile temperature
Number Required:	72; six per pad.
Dimensions:	6 feet long
Type:	Atkins Technical Compost Probe, model 50135-K or equivalent.

TABLE 3-7. MAJOR EQUIPMENT LIST FOR 50-PAD (16,000 TONS PER YEAR) SCENARIO

<u>Treatment System Components</u>

1. Backhoe

Function:	To excavate sediments from lagoons or other source areas and load them into dump trucks. Also to load sediments from staging pad areas into the compost mixer.
Number Required:	One
Production Rate:	120 cubic yards per hour
Bucket Capacity:	1 cubic yard
Type:	Caterpillar 225 backhoe or equivalent

2. Dump Truck

Function:	To transport the excavated sediments from source area to mixing area. Also, to transport treated compost from pads to fill location.
Number Required:	Two
Capacity:	12 cubic yards

3. Alfalfa Tub Grinder

Function:	To shred the baled alfalfa to a size of 2 to 3 inches prior to addition to the compost mixer.
Number Required:	One
Production Rate:	15 tons per hour of alfalfa
Dimensions:	9 feet diameter by 11 feet high (typical)
Type:	Stationary; electric or equivalent

TABLE 3-7. MAJOR EQUIPMENT LIST FOR 50-PAD (16,000 TONS PER YEAR) SCENARIO (continued)

4. Front End Loader (Amendment Materials)	
Function:	To transfer the amendment materials from the storage area into the compost mixer.
Number Required:	One
Production Rate:	65 cubic yards per hour
Bucket Capacity:	1 cubic yard
Dimensions:	A cycle time of 0.5 minute
Type:	Caterpillar 910 wheel loader or equivalent
5. Front End Loader (Alfalfa Processing)	
Function:	To load and unload the alfalfa tub grinder
Number Required:	One
Production Rate:	130 cubic yards per hour
Bucket Capacity:	2 cubic yards
Dimensions:	A cycle time of 0.5 minute
Type:	Caterpillar 926 wheel loader or equivalent.
6. Compost Mixer	
Function:	To thoroughly mix the amendment materials with the sediments to form the compost material.
Number Required:	Three; trailer-mounted
Production Rate:	56 cubic yards per hour
Capacity:	15 to 20 cubic yards per batch

TABLE 3-7. MAJOR EQUIPMENT LIST FOR 50-PAD (16,000 TONS PER YEAR) SCENARIO (continued)

Dimensions:	24 feet long, 9 feet high, and 9 feet wide
Type:	Batch mixer; carbon steel, diesel powered or equivalent
Bucket Capacity:	2 cubic yards
Dimensions:	A cycle time of 0.5 minute
Type:	Caterpillar 926 wheel loader or equivalent
7. Front-End Loader (Compost)	
Function:	To transfer wood chips and mixed compost to the compost pads and build the compost piles. Also to transfer compost from pads to dump trucks for disposal.
Number Required:	Three
Production Rate:	130 cubic yards per hour
Bucket Capacity:	2 cubic yards
Dimensions:	A cycle time of 0.5 minute
Type:	Caterpillar 926 wheel loader or equivalent
8. Compost Pile Blowers	
Function:	To provide air to the compost piles for oxygen, moisture, and temperature control.
Number Required:	50; one per pad
Capacity:	46,900 cfm per blower at required discharge pressure
Type:	Centrifugal; radial-blade type, explosion proof.

TABLE 3-7. MAJOR EQUIPMENT LIST FOR 50-PAD (16,000 TONS PER YEAR) SCENARIO (continued)

9. Compost Pile Water Pump

Function:	To recycle water from collection pond to the compost pile.
Number Required:	Two; one operating, one standby.
Capacity:	10 gpm at required TDH
Type:	Centrifugal; explosion proof.

10. Compost Pile Thermocouples

Function:	To monitor compost pile temperature.
Number Required:	300; six per pad.
Dimensions:	6 feet long
Type:	Atkins Technical Compost Probe, model 50135-K or equivalent.

11. Analytical Equipment

Function:	To monitor compost pile removal efficiency.
Number Required:	One High Pressure Liquid Chromatograph (HPLC); one exhaust hood

TABLE 3-8. MAJOR EQUIPMENT LIST FOR 124-PAD (40,000 TONS PER YEAR) SCENARIO

Treatment System Components

1. Backhoe

Function:	To excavate sediments from lagoons or other source areas and load them into dump trucks. Also to load sediments from staging pad into the compost mixer.
Number Required:	One
Production Rate:	120 cubic yards per hour
Bucket Capacity:	1 cubic yard
Type:	Caterpillar 225 backhoe or equivalent

2. Dump Truck

Function:	To transport the excavated sediments from source area to mixing area. Also, to transport treated compost from pads to fill location.
Number Required:	Four
Capacity:	12 cubic yards

3. Alfalfa Tub Grinder

Function:	To shred the baled alfalfa to a size of 2 to 3 inches prior to addition to the compost mixer.
Number Required:	One
Production Rate:	15 tons per hour of alfalfa
Dimensions:	9 feet diameter by 11 feet high
Type:	Stationary; electric or equivalent

TABLE 3-8. MAJOR EQUIPMENT LIST FOR 124-PAD (40,000 TONS PER YEAR) SCENARIO (continued)

4. Front-End Loader (Amendment Materials)	
Function:	To transfer the amendment materials from the storage area into the compost mixer.
Number Required:	Three
Production Rate:	65 cubic yards per hour
Bucket Capacity:	1 cubic yard
Dimensions:	A cycle time of 0.5 minute
Type:	Caterpillar 910 wheel loader or equivalent
5. Front-End Loader (Alfalfa Processing)	
Function:	To load and unload the alfalfa tub grinder.
Number Required:	Two
Production Rate:	130 cubic yards per hour
Bucket Capacity:	2 cubic yards
Dimensions:	A cycle time of 0.5 minute
Type:	Caterpillar 926 wheel loader or equivalent.
6. Compost Mixer	
Function:	To thoroughly mix the amendment materials with the sediments to form the compost material.
Number Required:	Seven, trailer-mounted
Production Rate:	56 cubic yards per hour

TABLE 3-8. MAJOR EQUIPMENT LIST FOR 124-PAD
(40,000 TONS PER YEAR) SCENARIO
(continued)

	Capacity:	15 to 20 cubic yards per batch
	Dimensions:	24 feet long, 9 feet high, and 9 feet wide
	Type:	Batch mixer; carbon steel, diesel powered or equivalent.
	Dimensions:	A cycle time of 0.5 minute.
	Type:	Caterpillar 926 wheel loader or equivalent.
7.	Front-End Loader (Compost)	
	Function:	To transfer woodchips and mixed compost to the compost pads and build the compost piles. Also, to transfer compost from pads to dump trucks for disposal.
	Number Required:	Six
	Production Rate:	130 cubic yards per hour
	Bucket Capacity:	2 cubic yards
	Dimensions:	A cycle time of 0.5 minute
	Type:	Caterpillar 926 wheel loader or equivalent.
8.	Compost Pile Blowers	
	Function	To provide air to the compost piles for oxygen, moisture and temperature control.
	Number Required:	124
	Capacity:	46,900 cfm per blower at required discharge pressure.

TABLE 3-8. MAJOR EQUIPMENT LIST FOR 124-PAD
(40,000 TONS PER YEAR) SCENARIO
(continued)

	Type:	Centrifugal; radial-blade type, explosion proof.
9.	Compost Pile Water Pump	
	Function:	To supply recycle water from collection pond to the compost pile.
	Number Required:	12: Ten operating, two standby.
	Capacity:	10 gpm at required TDH
	Type:	Centrifugal; explosion proof.
10.	Compost Pile Thermocouples	
	Function:	To monitor compost pile temperature
	Number Required:	744; six per pad.
	Dimensions:	6 feet long
	Type:	Atkins Technical Compost Probe, model 50135-K or equivalent.
11.	Analytical Equipment	
	Function:	To monitor compost pile removal efficiency.
	Number Required:	One High Pressure Liquid Chromatograph (HPLC); one exhaust hood

compensate for lag periods in certain areas. The laborers will likewise be trained in all plant areas to allow for interchanging of personnel. A laborer is assigned to each piece of heavy equipment to assist the operator. The plant operations staff will be responsible for sampling, analysis, and overall plant supervision. A full time chemist is to be used for random sample analysis and verification of compost explosives concentrations upon completion of composting the cycle.

3.5.3 Construction Requirements. The compost treatment area as assumed will require compliance with the Resource Conservation and Recovery Act (RCRA) facility design requirements including a double liner system and a drainage collection system. This will require a certain amount of site preparation work including the following items:

- Site preparation.
  - Clearing and grubbing.
  - Excavation for liner system.
  - Subgrade preparation.
  - Final site grading.
  - Seeding and mulch.
- Concrete work.
  - Concrete pads for compost piles (epoxy coated for increasing longevity).
  - Containment berm.
  - Site paving.
- Fencing.
  - 6-foot galvanized steel chainlink fence.
- Geosynthetic lining system.
  - Pads, including an 80-mL geomembrane liner, a 4-inch HDPE drainage collection pipe, and an 18-inch sand layer with a 10^{-2} transmissivity.
  - Pond, including two 80-mL geomembrane liners, 4-inch HDPE drainage collection piping, and an 18-inch sand layer with a 10^{-2} transmissivity.

3.5.4 Site closure. As with the facility design requirements actual closure requirements will depend upon regulatory requirements which cannot, at present, be fully determined.

4. ECONOMIC ANALYSIS AND SENSITIVITY

The applicability of composting as an alternative method for treatment of explosives-contaminated sediments will be determined in part by its relative cost. Although cost information is available for conventional (i.e., MSW or sludge composting) systems, economic information derived from past operating experience for explosives or other industrial composting is not available.

In this section, potential costs associated with composting of explosives-contaminated sediments are developed. These estimated costs are based upon the presently available information with respect to potential process operating parameters as developed in Section 3 of this study along with other necessary design and operating assumptions. The intent of this analysis is to evaluate the potential economic feasibility of composting explosives-contaminated sediments at the present level of process development and to identify areas in which further process development may be economically warranted.

4.1 Economic analysis - base case system.

4.1.1 Capital costs estimate.

4.1.1.1 Methodology and assumptions. Capital costs for the three conceptual aerated static pile composting systems presented in Section 3 were developed using conventional construction cost estimating procedures. Facility dimensions, materials requirements and quantities, and methods of construction (such as formwork and placement of concrete) were developed from the conceptual process development and site layouts presented in Section 3. Unit and total prices for facility construction were estimated based upon standard construction cost references. Unit prices for equipment were obtained either from standard references for conventional equipment or from vendor quotes for construction or agricultural equipment (backhoes, front-end loaders, a tub grinder, compost mixers, and dump trucks).

4.1.1.2 Geographic/site-specific assumptions. This task has developed a generalized conceptual approach to explosives-contaminated sediments composting which, by intention, should be adaptable to a variety of sites and situations. This process may have application under a wide variety of geographic, meteorological, and environmental conditions and location-specific factors may affect system costs. Such factors may include the following:

- The costs developed herein have assumed level topography for the purpose of estimating site work for construction. Due to the relatively large land area requirements inherent in the composting process, it is logical to assume that reasonably level, open areas would be selected for implementation when possible. Substantial deviations from this condition would affect cost.

- The extent of pile drainage/runoff management facilities (in particular, collect basin and the compost pile cover system) will vary widely from plants located in dry regions (such as the southwestern U.S.) to wetter regions (such as portions of the northwestern U.S. and the southeastern U.S.). For the purposes of this general facility development, the drainage collection basin assumes total capture from the RCRA area of a 6-inch rainfall event. Final sizing would depend upon site-specific meteorological data.

- Location-specific attention is warranted to such factors as wind load and frost-thaw cycles in order to verify the adequacy of the structural components of the system. These factors may also adversely affect the use of cover tarpaulins over the compost bins and may lower operating efficiencies during the winter months.

Additional assumptions upon which cost estimates were based include the following:

- The compost site is located as close as practicable to the lagoons requiring treatment to minimize hauling requirements. In this analysis, the one-way hauling distance from the lagoons to the facility was assumed to be one-eighth of a mile.

- Necessary site utilities (electric, water) are assumed to be provided to the plant. Cost for providing utilities to the site are not included.

- The facility will operate for 8 hours per day, 5 days per week or 2,080 hours per year. It was assumed that 80 hours would be deducted for holidays and/or down periods. Therefore, 2,000 hours of operations are provided for production (i.e., compost mixing, pile construction, etc.). The operation of the blowers and water pumps which are necessary during the compost pile composting phase will be monitored by a plant laborer (full-time, 24-hour, around-the-clock coverage). Site security is provided by a perimeter fence, and no security personnel are provided.

- The potential cost for permitting the facility and for delisting the finished product compost are not included in these estimates. Permitting costs may be variable. It might be noted that the cost of delisting may apply only to the first such facility operation and should not be incurred in subsequent cases.

- An allowance has been included for site closure.

In addition to capital costs, the costs of equipment delivery and contractor's markup, where appropriate, were estimated. The costs for design and engineering were estimated as a percentage of total capital cost.

4.1.1.3 Contingency. The capital costs, as presented, contain no contingency factor. A contingency factor (generally as a percentage of total capital) is conventionally added to various types of cost estimates to allow for unknown and unforeseeable factors or changes which may develop. Conceptually, the relative size of the contingency may relate to the degree of uncertainty associated with the system; under this approach new and developing processes, such as composting, would likely warrant a larger contingency than a more proven remedial process, such as incineration. At the same time, however, the inclusion of a large contingency may, to some extent, mask the promise of the process.

Costs are presented in this report without contingency in order to illustrate the potential for composting to be developed into an economically viable remedial alternative. It is important to realize that actual costs for implementation, particularly at the present state of development, involve a high level of uncertainty with regard to regulatory and technical requirements, which could result in higher costs. It is equally important to note that, to a significant extent, reduction in the magnitude of economic uncertainty will depend upon further process development and optimization.

4.1.1.4 Project financing. It has been assumed that funds for construction of remedial composting facilities would be obtained through government appropriations on a fiscal year basis. Therefore, no costs associated with project financing are included.

4.1.1.5 Results. Potential capital costs for the 12-pad (3,600 tons per year), the 50-pad (16,000 tons per year), and the 124-pad (40,000 tons per year) systems are presented in Tables 4-1, 4-2, and 4-3, respectively. Within the constraints discussed above with respect to both process parameters and construction-related variables, the capital costs have been estimated at $3,459,000, $9,554,000, and $21,247,000, respectively.

TABLE 4-1. POTENTIAL CAPITAL COSTS FOR 12-PAD (3,600 TONS PER YEAR) SYSTEM*

Equipment	$ 744,000
Equipment Installation Labor	43,000
Piping	403,000
Electrical	212,000
Concrete	731,000
Buildings	136,000
Site Work	543,000
Subtotal Capital	$ 2,812,000
7% Contractor's Markup	197,000
Total Capital	$ 3,009,000
Design at 5% Total Capital	150,000
Site Closure Costs	300,000
Total Capital Cost Estimate	$ 3,459,000

*The 12-pad case represents a 10 percent by volume sediment mixture following TNT kinetics (90 days per pile) resulting in 82 tons of sediment per pile or 3,600 tons of sediment treated per year.

TABLE 4-2. POTENTIAL CAPITAL COSTS FOR 50-PAD (16,000 TONS PER YEAR) SYSTEM*

Equipment	$ 1,635,000
Equipment Installation Labor	134,000
Piping	574,000
Electrical	632,000
Concrete	2,649,000
Buildings	533,000
Site Work	1,308,000
Subtotal Capital	$ 7,465,000
7% Contractor's Markup	523,000
Total Capital	$ 7,988,000
Design at 5% Total Capital	399,000
Site Closure Costs	1,167,000
Total Capital Cost Estimate	$ 9,554,000

*The 50-pad case represents a 10 percent by volume sediment mixture following TNT kinetics (90 days per pile) resulting in 82 tons of sediment per pile or 16,000 tons of sediment treated per year.

TABLE 4-3. POTENTIAL CAPITAL COSTS FOR 124-PAD (40,000 TONS PER YEAR) SYSTEM*

Equipment	$ 3,299,000
Equipment Installation Labor	295,000
Piping	1,252,000
Electrical	1,467,000
Concrete	6,240,000
Buildings	1,306,000
Site Work	2,789,000
Subtotal Capital	$ 16,648,000
7% Contractor's Markup	1,165,000
Total Capital	$ 17,813,000
Design at 5% Total Capital	891,000
Site Closure Costs	2,543,000
Total Capital Cost Estimate	$ 21,247,000

*The 124-pad case represents a 10 percent by volume sediment mixture following TNT kinetics (90 days per pile) resulting in 82 tons of sediment per pile or 40,000 tons of sediment created per year.

The net effect of capital cost on the final cost of remediation will depend upon the amount of material treated in the system, which is, in turn, related to the amount of the sediment in each pile, the length of the required composting period, and the length of the time the facility operates. The first two of these variables will be discussed in Subsection 4.2.2.

4.1.2 O&M cost estimate.

4.1.2.1 Methodology and assumptions. Estimates of potential operations and maintenance (O&M) costs were developed based upon the conceptual layouts presented in Section 3. The following presents the basic procedure used in developing this estimate.

The potential materials requirements and materials handling requirements were estimated from the process description in Section 3. These were used to develop equipment (capital) requirements presented above. For O&M costs, productivity rates (e.g., quantities of materials handled per hour) and fuel consumption rates were obtained from equipment vendor sources or published data [16] and used to estimate total operational hours and fuel for such activities as compost pile construction (mixing, grinding, pile stacking), remixing, and dismantling. As noted in Section 3.3.1.3, estimates of actual production rates, based upon theoretical rates, were used. Manpower requirements for these activities, including equipment operators and laborers, were estimated. From these estimates, annual operating costs associated with compost production were estimated, using the unit costs presented in Table 4-4.

The total cost of raw materials (alfalfa, straw/manure, wood chips) was estimated based upon quantities presented in Section 3. Unit costs for these materials, presented in Table 4-2, were obtained from vendor sources or current agricultural publications/periodicals in the Mid-Atlantic (Pennsylvania) area. These values generally represent minimal prices in this market for these materials, as of the spring of 1989.

Power costs for the compost aeration system were developed by assuming that the blowers operate for, on average, 10 minutes of every hour the compost pad is in operation (based upon municipal sludge composting experience) [14].

It was assumed that finished compost would be disposed of onsite (both back in the former settling lagoons and as a soil amendment or fill on plant property) so that no cost for disposal (e.g., landfilling) is incurred. It should be recognized that if offsite disposal (e.g., landfilling) after treatment is required, the economic viability of this process would be impaired, particularly since the total volume of

TABLE 4-4. OPERATING AND MAINTENANCE UNIT COSTS

Labor	
• Equipment Operators/Chemist	$18/hour
• Laborers	$12/hour
• Supervisor	$20/hour
Electric	$0.07/kwh
Diesel Fuel	$1.10/gallon
Alfalfa	$60/ton
Straw/Manure Mixture	$ 3/cy
Wood Chips	$10.75/cy

material requiring offsite transportation and disposal will be greater than the original volume of contaminated sediment. It is therefore assumed that the finished compost product will be delisted and used onsite.

In addition to costs directly associated with construction and manipulation of the compost piles, additional site support operating costs were estimated, including general operating personnel (one operator/maintenance man per shift), laboratory personnel (one chemist for facilities with onsite analytical capability for 50 and 124-pad systems), and general facility utilities (e.g., yard lighting).

The total labor requirement for each facility derived from the above methodology is presented in Table 4-5.

Maintenance was estimated at three percent of total capital cost. This cost for maintenance represents the scheduled preventive maintenance on all equipment (i.e., oil change, fluids check) and other routine activities (equipment painting, servicing, calibration) required to maintain full scale operation of the facility equipment. The remedial project length assumed in these analyses was 5 years. The useful life of the fixed facility would likely be significantly longer than 5 years, but the cleanup time allotted for remediation will likely be no longer than 5 years. Replacement of equipment during the 5-year operating life is not considered. At the same time, however, no salvage value was assumed for equipment at project closeout. It might be noted that reuse of equipment at other sites may be possible and that such reuse will result in cost savings.

The annual operating and maintenance costs were projected over the potential remedial period of 5 years. O&M costs over this period were inflated at 5 percent per year. O&M costs were converted to present worth assuming 8 percent annual interest, and assuming 2 years for design and startup, followed by 5 years of operation.

As with the capital costs, operating and maintenance costs are presented without contingency. The comments presented in Subsection 4.1.1.3 concerning contingency apply.

4.1.2.2 Results. The estimated potential operating and maintenance costs for the 12-pad, 50-pad, and 124-pad systems described herein are presented in Tables 4-6, 4-7, and 4-8, respectively. Annual first-year O&M costs for the 12-pad, 50-pad, and 124-pad systems were estimated at $600,000, $1,764,000, and $3,992,000 with 5-year present worth values of $2,608,000, $7,667,000, and $17,351,000, respectively.

TABLE 4-5. TOTAL LABOR REQUIREMENT FOR EXPLOSIVES COMPOSTING FACILITY LABOR (MAN-YEAR[a])

	12 pad (3,600 tpy)	50 pad (16,000 tpy)	124 pad (40,000 tpy)
Equipment Operators	2	3	19
Chemist	0[b]	1	1
Production Laborers	4	5	21
Supervisor	1	1	1
Site Support (Laborers)	4	4	4

[a]One man year = 2,000 hours.
[b]Analysis contracted offsite for this case.

TABLE 4-6. POTENTIAL OPERATIONS AND MAINTENANCE COSTS FOR 12-PAD (3,600 TONS OF SEDIMENT PER YEAR) SYSTEM

I. Constant Costs	
A. Power for Blowers/Pumps (394,124 kwh/yr at $0.07/kwh)	$ 28,000
B. Site Support Laborers (4 laborers at $12/hr for 2,080 hrs/yr)	100,000
II. Variable Costs	
A. Lighting (39,946 kwh/yr at $0.07/kwh)	3,000
B. Amendments (1,622 tons/yr at $50/ton)	81,000
C. Wood Chips ($955/pile for 44 piles/yr)	42,000
D. Power for Tub Grinder ($6.40/pile for 44 piles/yr)	1,000
E. Diesel Fuel (26,228 gal/yr at $1.10/gal)	29,000
F. Production Labor (Compost Mixing/ Pile Construction, See Table 4-5)	216,000
G. Analytical Labor (Offsite sample analysis)*	10,000
H. Maintenance at 3% of Total Capital	90,000
Total Annual O&M	$600,000

*For the 12-pad case the offsite analytical cost of $225 per sample for HPLC analysis [17] results in a lower annual cost than does the cost for a full chemist's salary ($37,000 per annum) and the HPLC equipment ($55,000). Therefore, for this case the offsite analysis was selected.

TABLE 4-7. POTENTIAL OPERATIONS AND MAINTENANCE COSTS FOR 50-PAD (16,000 TONS OF SEDIMENT PER YEAR) SYSTEM

I.	Constant Costs	
A.	Power for Blowers/Pumps (1,602,624 kwh/yr at $0.07/kwh)	$ 112,000
B.	Site Support Laborers (4 laborers at $12/hr for 2,080 hrs/yr)	100,000
II.	Variable Costs	
A.	Lighting (95,396 kwh/yr at $0.07/kwh)	7,000
B.	Amendments(7,226 tons/yr at $50/ton)	361.000
C.	Wood Chips ($955/pile for 196 piles/yr)	187,000
D.	Power for Tub Grinder ($6.40/pile for 196 piles/yr)	1,000
E.	Diesel Fuel (116,716 gal/yr at $1.10/gal)	128,000
F.	Production Labor (Compost Mixing/ Pile Construction see Table 4-5)	591,000
G.	Analytical Labor (Chemist)*	37,000
H.	Maintenance at 3% of Total Capital	240,000
Total Annual O&M		$1,764,000

*For the 50-pad case the onsite analysis cost for a full-time chemist and analytical equipment is approximately equal to the offsite cost. Therefore, for convenience purposes of having the laboratory onsite this option was chosen.

TABLE 4-8. POTENTIAL OPERATIONS AND MAINTENANCE COSTS FOR 124-PAD (40,000 TONS OF SEDIMENT PER YEAR) SYSTEM

I. Constant Costs	
A. Power for Blowers/Pumps (3,995,674 kwh/yr at $0.07/kwh)	$ 280,000
B. Site Support Laborers (4 laborers at $12/hr for 2,080 hrs/yr)	100,000
II. Variable Costs	
A. Lighting (176,602 kwh/yr at $0.07/kwh)	12,000
B. Amendments(17,990 tons/yr at $50/ton)	900,000
C. Wood Chips ($955/pile for 488 pile/yr)	466,000
D. Power for Tub Grinder ($6.4/pile)(488 piles/yr)	3,000
E. Diesel Fuel (290,634 gal/yr at $1.1/gal)	320,000
F. Production Labor (Compost Mixing/ Pile Construction see Table 4-5)	1,340,000
G. Analytical Labor (Chemist)*	37,000
H. Maintenance at 3% of Total Capital	534,000
Total Annual O&M	$3,992,000

*For the 124-pad case the onsite analysis costs for a full-time chemist and analytical equipment is less than the cost of offsite analysis.

4.1.3 Total project cost. The total project cost for the 12-pad, 50-pad, and 124-pad facilities, including construction, operation for 5 years and closeout, are estimated at $6,067,000, $17,221,000, and $38,598,000 as shown in Tables 4-9, 4-10, and 4-11, respectively. If operated for 5 years the total mass of contaminated sediment treated (at 10 percent sediment by volume) would be approximately 18,000 tons, 80,000 tons, and 200,000 tons for the 12-pad, 50-pad, and 124-pad systems with net costs per ton of sediment treated of $337, $215, and $193, respectively.

The net cost for any given remedial project of fixed size would depend to a significant extent upon the total quantity of sediment requiring treatment, particularly since a significant initial (capital) costs investment is required. The basic system described herein was developed essentially in modular fashion so that a variable number of compost pads could, theoretically, be constructed to help match throughput capacity with site-specific needs. Factors likely to affect throughput capacity and, therefore, total project cost are considered in the next subsection.

Cost curves were developed for the capital costs, operations and maintenance (O&M) costs, and total project costs from the cost analysis performed on the 12-pad, 50-pad, and 124-pad facilities (Figure 4-1). These curves represent the estimated costs in thousands of dollars as a function of system throughput in tons treated over a 5-year operating life. It must be noted that these curves were developed for use when comparing alternative treatment methods to composting. An estimated cost could be obtained from the curves for comparison. However, for a more accurate cost comparison the facility should be analyzed by a detailed method.

Although the total cost of the treatment facility naturally increases with the size of the facility, the net unit cost (per ton of sediment treated) decreases with increasing system size, as demonstrated in Tables 4-9, 4-10, and 4-11. This effect is illustrated in Figure 4-2 in terms of capital, O&M, and total cost components for the three conceptual treatment systems developed herein. Thus, some economy in net processing cost should be achieved in larger facilities so long as, of course the quantity of sediment requiring treatment is sufficiently large to make effective use of the larger facility through the permissible remedial period. For remediation of any given quantity of contaminated sediment, the optimal economic approach would be based upon minimizing total project cost, consistent with the length of the remediation period.

As presently developed, and illustrated in Figure 4-1, the cost components for the compost facility increase in essentially

TABLE 4-9. TOTAL PROJECT COST FOR 12-PAD (3,600 TONS OF SEDIMENT PER YEAR) SYSTEM

I. Capital Costs	
Equipment	$ 744,000
Equipment Installation Labor	43,000
Piping	403,000
Electrical	212,000
Concrete	731,000
Buildings	136,000
Site Work	543,000
Subtotal Capital	$ 2,812,000
7% Contractor's Markup	197,000
Total Capital	$ 3,009,000
Design at 5% Total Capital	150,000
Site Closure	300,000
Total Capital Cost Estimate	$ 3,459,000
II. Operations and Maintenance (O&M)	
A. Constant Costs	
1. Power for Blowers/Pumps	$ 28,000
2. Operator's Labor	100,000
B. Variable Costs	
1. Lighting	3,000
2. Amendments	81,000
3. Wood Chips	42,000
4. Power for Tub Grinder	1,000
5. Diesel Fuel	29,000
6. Production Labor (Compost Mixing/Pile Construction)	216,000
7. Analytical Labor (Offsite Sample Analysis)	10,000
8. Maintenance at 3% of Total Capital	90,000
Total Annual O&M	$ 600,000
5 Year Present Worth O&M	$ 2,608,000
Total 5 Year Project Cost	$ 6,067,000
5 Year Tons of Sediment Treated	18,000
Cost Per Ton of Sediment	$ 337

TABLE 4-10. TOTAL PROJECT COST FOR 50-PAD (16,000 TONS OF SEDIMENT PER YEAR) SYSTEM

I. Capital Costs	
Equipment	$ 1,635,000
Equipment Installation Labor	134,000
Piping	574,000
Electrical	632,000
Concrete	2,649,000
Buildings	533,000
Site Work	1,308,000
Subtotal Capital	$ 7,465,000
7% Contractor's Markup	523,000
Total Capital	$ 7,988,000
Design at 5% Total Capital	399,000
Site Closure	1,167,000
Total Capital Cost Estimate	$ 9,554,000
II. Operations and Maintenance (O&M)	
A. Constant Costs	
1. Power for Blowers/Pumps	$ 112,000
2. Operator's Labor	100,000
B. Variable Costs	
1. Lighting	7,000
2. Amendments	361,000
3. Wood Chips	187,000
4. Power for Tub Grinder	1,000
5. Diesel Fuel	128,000
6. Production Labor (Compost Mixing/Pile Construction)	591,000
7. Analytical Labor (Chemist)	37,000
8. Maintenance at 3% of Total Capital	240,000
Total Annual O&M	$ 1,764,000
5 Year Present Worth O&M	$ 7,667,000
Total 5 Year Project Cost	$17,221,000
5 Year Tons of Sediment Treated	80,000
Cost Per Ton of Sediment	$ 215

TABLE 4-11. TOTAL PROJECT COST FOR 124-PAD (40,000 TONS OF SEDIMENT PER YEAR) SYSTEM

I. Capital Costs	
Equipment	$ 3,299,000
Equipment Installation Labor	295,000
Piping	1,252,000
Electrical	1,467,000
Concrete	6,240,000
Buildings	1,306,000
Site Work	2,789,000
Subtotal Capital	$ 16,648,000
7% Contractor's Markup	2,543,000
Total Capital	$ 17,813,000
Design at 5% Total Capital	891,000
Site Closure	2,543,000
Total Capital Cost Estimate	$ 21,247,000
II. Operations and Maintenance (O&M)	
A. Constant Costs	
1. Power for Blowers/Pumps	$ 280,000
2. Operator's Labor	100,000
B. Variable Costs	
1. Lighting	12,000
2. Amendments	900,000
3. Wood Chips	466,000
4. Power for Tub Grinder	3,000
5. Diesel Fuel	320,000
6. Production Labor (Compost Mixing/Pile Construction)	1,340,000
7. Analytical Labor (Chemist)	37,000
8. Maintenance at 3% of Total Capital	534,000
Total Annual O&M	$ 3,992,000
5 Year Present Worth O&M	$ 17,351,000
Total 5 Year Project Cost	$ 38,598,000
5 Year Tons of Sediment Treated	$ 200,000
Cost Per Ton of Sediment	$ 193

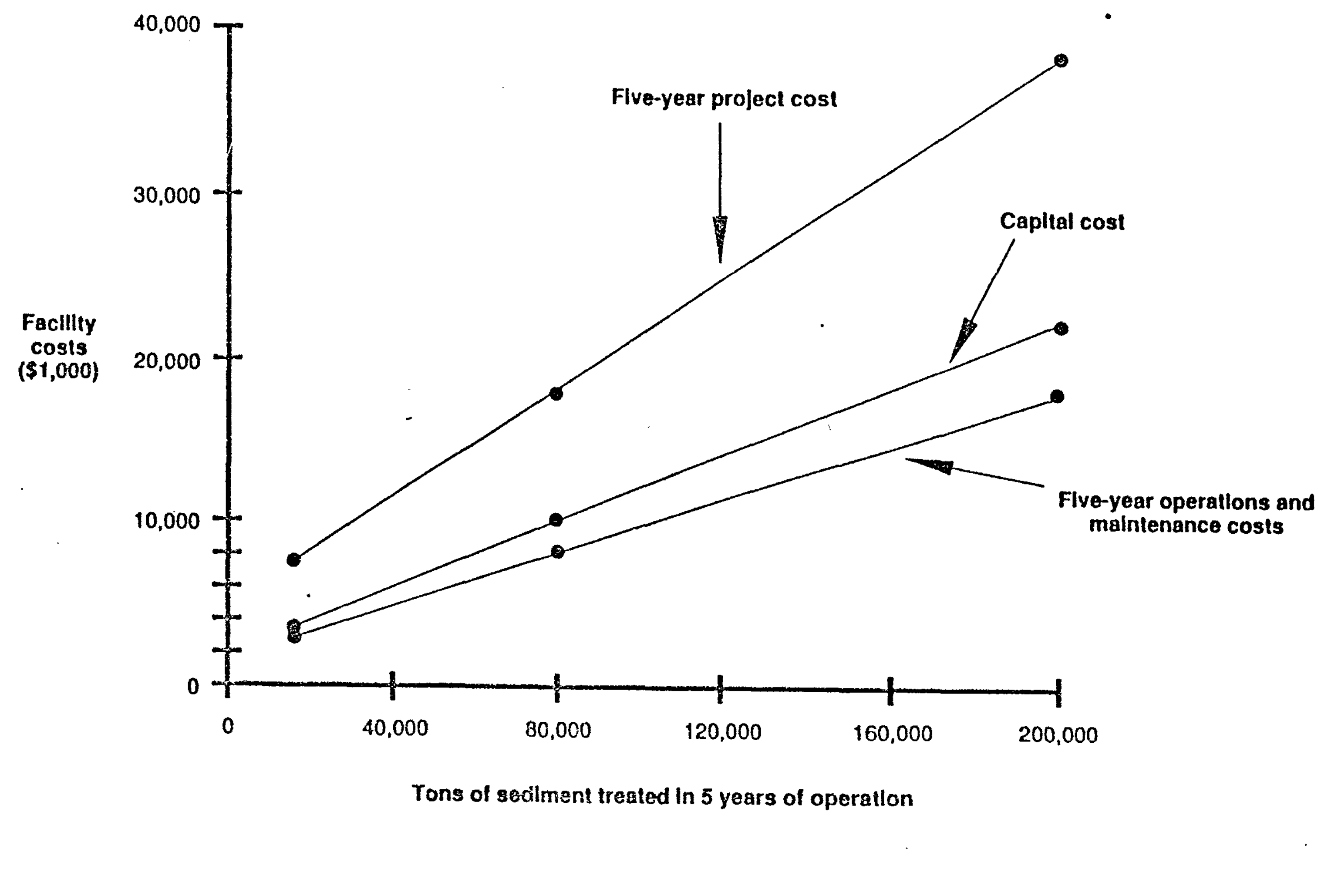

Figure 4-1. Facility costs as a function of 5 year tons of sediment treated.

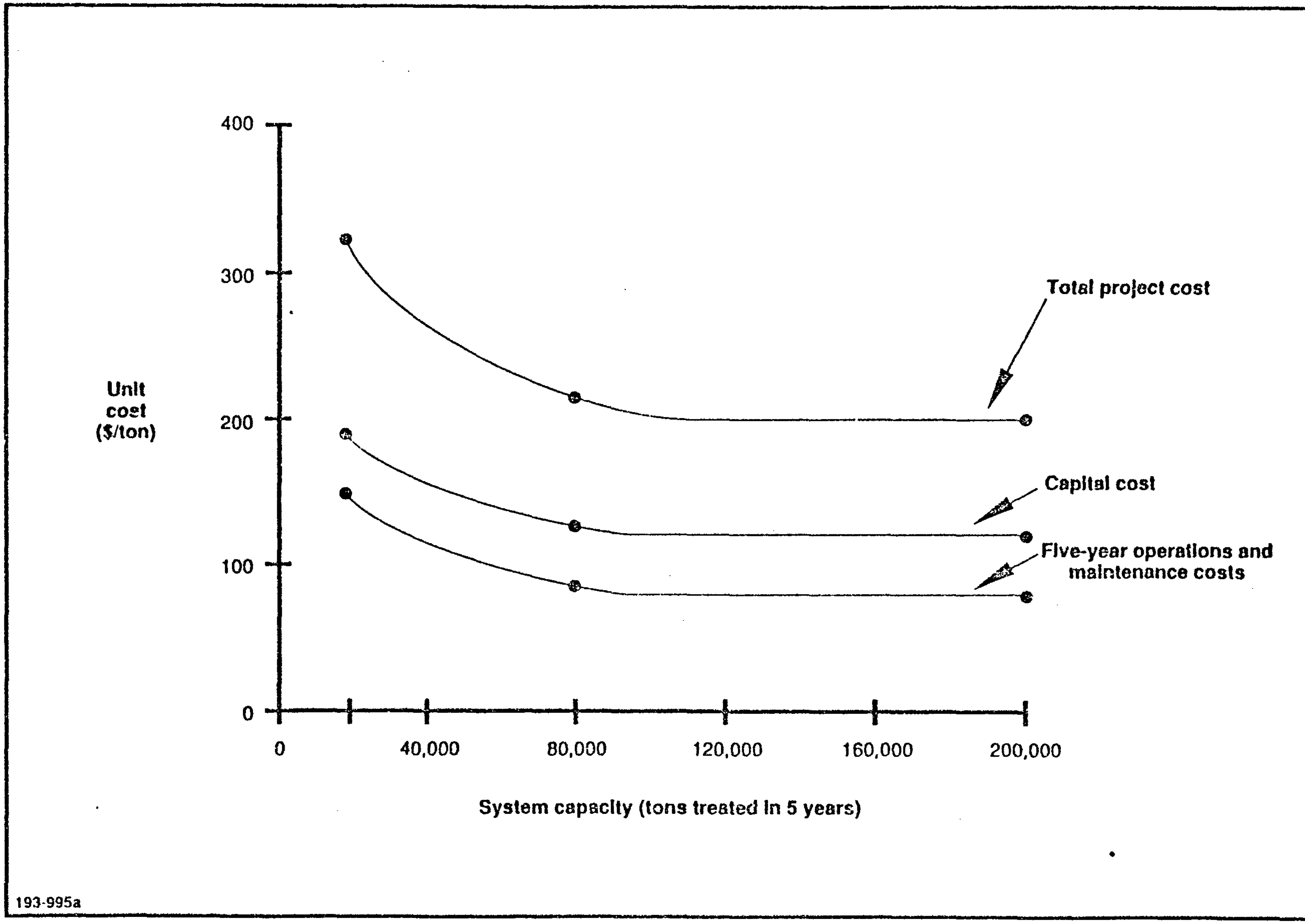

Figure 4-2. The effects of facility size on unit cost per ton of sediment treated.

linear fashion with increasing system size. The apparent rate of cost increase indicates that, for example, doubling system size does not result in a doubling of cost, and as illustrated in Figure 4-2, economy in the net processing cost is achieved. It might also be expected that, with further refinement of process parameters and economic information, relative economy of scale in direct costs will also be observed, resulting in a nonlinear (decreasing) rate of increase in total cost with project size.

4.2 Sensitivity considerations. For any given remedial project, the minimum economic approach would likely depend upon both minimizing the capital and O&M costs themselves and maximizing the total quantity of materials treated for those investments. The key to the first of these would be to build and operate in the least expensive manner consistent with performance criteria and regulatory requirements. The key to the second is to maximize throughput of whatever system is built. These issues are addressed in the following subsections. For the sake of simplicity, the effect of various assumptions and parameters on process economics is presented using the intermediate size (50 pad) facility as the illustrative example.

4.2.1 Minimal capital investment. The conceptual composting system as presented herein is intended to approximate a relatively minimal capital investment system (under the stated assumptions with respect to process parameters and regulatory requirements), and as such represents the results of several rounds of refinements. The minimal capital investment system is partly driven by the short remedial period (as compared to the potential useful operating life of the facility) and the minimal salvage potential obtained from the equipment. However, this system will require additional operator attention and may raise issues from a regulatory standpoint (see Subsection 2.3). Other site-specific physical or climatological conditions may favor or require more capital features for the composting system. Therefore, several additional capital items that may be considered on a case-by-case basis are discussed here.

Capital items that may be considered on a case-by-base basis include the following:

- Fixed structures over the compost pad area may be considered to provide control of runon and runoff in lieu of the tarpaulin system. A wide range of options exists which could warrant further investigation, including the following: 1) tent type structures, which require minimal foundation and can possibly be reused at other sites facilities; 2) greenhouse type structures, which may provide additional heat for the compost piles; and (3) pre-engineered (metal) buildings.

Both individual buildings over each pad and a shed roof over the entire composting area may be considered. Inclusion of these structures would involve not only the cost of the buildings themselves, but also the cost of building foundations. As presently envisioned, a tarp system would be devised to provide runoff control. Since the composting process itself is basically water consumptive, it may be feasible to eliminate covers altogether in dry regions. The site-specific approach to water management would be based upon a water balance for the specific meteorological conditions pertinent to the site.

- Conveyor systems may be considered for materials handling, particularly within the actual composting area. Once again, several possible arrangements may be considered, including conveyors transporting the compost mixtures to each pad automatically. The cost, complexity, and maintenance requirements of such systems would be weighted against their potential for increasing system throughput and decreasing operating labor. The system used in this analysis utilized heavy equipment and manual labor for materials handling.

- Site support structures for personnel (in lieu of rental trailers), and structures to house mixing equipment may be considered. Such structures would likely take the form of pre-engineered buildings, although tent-type structures may be useful for protection from precipitation. Housing of the mixing equipment may be advantageous to improve runoff control and control noise or dust. For example, in high rainfall areas a fixed structure enclosing the compost mixer would prevent rainwater from entering the mixer. In the present analysis, a trailer is used for site support facilities and tarps are used to cover the mixing equipment.

- The compost pad aeration system has been simplified in this analysis. In a preliminary layout, each pad had six small blowers and a more complex air distribution network with fixed (PVC) aeration piping. In the revised layout, a single blower with ductwork is assumed, with a less extensive distribution network (less trenching), using flexible tubing for air distribution. It must be recognized that selection of the air distribution system represents a compromise between cost and complexity on the one hand and the requisite degree of homogenity and process control on the other.

The preliminary capital cost for a 50-pad site with no contingency incorporating the more extensive capital facilities noted above ranged as high as $12,893,000. Thus, the net capital cost reduction attributable to the above-rated changes was approximately 26 percent, to the present estimate of $9,554,000. It should be recognized that the possible need (if any) for capital items should be evaluated on a case-by-case basis.

Several other system variations or modifications were also considered for their potential cost savings. However, these were, for reasons provided below, not incorporated into the system discussed herein. These variations included the following:

- Elimination of the RCRA liner under the compost area. Although cost savings could be achieved, this RCRA liner has been retained at present since the compost pile may be classified as a waste pile (Subsection 2.3).

- Elimination of wooden walls (bins) between compost pads. The capital savings associated with this step were estimated to be relatively small. While the wooden bins may, to some extent, complicate remixing of the pile, they may also contribute to controlling airflow and maintaining homogenity. In addition, the bins allow for the construction of a larger compost pad, since in their absence the pile configuration would be trapezoidal in cross section.

- Elimination of aeration trenches under the compost pads. In this approach, flexible aeration tubing would be placed in the compost pile itself. This is common practice in municipal sludge composting. Elimination of trenches would result in significant capital cost savings in terms of concrete formwork and trench frames and covers. It should be noted, however, that when used in this fashion in municipal composting plants, flexible tubing is essentially a disposable item since it is generally damaged in dismantling the pile. While its low unit cost may still make it attractive, particularly for short-term projects, disposal of the used tubing may pose a problem. This tubing may be considered a RCRA hazardous waste unless it can be decontaminated. While there is apparently some interest in recycling the tubing used at municipal waste compost facilities, decontamination of the tubing would be required, at a cost to the facility. Otherwise, alternative disposal may be necessary (e.g., commercial RCRA or sanitary landfilling). Because of the uncertainty associated with disposal of the tubing, this option has not been included in the final facility cost estimate.

4.2.2 Sediment ratio and amendment mixture. The compost process is, to a significant extent, a materials handling operation, and costs are determined in part by the total volume of material to be handled. For this reason, one obvious key to optimizing economics would involve maximizing the proportion of contaminated sediment present in the compost mixture.

The most recent field demonstration studies have been conducted at a volumetric sediment ratio of 3 percent. Based upon available literature, the base case analysis presented in this study has assumed a 10 percent volumetric mixture.

In this section, the potential economics of composting at significantly higher sediment ratios is considered. The technical viability of the process under such conditions will require verification.

In this analysis, the volumetric sediment fraction in the standard pile was varied from 3 percent to 40 percent. The remaining volume of the pile was made up of the "standard" amendment mixture containing 48 percent alfalfa and 52 percent straw/manure by volume. By calculation, this range of variation would alter the density of the resulting compost mixture from approximately 180 lb/cy (at 3 percent) to 990 lb/cy (at 40 percent). Therefore, the density at 40 percent sediment is roughly comparable to the density of sewage sludge compost. Furthermore, the LAAP field demonstration indicated that compost piles containing as much as 39 percent contaminated sediment by volume may be able to achieve near-thermophilic temperatures (48 to 51°C) although their ability to maintain such temperatures is uncertain.

Only the relative proportions of sediment and amendment mixture were altered. The standard woodchip base was used for all piles. It is assumed, for simplicity, that the bulk of the capital costs were relatively unaffected by alteration in sediment fraction over this range, as long as the total number of compost pads and volumes of each pile were unchanged. It should be noted that, at some sufficiently large change in composition, resizing of various materials storage and handling facilities would be necessary. The resulting pile composition is tabulated in Table 4-12.

It is also assumed that many operating costs, other than raw materials, were essentially unaffected by changes over this range. It is likely that, at some sufficiently large change in compost composition, the aeration operating cycle and remixing requirements may possibly change (see Section 3). As compost mixture density increases, blower power requirements for achieving a given airflow rate through the mixture may increase.

TABLE 4-12. EFFECT OF SEDIMENT FRACTION ON COMPOST PILE COMPOSTION

Volume Mixture		Volumetric Composition[1]		Mass Composition[2]		Net Compost Density	
Sediment %	AH[3] %	Sediment (yd^3/Pile)	AH (yd^3/Pile)	Sediment (Tons/Pile)	AH (Tons/Pile)	(lb/yd^3)	($Tons/yd^3$)
3	97	21	690	24	40	180	0.090
7	93	50	611	58	38	270	0.135
10	90	71	640	82	37	335	0.167
20	80	142	569	163	33	551	0.276
30	70	213	498	245	29	771	0.385
40	60	284	427	327	25	990	0.495

[1] Assumes 711 yd3/pile.
[2] Sediment density = 2,300 lb/yd3; amendment mixture (AH) density = 115 lb/yd3.
[3] Amendment mixture (alfalfa and straw/manure).

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At the same time, however, the increasing soil fraction may result in a lower total temperature rise and correspondingly lower required airflow for heat removal. There is not, at present, sufficient information on these variables to support detailed analysis. It should, however be noted that the maximum density used in these analyses (990 lb/cy at 40 percent sediment) was equal to or less than that of municipal sludge compost. Therefore, the use of municipal sludge operating parameters should not be a gross underestimation of power cost for aeration.

Finally, it is assumed that process kinetics were essentially unchanged by variation in sediment fraction over this range. This is a significant assumption and subject to verification. It is important to recognize that, from the standpoint of economics, the net throughput of the system per unit time is a function of both sediment fraction in the mixture andth: rate of degradation, and that if a large increase in sediment fraction can be achieved without a proportionally large decrease in kinetics, overall throughput can be increased. For all previously discussed analyses the compost period was assumed to be that of TNT (90 days). Further consideration of effects of variable kinetics on the cost per ton of sediment are presented in Subsection 4.2.3.

The results of this analysis for various sediment fractions and TNT kinetics are shown in Table 4-13. Two effects on net cost per ton of sediment are immediately apparent. First, decreasing the amount of amendment in the mixture (see also Table 4-12) results in a savings in annual raw materials costs and thus in total operating costs. More significantly, the sediment throughput rate of the system increases dramatically, and net cost per ton of sediment is concommitantly reduced.

It should also be noted that the above evaluation is based upon estimates of minimum current prices for specific amendment materials previously used in the field demonstration. It has not been definitely established that these are the only suitable amendment materials. Furthermore, their prices may be subject to fluctuation. Other potentially useful amendment materials should be identified and evaluated.

4.2.3 Process kinetics/compost period. In this subsection the potential effects of altering the length of the required compost period on net costs of the process are considered. While one obvious factor which would result in such a change would be a change (hopefully, an increase) in process kinetics as a result of some alteration in process parameters, two other factors, both related to as yet undefined performance or regulatory criteria, may result in such a change. The first of

TABLE 4-13. AERATED STATIC PILE COMPOSTING WITH TNT KINETICS FOR A 50-PAD OPTION AND VARIABLE SEDIMENT FRACTION WITH NO CONTINGENCY

Sediment Fraction, Volume %	3	7	10	20	30	40
Compost Period, Days	90	90	90	90	90	90
Piles per Year	196	196	196	196	196	196
Tons Treated per Year	4,802	11,218	16,033	32,066	48,079	64,112
Tons Amendments	7,781	7,468	7,232	6,429	5,625	4,822
I. Capital Costs						
Equipment	$1,635,000	$1,635,000	$1,635,000	$1,635,000	$1,635,000	$1,635,000
Equipment Installation Labor	134,000	134,000	134,000	134,000	134,000	134,000
Piping	574,000	574,000	574,000	574,000	574,000	574,000
Electrical	632,000	632,000	632,000	632,000	632,000	632,000
Concrete	2,649,000	2,649,000	2,649,000	2,649,000	2,649,000	2,649,000
Buildings	533,000	533,000	533,000	533,000	533,000	533,000
Site Work	1,308,000	1,308,000	1,308,000	1,308,000	1,308,000	1,308,000
Subtotal Capital	$7,465,000	$7,465,000	$7,465,000	$7,465,000	$7,465,000	$7,465,000
7% Contractor's Markup	523,000	523,000	523,000	523,000	523,000	523,000
Total Capital	$7,988,000	$7,988,000	$7,988,000	$7,988,000	$7,988,000	$7,988,000
Design at 5% Total Capital	399,000	399,000	399,000	399,000	399,000	399,000
Site Closure	1,167,000	1,167,000	1,167,000	1,167,000	1,167,000	1,167,000
Total Capital Cost Estimate	$9,554,000	$9,554,000	$9,554,000	$9,554,000	$9,554,000	$9,554,000
II. Operations & Maintenance (O&M)						
A. Constant Costs						
1. Power for Blowers/Pumps	$ 112,000	$ 112,000	$ 112,000	$ 112,000	$ 112,000	$ 112,000
2. Site Support Laborers	100,000	100,000	100,000	100,000	100,000	100,000
B. Variable Costs						
1. Lighting	7,000	7,000	7,000	7,000	7,000	7,000
2. Amendments	389,000	373,000	361,000	321,000	281,000	241,000
3. Woodchips	187,000	187,000	[illegible]	187,000	187,000	187,000
4. Power for Tub Grinder	1,000	1,000	1,000	1,000	1,000	1,000
5. Diesel Fuel	126,000	127,000	128,000	132,000	135,000	139,000
6. Production Labor	591,000	591,000	591,000	591,000	591,000	591,000
7. Analytical Labor (Chemist)	37,000	37,000	37,000	37,000	37,000	37,000
8. Maintenance at 3% of Total Capital	240,000	240,000	240,000	240,000	240,000	240,000
Total Annual O&M	$1,790,000	$1,775,000	$1,764,000	$1,728,000	$1,691,000	$1,655,000
5 Year Present Worth O&M	$7,780,000	$7,715,000	$7,667,000	$7,511,000	$7,350,000	$7,193,000
Total 5 Year Project Cost	$17,334,000	$17,269,000	$17,221,000	$17,065,000	$16,904,000	$16,747,000
5 Year Tons of Sediment Treated	24,000	56,000	80,000	160,000	240,000	321,000
Cost per Ton of Sediment	$ 722	$ 308	$ 215	$ 107	$ 70	$ 52

Note: Totals rounded to nearest $1,000.

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these would be the determination that, in a given situation, the less amenable contaminants, such as HMX, would not be present at levels requiring treatment. While the base case analyses assumed that the compost period is dictated by TNT kinetics (90 days for 99.5 percent removal), the lowest degradation rate of the four contaminants studied (HMX) is presented in this analysis for comparison (see Tables 4-14 and 4-15).

The second potential change in performance criteria would be the determination that, in a given situation, a lower percentage conversion would be required, either because initial concentrations were lower or because permissible residual concentrations were higher. The analyses presented thus far have been based upon an assumed requirement for approximately 99.5 percent conversion of TNT.

For this sensitivity analysis, it is assumed that, for each constructed compost pad, a change in the required compost period would result in a change in the number of piles processed per year. For example, a decrease in the period from 90 days to 60 days would translate roughly into an increase from four to six piles of completed compost per pad per year (with some allowance for the extra time required for pile construction/dismantling). It is also assumed that such a change would result in an essentially similar total number of compost pad operating days per year, (four piles at 90 days each, being approximately equal to six piles at 60 days each) and that the cost per day of operating each pad containing a compost pile would be constant.

Therefore, in this analysis, costs associated with compost pile construction and dismantling were developed on a cost per pile basis. These included such items as amendment (raw materials) costs and expense (including labor) associated with materials handling. It should be recognized that, as the number of piles constructed per year increases, some increase is required in equipment, thus altering capital cost slightly. This factor has been considered by estimating the total number of equipment operating hours per year for each scenario and using estimated equipment productivity rates to determine the number of equipment pieces. Likewise, utilities (fuel, electric) associated with pile construction were estimated on a per pile basis.

Operating costs associated with pile operation (e.g., power for blowers) were assumed approximately equal for a constant number of pad-operating days per year (see above). Likewise, site support operating costs for a constant number of operating days per year were fixed. Analytical costs varied with the number of piles requiring testing per year.

TABLE 4-14. AERATED STATIC PILE COMPOSTING WITH VARIABLE KINETICS FOR A 50-PAD OPTION AND 7% SEDIMENT FRACTION WITH NO CONTINGENCY

Compost Period, Days	180	90	60	30	10
Piles per Year	98	196	294	588	1,764
Tons Treated per Year	5,635	11,270	16,905	33,810	101,430
Tons Amendments	3,731	7,462	11,172	22,344	67,032
I. Capital Costs					
Equipment	$ 1,373,000	$ 1,635,000	$ 1,897,000	$ 2,964,000	$ 6,361,000
Equipment Installation Labor	134,000	134,000	134,000	134,000	134,000
Piping	574,000	574,000	574,000	574,000	574,000
Electrical	632,000	632,000	632,000	632,000	632,000
Concrete	2,649,000	2,649,000	2,649,000	2,649,000	2,649,000
Buildings	533,000	533,000	533,000	533,000	533,000
Site Work	1,308,000	1,308,000	1,308,000	1,308,000	1,308,000
Subtotal Capital	$ 7,203,000	$ 7,465,000	$ 7,727,000	$ 8,794,000	$12,191,000
7% Contractor's Markup	504,000	523,000	541,000	616,000	853,000
Total Capital	$ 7,707,000	$ 7,988,000	$ 8,268,000	$ 9,410,000	$13,044,000
Design at 5% Total Capital	385,000	399,000	413,000	471,000	652,000
Site Closure	1,167,000	1,167,000	1,167,000	1,167,000	1,167,000
Total Capital Cost Estimate	$ 9,259,000	$ 9,554,000	$ 9,848,000	$11,048,000	$14,863,000
II. Operations & Maintenance (O&M)					
A. Constant Costs					
1. Power for Blowers/Pumps	$ 112,000	$ 112,000	$ 112,000	$ 112,000	$ 112,000
2. Operators' Labor	100,000	100,000	100,000	100,000	100,000
B. Variable Costs					
1. Lighting	7,000	7,000	7,000	7,000	7,000
2. Amendments	187,000	373,000	560,000	1,120,000	3,360,000
3. Woodchips	94,000	187,000	281,000	562,000	1,685,000
4. Power for Tub Grinder	1,000	1,000	2,000	4,000	11,000
5. Diesel Fuel	57,000	127,000	191,000	382,000	1,146,000
6. Production Labor	341,000	591,000	840,000	1,589,000	4,446,000
7. Analytical Labor (Chemist)	37,000	37,000	37,000	37,000	37,000
8. Maintenance at 3% of Total Capital	231,000	240,000	248,000	282,000	391,000
Total Annual O&M	$ 1,167,000	$ 1,775,000	$ 2,378,000	$ 4,195,000	$11,295,000
5 Year Present Worth O&M	$ 5,072,000	$ 7,715,000	$10,336,000	$18,234,000	$49,094,000
Total 5 Year Project Cost	$14,331,000	$17,269,000	$20,184,000	$29,282,000	$63,957,000
5 Year Tons of Sediment Treated	28,000	56,000	85,000	169,000	507,000
Cost per Ton of Sediment	$ 512	$ 308	$ 237	$ 173	$ 126

Note: All numbers rounded to nearest $1,000.

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TABLE 4-15. AERATED STATIC PILE COMPOSTING WITH VARIABLE KINETICS FOR A 50-PAD OPTION AND 10% SEDIMENT FRACTION WITH NO CONTINGENCY

Compost Period, Days	180	90	60	30	10
Piles per Year	98	196	294	588	1,764
Tons Treated per Year	8,016	16,033	24,049	48,098	144,295
Tons Amendments	3,616	7,232	10,849	21,697	65,091
I. Capital Costs					
Equipment	$ 1,373,000	$ 1,635,000	$ 1,897,000	$ 2,964,000	$ 6,361,000
Equipment Installation Labor	134,000	134,000	134,000	134,000	134,000
Piping	574,000	574,000	574,000	574,000	574,000
Electrical	632,000	632,000	632,000	632,000	632,000
Concrete	2,649,000	2,649,000	2,649,000	2,649,000	2,649,000
Buildings	533,000	533,000	533,000	533,000	533,000
Site Work	1,308,000	1,308,000	1,308,000	1,308,000	1,308,000
Subtotal Capital	$ 7,203,000	$ 7,465,000	$ 7,727,000	$ 8,794,000	$12,191,000
7% Contractor's Markup	504,000	523,000	541,000	616,000	853,000
Total Capital	$ 7,707,000	$ 7,988,000	$ 8,268,000	$ 9,410,000	$13,044,000
Design at 5% Total Capital	385,000	399,000	413,000	471,000	652,000
Site Closure	1,167,000	1,167,000	1,167,000	1,167,000	1,167,000
Total Capital Cost Estimate	$ 9,259,000	$ 9,554,000	$ 9,848,000	$11,048,000	$14,863,000
II. Operations & Maintenance (O&M)					
A. Constant Costs					
1. Power for Blowers/Pumps	112,000	112,000	112,000	112,000	112,000
2. Operators' Labor	100,000	100,000	100,000	100,000	100,000
B. Variable Costs					
1. Lighting	7,000	7,000	7,000	7,000	7,000
2. Amendments	181,000	361,000	542,000	1,085,000	3,255,000
3. Woodchips	94,000	187,000	281,000	562,000	1,685,000
4. Power for Tub Grinder	1,000	1,000	2,000	4,000	11,000
5. Diesel Fuel	57,000	128,000	191,000	382,000	1,146,000
6. Production Labor	341,000	591,000	840,000	1,589,000	4,446,000
7. Analytical Labor (Chemist)	37,000	37,000	37,000	37,000	37,000
8. Maintenance at 3% of Total Capital	231,000	240,000	248,000	282,000	391,000
Total Annual O&M	$ 1,161,000	$ 1,764,000	$ 2,360,000	$ 4,160,000	$11,190,000
5 year Present Worth O&M	$ 5,046,000	$ 7,667,000	$10,258,000	$18,082,000	$48,638,000
Total 5 Year Project Cost	$14,305,000	$17,221,000	$20,106,000	$29,130,000	$63,501,000
5 Year Tons of Sediment Treated	40,000	80,000	120,000	240,000	721,000
Cost per Ton of Sediment	$ 358	$ 215	$ 168	$ 121	$ 88

Note: All numbers rounded to nearest $1,000.

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The results of this analysis for composting periods varying from 10 to 180 days are presented in Tables 4-14 and 4-15, for compost mixture sediment fractions of 7 and 10 percent respectively. The 180-day composting period corresponds to roughly 99.5 percent removal of HMX under the kinetics determined from the LAAP Pilot Study, while a 90-day compost period corresponds to slightly less than 99.5 percent removal of TNT (in actuality, 99.46 percent removal). Two effects are immediately apparent. First, and predictably, pile production expense increases significantly as the processing rate (piles per year) increases.
Secondly, however, the mass throughput of the system increases dramatically, making more efficient use of fixed costs (including capital) and resulting in a net decrease in cost per ton of sediment treated.

4.2.4 Summary of sensitivity analyses. The conceptual analyses presented in this section indicate that in light of the significant fixed costs associated with development of a composting system, the primary factor in achieving economical operation is increasing the total sediment throughput of the system. Potential mechanisms for achieving such increases include the following:

- Increasing the operating life of the facility (which may be limited by regulatory constraints for a remedial operation). Typically the governing agency desires the most rapid cleanup period practically available. It should, however, be recognized that the constructed facility could have a useful operating life (in terms of its durability) greatly exceeding the assured 5 year remedial period. In this sense the 5 year operating life offers limited opportunity for capital cost recovery. With a larger remedial period a smaller fixed facility could be used to process a given quantity of sediment, enhancing cost recovery.

- Increasing the sediment fraction in the pile (subject to testing).

- Decreasing the required length of the compost period (subject to testing and/or regulatory clarification).

It is important to recognize the potential inter-relationships between operating variables in determining optimal operating conditions.

4.3 Alternative composting systems. This section of the report will present a mechanical composting system approach to treat explosives-contaminated sediments. A discussion of conventional sewage sludge composting processes was given in Subsection 2.1 of this report. A brief description of typical windrow, aerated static pile, and mechanical (in vessel) composting systems was presented in order to establish their methods of operation. A recent survey of municipal solid waste (MSW) composting systems vendors is presented in Table 4-16 [18]. This table lists mechanical composting systems which are currently available to manage sludge or MSW. Of the 24 systems listed, 2 are static pile, 6 are windrow, and 15 are mechanical, with one equipment vendor. The operating parameters indicated in Table 4-16 are those recommended for solid waste composting. Treatment efficiencies for MSW under the stated conditions were not identified. It should be noted that all of the mechanical composting systems currently in use are followed by either aerated static pile or windrow composting.

4.3.1 Mechanical composting system. In order to compare on a preliminary basis the aerated static pile composting system presented in this report to a possible mechanical composting system, several vendors were contacted. Vendor response was limited to systems that these vendors have built in the past. One vendor, the Fairfield Service Co., provided limited cost information. These costs were for the reactor vessel and treatment of MSW compost.

Cost information provided by Fairfield was based upon recent installations of their system for MSW composting. The Fairfield system uses a circular tank in which composting is conducted. Compost material is conveyed into the tank, where it is mixed and agitated by a set of augurs suspended from a bridge which travels around the vessel. When used for MSW composting the digester has a detention time of 15 days, which is generally followed by a curing period of approximately 30 days.

It should be recognized that the effectiveness of this (or another) mechanical composter in treating explosives-contaminated wastes is unknown. The extent of explosives removals in the nominal detention time of 14 days is unknown. At present it would appear quite unlikely that complete removal would occur in this period, and a subsequent treatment period might be required. Alternatively, it may be possible to reconfigure the reactor to provide a longer detention time (although for a given reactor size, this would lower net throughput).

It should also be recognized that the costs provided by Fairfield reflect only their experience in MSW composting. Neither the particular requirements and parameters of explosives composting, nor site specific factors with respect to installation and operation, can presently be evaluated. Lastly, the Fairfield system is presently used for nonhazardous wastes, and its suitability for hazardous/explosives wastes has not been determined. These constraints should be considered in evaluating costs presented below.

TABLE 4-16. MUNICIPAL SOLID WASTE (MSW) COMPOSTING FACILITIES

Vendor	Configuration	Reported Retention Time
Agripost	Static windrow (enclosed)	
American Recovery Corporation	In vessel	
Ashbrook-Simon-Hartley	Tunnel reactor (in vessel)	10 days in vessel, several weeks of curing
Bedminster Bioconversion	Eweson digester	
Buhler-Miag	Aerated windrows	
California Co-Composting Systems, Inc.	Rotating drum; aerated windrows	28 days in vessel, 4-6 mo. curing
Cholla Waste Management, Inc.	Proprietary	
Compost Systems Company	Options: 1) horizontal bin (Paygro) 2) circular digester (Fairfield) 3) horizontal plug flow (Dynatherm)	14-21 days in vessel, 30 days curing
Daneco	Aerated static pile, with positive and negative pressure aeration	
Ebara	Round trip paddling fermentor (horizontal bin with paddles)	10 days in vessel, 20 days curing
Ecological Technologies, Inc. (Ecotech)	Windrow (uses inoculum)	
Environmental Recovery Systems, Inc.	Windrows	3-6 weeks

TABLE 4-16. MUNICIPAL SOLID WASTE (MSW) COMPOSTING FACILITIES (CONTINUED)

Vendor	Configuration	Reported Retention Time
Estech Corp.	Rotary drum digester, followed by windrow curing	5 days in vessel
Fairfield Service Co.	Circular agitated bed in vessel system (Fairfield digester), followed by curing	14 days in vessel, 30 days curing
Geotech	Does not do actual composting - sells equipment	
Harbert-Triga	Fermentation tower, followed by windrow curing	7 days in tower
Lundell	Testing two systems: 1) Windrow; 2) Enclosed upright silo (possibly with bacterial supplementation)	3-4 weeks in silo
Organic Waste Systems	Dry anaerobic (fermentation) system with biogas recovery	16-21 days in tower
OTV	Longitudinal silo with horizontal shaft paddle wheel to move compost thru silo, and forced aeration system	10-15 days in silo 60 days curing
Recomp, Inc.	Eweson digester	4-5 days in vessel 14-21 days curing
Riedel Waste Disposal Systems	Rotating drum	8-10 hours in drum 21 days in aerated static piles
Royer Industries, Inc.	Enclosed dynamic composting system with compost tuner, self regulating air system, followed by curing	21 days in vessel
Trash Reduction Systems, Inc.	Shredding 1 handling equipment only then windrow, curing	21-42 days windrow, 30-42 days curing
WPF Corporation	Completely enclosed (MSW) processing system MSW mixed with sludge, then windrow or aerated pile	17 days windrow 21 days piles 6 weeks curing
24 Companies		

Pretreatment costs were developed in this study for supplying the unit estimated for a 14-day reactor retention time and a 90-day (based on TNT kinetics) reactor retention time. The following sections will present the capital and operations and maintenance costs for this mechanical composting system was performed and this analysis is for preliminary comparison only.

4.3.2 Costs and assumptions. To develop the costs for the mechanical composting system the following assumptions were used:

- The Fairfield digester unit will be used to compost the sediment/amendment mixture for this comparative analysis. Costs for the reactor were obtained from the vendors.
- A typical reactor throughput is 150 tons per day of compost for a 116-foot diameter digester with a 14-day retention time.
- The compost mixture density is 1000 lb per yd^3 resulting in a volumetric throughput of 300 yd^3 per day.
- No pad is necessary for all alfalfa and straw/manure storage. These materials will be staged on visqueen (plastic sheeting).
- No pad is necessary for sediment storage. The sediment will be staged in the dump truck or on plastic (visqueen sheeting).
- The compost mixer will be staged on a 6-inch concrete pad (40 feet by 40 feet).
- The compost mixer will operate for 8 hours per day (one shift). The mixing step is provided to more thoroughly mix the compost prior to entering the digestor.
- The amendment mixture is 48 percent alfalfa and 52 percent straw/manure.
- The compost mixer must provide 300 yd^3 per day to the digester.

In this analysis it is assumed that the compost will be prepared and mixed initially prior to entering the reactor vessel. When employed for MSW composting, the Fairfield system includes a shredding operation to reduce the material to a coarse grind and a pulper to provide the final grind prior to entering the vessel. For explosives composting these steps have been replaced with initial mixture preparation steps similar to those used for the aerated static pile previously presented. It might be noted that if the in vessel agitator could provide this function, capital cost could be reduced.

4.4 Results

4.4.1 Effect of sediment fraction at nominal 14-day retention time.

Using these assumptions, capital and O & M costs were developed for several sediment fractions. These costs are presented in Table 4-17. Costs for any post-vessel treatment/curing stage are not included. It can be seen that the capital costs as well as the O&M costs for the reactor/treatment section of the plant are independent of sediment fraction. The table also shows that as the sediment fraction is increased, the net cost per ton of sediment treated decreases. A comparison with Table 4-13 suggests that, at the present level of knowledge the mechanical system would be more expensive than aerated static pile composting. The need for additional treatment would further increase cost.

4.4.2 Retention time variation. To illustrate the effect of varying retention time on the reactor (mechanical) composting system, a cost analysis was completed for the reactor system with a 90-day retention time. This analysis was performed by assuming that the reactor could be configured during construction and operated in a manner to provide a net retention time of 90 days, should such a period be necessary to achieve adequate treatment. The obvious effect of such a change would be to decrease the net throughput rate for a given size reactor or, conversely, to increase the size and/or number of reactors necessary to maintain a specified system capacity. Since limited cost data were available for reactors of varying sizes, these cases were not considered, and costs were presented for producing compost from a single reactor of the size noted previously.

This cost analysis is presented in Table 4-18. A comparison between this table and Table 4-17 shows that the net cost per ton of sediment treated will significantly increase if a 90-day in-vessel compost period is required.

TABLE 4-17. MECHANICAL COMPOSTING WITH A 14-DAY RETENTION TIME

	Sediment Fraction		
	10%	20%	40%
Capital			
• Material Prep/Pretreatment	$ 718,000	$ 718,000	$ 718,000
• Reactor/Treatment	$2,674,000	$2,674,000	$2,674,000
Subtotal Capital	$3,392,000	$3,392,000	$3,392,000
Operations & Maintenance (O&M)			
• Material Prep/Pretreatment	$ 504,000	$ 482,000	$ 438,000
• Reactor/Treatment	$ 190,000	$ 190,000	$ 190,000
Subtotal O&M	$ 694,000	$ 672,000	$ 628,000
5 Year Present Worth O&M	$3,016,000	$2,921,000	$2,730,000
Total 5 Year Project Cost	$6,408,000	$6,313,000	$6,122,000
Tons Treated in 5 Years	11,000	23,000	45,000
Cost Per Ton of Sediment	$ 583	$ 274	$ 136

TABLE 4-18. MECHANICAL COMPOSTING WITH A 90-DAY RETENTION TIME

	Sediment Fraction		
	10%	20%	40%
Capital			
• Material Prep/Pretreatment	$ 718,000	$ 718,000	$ 718,000
• Reactor/Treatment	$2,674,000	$2,674,000	$2,674,000
Subtotal	$3,392,000	$3,392,000	$3,392,000
Operations & Maintenance (O&M)			
• Material Prep/Pretreatment	$ 229,000	$ 226,000	$ 219,000
• Reactor/Treatment	$ 190,000	$ 190,000	$ 190,000
Subtotal O&M	$ 419,000	$ 416,000	$ 409,000
5 Year Present Worth O&M	$1,821,000	$1,808,000	$1,778,000
Total 5 Year Project Cost	$5,213,000	$5,200,000	$5,170,000
Tons Treated in 5 Years	2,000	4,000	7,000
Cost Per Ton of Sediment	$ 2,607	$ 1,300	$ 739

5. CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to develop a system for the implementation of composting as a remedial technology for explosives-contaminated soils and sediments at various Army Ammunition Plants (AAPs) and Army Depots (ADs). The task included the development of conceptual design and operating requirements for such facilities and the evaluation of potential costs associated with their construction and operation. The present state of process development is represented by recent field demonstrations conducted by WESTON for USATHAMA under previous task orders at Louisiana Army Ammunition Plant (for TNT, RDX, and HMX) and Badger Army Ammunition Plant (for nitrocellulose).

Although these previous USATHAMA field studies have demonstrated the destruction of the explosives TNT, RDX, and HMX under composting conditions, this study indicates that direct implementation of the process as used in these preliminary investigations may prove expensive. However, further evaluation of several process design and operating parameters may result in significant economic improvements. This report has been prepared to present an appraisal of the potential for composting of explosives-contaminated sediments based upon currently available information and to identify areas in which further development is warranted.

Areas in which further investigation is warranted include the following:

- The possibility of significantly increasing sediment ratio in the compost mixture should be examined. Such an increase would result in some savings in raw materials (amendment) costs, and, perhaps more importantly, make significantly more effective use of the compost facility by significantly increasing the throughput of the system for minimal additional investment. Although previous USATHAMA studies used a sediment ratio of 3 percent (by volume), literature indicates that values of 10 percent may be possible. Furthermore, a preliminary test during the previous field demonstration at LAAP indicated that self-heating of the compost pile may be achievable at volumetric sediment ratios of 36 percent (although thermophilic conditions were not maintained). Calculations indicate that the bulk density of the compost mixture at such ratios may approximate that of sludge compost suggesting that its handling under composting conditions should be feasible.

- The minimum required treatment (composting) period to achieve adequate destruction of the target contaminants should be evaluated. This determination is primarily dependent upon regulatory requirements either in terms of required destruction efficiencies or permissible residual explosives concentrations. At present process and economic evaluations can only be made for various assumed destruction efficiencies, as no information is available on possible or acceptable residual concentrations.

- The process effects and economics of various amendments should be evaluated. As indicated in this study, amendment addition constitutes a significant fraction of the total processing costs, even assuming minimal published prices for the amendments evaluated to date. Minimal cost materials, which provide adequate carbon and nutrient levels, should be tested. Optimally, a range of such materials should be identified to allow for geographic-specific availability and for price fluctuations. Candidate materials may include various plant materials and nonhazardous organic wastes.

- Compost mixture mixing requirements should be considered, as this parameter likely affects process control and stability as well as capital mixing (equipment) and operating (labor) costs. Requirements for the initial preparation of the compost mixture from the sediments and amendments, with respect to such factors as mixing time, mixing energy, and final particle size should be determined so that performance specifications for mixing equipment can be developed. In addition, the necessary frequency and extent of remixing, during the compost period, should be identified, as this factor will fundamentally affect management of the pile. Minimal remixing requirements, as assumed in this study, may be accomplished by manual remixing of the pile. Increasing the required frequency may, at some point warrant consideration of mechanical mixing devices, with the extreme case of essentially continuous mixing being represented by certain in-vessel composting systems.

- Additional definition of facility construction requirements, particularly as determined by CERCLA/RCRA provisions, should be sought as these requirements will affect both capital and operating cost. Of particular note is the level of expense and effort associated with leachate generation and runoff control. The use of fixed structures covering the compost area entails substantial capital investment. While the use of temporary covers (e.g. tarpaulins) reduces this expense significantly, it complicates the management of the pile, particularly with respect to remixing and moisture addition. It should also be noted that the extent of runoff management, as well as a variety of other construction and operating requirements, will be significantly affected by the specific geographic location in which the process is used.

In addition to the primary issues discussed above, which may fundamentally affect the design, implementation, and economics of this technology, there are a variety of process-related parameters that should be determined to optimize the process configuration. While these parameters could be investigated during any additional preliminary field studies, useful information can also be obtained during the early operating stages of an actual facility so long as the design of that facility is sufficiently conservative to cover the least favorable predicted ranges for such parameters. Examples of such parameters include:

- Required airflow rates (and resulting aeration system requirements), including, as necessary, the effect of various sediment ratios and resulting bulk densities.

- Moisture addition requirements, as they determine both management of runoff and the requirement for makeup water.

- Disposal of the treated compost mixture was assumed to be land application at no cost to the facility. As the development of this technology advances, the classification of the treated material must be confirmed; RCRA delisting may be required and should be initiated early in the process development.

- The identification of materials handling/mixing equipment for the conceptual system in this study did not evaluate or identify the range of equipment available and potentially applicable. Equipment was identified from the LAAP pilot study and preliminary discussions with vendors. No attempt was made to identify the optimal or most efficient equipment. Some field testing of possible equipment should be considered to confirm expected performance of these units.

The analysis presented in this investigation represents an assessment of the potential applicability of composting for treatment of explosives-contaminated sediments. Additional definition of the issues and factors noted above will contribute to verification of this potential.

6. REFERENCES

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APPENDIX A

INFORMATION REQUIREMENTS FOR RCRA PART B APPLICATION FOR SUBPART L (WASTE PILES)

APPENDIX A

INFORMATION REQUIREMENTS FOR RCRA PART B APPLICATION FOR SUBPART L (WASTE PILES)

SUBJECT REQUIREMENT: 40 CFR Section Nos.

1. LINER ENGINEERING REPORT

1.1 Liner description: 270.18(c)(1), 264.251(a)(1)(1). Describe the type of liner, its material, USCS-type data for soil liners, the liner's thickness and, for synthetics, the manufacturer and the product's name.

1.2 Liner location relative to high water table: 270.18(c)(1), 264.251(a)(1)(1). Provide data showing seasonal fluctuations in the depth to the water table and the location of the seasonal high water table in relation to the liner system.

1.3 Calculation of required soil liner thickness: 270.18(c)(1), 264.251(a)(1)(1). For unit utilizing a primary soil liner, demonstrate that the thickness of the soil liner is sufficient to retard liquid flow through it such that leachate would be wholly contained throughout the active life of the unit. Calculations using either numerical simulation techniques (unsaturated flow conditions) or D'arcy Law-derived transit time equations (saturated flow conditions) must be provided.

1.4 Liner strength requirements: 270.18(c)(1), 264.251(a)(1)(1). Provide the results of calculation defining the minimum strength requirement for liners considering:

- Internal and external pressure gradients.
- Stresses resulting from settlement, compression, or uplift.
- Climatic conditions (freeze-thaw stress).
- Installation stresses.
- Operating stresses.

1.5 Liner strength demonstration: 270.18(c)(1), 264.251(a)(1)(1). Provide data showing that the liner exceeds the calculated minimum strength requirement.

Liner/Waste Compatibility Testing Results: 270.18(c)(1), 264.251(a)(1)(1).

Provide the results of liner/waste compatibility testing demonstrating that liner strength and performance are still adequate after exposure to waste leachates. Both primary and secondary leachates must be used in this testing.

1.6 Liner installation: 270.18(c)(1), 264.251(a)(1)(1). Describe the procedures for installing the liner(s).

1.6.1 Synthetic liner seaming: 270.18(c)(1), 264.251(a)(1)(1). Describe the techniques to be utilized to bond membrane liner seams and the strength and chemical compatibility of the seams.

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1.6.2 Soil liner compaction: 270.18(c)(1), 264.251 (a)(1)(1). Describe the procedures for installing the soil liner and compacting the liner to achieve the desired permeability. Include the maximum height of lifts to be placed.

1.6.3 Installation inspection/testing programs: 270.18(c)(1), 264.254(a). Describe the inspection, monitoring, sampling, and testing methods (and frequencies) to be employed during liner installation to assure that the liner system as installed meets the design requirements.

1.7 Liner coverage: 270.18(c)(1), 264.251(a)(1)(iii). Demonstrate that the liner will be installed to cover all surrounding earth likely to be in contact with the waste or leachate.

1.8 Liner exposure prevention: 270.18(c)(1), 264.251(a)(1)(1). Demonstrate that the liner will not be exposed to wind or sunlight or, if exposure is to be permitted, that such exposure will not result in unacceptable liner degradation.

1.9 Synthetic liner bedding: 270.18(c)(1), 264.251(a)(1)(i). Demonstrate that sufficient bedding will be provided above and below the liner to prevent rupture during installation and operation.

2. LINER FOUNDATION DESIGN DESCRIPTION: 270.18(c)(1), 264.251(a)(1)(11). Describe the liner foundation design and materials of construction. Describe the capability of the foundation to support any expected static and dynamic leadings.

2.1 Subsurface exploration data: 270.18(c)(1), 264.251(a)(1)(11). The engineering characteristics of the foundation materials must be verified through subsurface explorations. These efforts must be described and include:

- Test borings.
- Test pits or trenches.
- In situ tests.
- Geophysical exploration methods.

2.2 Laboratory testing data: 270.13(c)(1), 264.251(a)(1)(ii). Results from sufficient index testing must be provided to classify the site materials. Other lab test data must be provided to evaluate the engineering properties of the foundation materials, particularly for strength, hydraulic conductivity, compressibility, and other important design parameters.

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2.3 Engineering analyses: 270.18(c)(1), 264.251(a)(1)(ii). Engineering analyses must be provided which are based on the data through subsurface exploration and laboratory testing programs.

2.3.1 Settlement potential: 270.18(c)(1), 264.251(a)(1)(ii). Provide estimates of the total and differential settlement, including immediate settlement, primary consolidation and secondary consolidation. Stresses imposed by liners, wastes, and equipment must be considered.

2.3.2 Bearing capacity and stability: 270.18(c)(1), 264.251(a)(1)(ii). Provide estimates of the bearing capacity and stability of the foundation, demonstrating that allowable bearing capacity will not be exceeded.

2.3.3 Potential for bottom heave or blowout: 270.18(c)(1), 264.251(a)(1)(ii). Provide estimates of the potential for bottom heave or blowout due to unequal hydrostatic or gas pressures.

2.3.4 Construction and operational leading: 270.18(c)(1), 264.251(a)(1)(ii). Demonstrate that the foundation is capable of providing adequate support for construction equipment and operating equipment (e.g., dredges).

2.4 Foundation installation procedures: 270.18(c)(1), 264.251(a)(1)(ii). For installed foundations, provide a description of the foundation installation procedures.

2.5 <u>Foundation installation inspection program</u>: 270.18(c)(1), 264.251(a)(1)(ii). Describe the inspection, monitoring, sampling, and testing methods (and frequencies) to be employed during foundation installation to assure that the foundation as installed meets the design requirements.

3. LEACHATE COLLECTION AND REMOVAL SYSTEM: 270.18(c), 264.251(a)(2). Provide information describing the design and operation of a system to collect and remove leachate from any portions of existing waste piles and from new waste piles.

3.1 System design and operation: 270.18(c), 264.251(a)(2). Describe the design features of the leachate collection and removal system and how the system will function to remove collected leachate in a timely manner. Describe the features that will prevent leachate depth over the liner from exceeding 1 foot.

3.2 Chemical resistance: 270.18(c), 264.251(a)(2)(i)(A). Demonstrate that the leachate collection and removal system components are chemically resistant to the waste managed in the pile and the leachate expected to be generated.

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3.3.3 Strength of materials: 270.18(c), 264.251(a)(2)(i)(8). Demonstrate that system components are of sufficient strength and thickness to prevent collapse under expected static and dynamic leadings.

3.4 Prevention of clogging: 270.18(c), 264.251(a)(2)(ii). Demonstrate that the system design and operation will prevent clogging throughout the active life of the pile.

3.5 Installation: 270.18(c), 264.251(a)(2). Describe the methods to be employed to install the leachate collection and removal system. Include a description of the inspection program to be implemented to assure installation in accordance with design requirements.

3.6 Maintenance: 270.13(c), 264.251(a)(2). Describe anticipated maintenance activities that will be used to assure proper leachate management system operation throughout the pile's expected active life.

4. RUNON CONTROL SYSTEM: 270.18(c)(2), 264.251(c). Describe the system that will be used to prevent runon onto active portions of piles.

4.1 <u>Calculation of peak flow</u>: 270.18(c)(2), 264.251(c). Identify the peak surface water flow expected to result from a 24-year design storm. Describe the data sources and methods used to make the peak flow calculation.

4.2 <u>Design and performance</u>: 270.18(c)92), 264.251(c). Describe the runon control system design. Demonstrate that system design will prevent runon from reaching active portions of the unit.

4.3 <u>Construction</u>: 270.18(c)(2), 264.251(c). Describe the methods to be employed to construct the runon control system. Include descriptions of any construction inspection program to be utilized to assure construction in accordance with design requirements.

4.4 <u>Maintenance</u>: 270.18(c)(2), 264.251(c). Describe any maintenance activities required to assure continued proper runon system operation throughout the unit's active life.

5. RUNOFF CONTROL SYSTEM: 270.18(c)(3), 264.251(d). Describe the runoff control system to be used to collect and control runoff from active portions.

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5.1 Calculation of peak flow: 270.18(c)(3), 264.251(d). Identify the total runoff volume expected to result from a 24-hour, 25-year storm. Describe data sources and methods used to make the peak flow calculation.

5.2 Design and performance: 270.18(c)(3), 264.251(d). Describe the runoff collection and control system design. Demonstrate that the system has sufficient capacity to collect and hold the total runoff volume calculated in D-3g(1).

5.3 Construction: 270.18(c)(3), 264.251(d). Describe the methods to be employed to construct the runoff collection and control system. Include descriptions of any construction inspection program to be employed to assure construction in accordance with design requirements.

5.4 Maintenance: 270.18(c)(3), 264.251(d). Describe any maintenance activities required to assure continued proper runoff system operation throughout the unit's active life.

6. MANAGEMENT OF COLLECTION AND HOLDING UNITS: 270.18(c)(4), 264.251(e). Describe how collection and holding facilities associated with runon and runoff control systems will be emptied or otherwise managed expeditiously after storms to maintain system design capacity.

7. CONTROL OF WIND DISPERSAL: 270.18(c)(5), 264.251(f). If the pile contains any particulate matter which may be subject to wind dispersal, describe how the pile is covered or otherwise managed to control wind dispersal.

8. GROUNDWATER MONITORING EXEMPTION: 270.18(b), 264.90 (b)(2). If an exemption from the Subpart F groundwater monitoring requirement is sought, provide data demonstrating that the following conditions are met.

8.1 Engineered structure: 264.90(b)(2)(i). Provide design data showing that the unit for which the exemption is sought is an engineered structure.

8.2 No liquid waste: 264.90(b)(2)(ii). Describe procedures for ensuring that no liquid waste or waste-containing free liquids will be received by or contained in the unit.

8.3 Exclusion of liquids: 264.90(b)(2)(iii). Provide design and operating data demonstrating how liquids, precipitation, and other runon and runoff will be excluded from the unit.

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8.4 Containment system: 264.90(b)(2)(iv). Describe the containment system (both inner and outer layers) which will enclose the waste.

8.5 Leak detection system: 264.90(b)(2)(v). Describe the design and operating data demonstrating the leak detection system built into each containment layer.

8.6 Operation of leak detection system: 264.90(b)(2)(vi). Demonstrate the means for ensuring continuing operation and maintenance of the leak detection systems during the active life of the unit and the closure and post-closure care periods.

8.7 No migration: 264.90(b)(2)(vii). Demonstrate to a reasonable degree of certainty that the unit will not allow hazardous constituents to migrate beyond the outer layer of the containment system prior to the end of the post-closure care period.

9. TREATMENT WITHIN THE PILE: 270.18(e). If any treatment is accomplished in the pile, provide the following descriptions.

9.1 Treatment process description: 270.18(e). Describe the process by which wastes are treated and the effect of the treatment on the wastes.

9.2 Equipment used: 270.18(e). Describe any equipment or other materials required to initiate or promote treatment.

9.3 Residuals description: 270.18(e). Describe the nature and quantity of the wastes remaining in the pile after treatment is complete.