AD-A241 033

(2)

US Army Corps of Engineers

Toxic and Hazardous Materials Agency

PROCESS AND ECONOMIC FEASIBILITY OF USING COMPOSTING TECHNOLOGY TO TREAT WASTE NITROCELLULOSE FINES

CONTRACT NO. TV-79414T
REPORT NUMBER CETHA-TE-CR-91012

PREPARED FOR:

U.S. ARMY TOXIC AND HAZARDOUS MATERIALS AGENCY
Aberdeen Proving Ground, Maryland 21010-5401

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MARCH 1991

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT UNLIMITED
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) CETHA-TE-CR 91012
6a. NAME OF PERFORMING ORGANIZATION TENNESSEE VALLEY AUTHORITY; 6b. OFFICE SYMBOL (If applicable) CEB 3A	7a. NAME OF MONITORING ORGANIZATION U.S. ARMY TOXIC AND HAZARDOUS MATERIALS AGENCY
6c. ADDRESS (City, State, and ZIP Code) TVA RESERVATION MUSCLE SHOALS, AL 35660-1010	7b. ADDRESS (City, State, and ZIP Code) ATTN: CETHA-TS-D ABERDEEN PROVING GROUND, MD 21010-5401
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U.S. ARMY TOXIC AND HAZARDOUS MATERIALS AGENCY; 8b. OFFICE SYMBOL (If applicable) CETHA-TS-D	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER CONTRACT NO. TV-79414T
8c. ADDRESS (City, State, and ZIP Code) ATTN: CETHA-TS-D ABERDEEN PROVING GROUND, MARYLAND 21010-5401	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
2102040	R16		

11. TITLE (Include Security Classification)
PROCESS AND ECONOMIC FEASIBILITY OF USING COMPOSTING TECHNOLOGY TO TREAT WASTE NITROCELLULOSE FINES

12. PERSONAL AUTHOR(S)
C. E. BREED, K. E. MCGILL, M. C. CRIM, C. W. BROWN

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
FINAL	FROM 10/89 TO 3/91	1991, March, 31	59

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	COMPOSTING, NITROCELLULOSE, ECONOMIC FEASIBILITY

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

An evaluation of the process and economic feasibility of using composting technology to dispose of waste nitrocellulose (NC) fines (slurried in water) from the Radford Army Ammunition Plant (RAAP) was undertaken by the Tennessee Valley Authority (TVA) for the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA). Two general categories of composting technology were evaluated; (1) static pile processing in which the NC fines are mixed with composting amendments and stacked in long aerated piles, and (2) in-vessel processing in which NC composting is carried out inside a process vessel and the compost mix is handled by mechanical processing equipment.

For the static pile process evaluation, a detailed conceptual design was made to provide a basis for estimation of capital and operating costs. This design was then evaluated at two levels of waste NC fines throughput, 6000 pounds per day (dry basis) and 2000 pounds per day (dry basis).

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Erik Hangeland	22b. TELEPHONE (Include Area Code) (301) 671-2054; 22c. OFFICE SYMBOL CETHA-TS-D

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

19. For the in-vessel process evaluation, commercial and demonstration scale composting facilities were visited by TVA personnel to gather process and economic information. This information was then modified conceptually to reflect operation of the particular process with NC fines at a throughput of 5000 pounds per day. The in-vessel processes evaluated were:

* Metcalf and Eddy (Paygro) process in Baltimore, Maryland
* Fairfield process in Plattsburgh, New York
* Ebara process in Seven Springs, Pennsylvania

The results determined that both types of composting technology, static pile and in-vessel, are technically feasible methods of disposing waste NC in slurry form. However, recent studies of NC composting in a soil matrix indicate that the biological destruction rate of NC is slower than the destruction rate of commonly composted materials (e.g., sewage sludge). Based on these studies, it is expected that composting of RAAP's NC fines will require a longer than normal retention time and a relatively low initial concentration of NC in the compost mix.

The estimated cost of composting RAAP's NC fines is significantly lower than the estimated cost of incineration, an alternative destruction method being considered by USATHAMA. According to a USATHAMA estimate, the cost of NC incineration is about $2000 per dry ton of NC. In comparison, the cost of composting is estimated to range from $455 per dry ton of NC (6000 lb/day process) to $754 per dry ton (2000 lb/day process), based on the static pile process economic evaluation presented in this study.

Further laboratory and pilot-scale research work is recommended to determine optimum operating conditions and to establish an accurate design basis for a full-scale installation.

PROCESS AND ECONOMIC FEASIBILITY OF USING COMPOSTING TECHNOLOGY TO TREAT WASTE NITROCELLULOSE FINES

PREPARED FOR COMMANDER
U.S. ARMY TOXIC AND HAZARDOUS
MATERIALS AGENCY
ABERDEEN PROVING GROUND, MARYLAND 21001-5401

CONTRACT NO. TV-79414T
USATHAMA REFERENCE: CETHA-TE-CR-91012

MARCH 1991

TENNESSEE VALLEY AUTHORITY
NATIONAL FERTILIZER & ENVIRONMENTAL RESEARCH CENTER
MUSCLE SHOALS, ALABAMA 35660-1010

ABBREVIATIONS

AAP	Army Ammunition Plant
C/N	Carbon to Nitrogen Weight Ratio
CASBL	Continuous Automated Single Base Line (at RAAP)
cfm	Cubic Feet Per Minute (actual)
cu. yd.	Cubic Yards
dia.	Diameter
gpm	Gallons per Minute
kg	Kilogram
KWH	Kilowatt Hours
lb	Pound
mg	Milligram
NC	Nitrocellulose
pH	Measure of acid or base strength
ppm	Parts per million
RAAP	Radford Army Ammunition Plant
TVA	Tennessee Valley Authority
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
°C	Degrees Centigrade

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I. SUMMARY

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Further laboratory and pilot-scale research work is recommended to determine optimum operating conditions and to establish an accurate design basis for a full-scale installation.

II. INTRODUCTION

The manufacture of nitrocellulose (NC) at Radford Army Ammunition Plant (RAAP) in Radford, Virginia, generates water streams containing waste NC fines. These fines settle out and accumulate in various process lagoons and holding pits. In the past, fines which could not be recycled back into the process have been disposed by removing them from these collection points in the process and then burning openly.

The U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) is working with Radford AAP to find a more environmentally acceptable method of disposing of waste NC fines. In 1987, USATHAMA contracted with A. D. Little, Inc. to study options for recovering and treating/disposing Radford's waste NC. In their report, A. D. Little, Inc., favored a three-step process involving cross-flow microfiltration for recovery, followed by alkaline hydrolysis and biological waste water treatment for disposal. The success of the microfiltration tests conducted by A. D. Little, Inc., has prompted efforts to examine the possibility of using microfiltration to capture NC fines at key points in the process, where the NC is suitable for recycling back to the process. However, it is still expected that even a fully successful recycling program will still leave a substantial quantity of waste NC fines.

Later, in a study conducted in 1989 by Roy F. Weston, Inc., for USATHAMA, it was determined that soils that have been contaminated with NC-based propellants can be successfully composted to destroy the NC contaminant. (This study was conducted using contaminated soils at Badger Army Ammunition Plant.)

USATHAMA has now contracted with the Tennessee Valley Authority (TVA) to examine the process and economic feasibility of using composting to destroy Radford's waste NC fines. This study seeks to determine from literature sources the approximate processing conditions that would be required to effectively compost NC, and to propose conceptual designs from which capital and operating costs can be estimated.

The current state of technology in composting is such that composting processes can be divided into two basic categories: static pile and in-vessel. With static pile processes, any compostable organic material is mixed with recycled finished compost and other amendments (e.g., sawdust, straw, horse feed) and laid out in long piles called static piles. The piles remain in place until the organic material is fully decomposed and stabilized. Microorganisms in the piles are provided with oxygen by frequent mechanical turning of the piles and/or forced aeration, depending upon the particular requirements of the organic material. (If the pile is mechanically turned to provide aeration, it may be referred to as a windrow rather than a static pile.)

The in-vessel composting processes are generally commercial or near-commercial processes in which composting takes place inside some type of vessel, and the compost materials are mixed, transported, and handled by mechanical equipment.

Both types of processes, static pile and in-vessel, are evaluated in this study. Due to the flexibility and simplicity of static pile processes, a detailed conceptual static pile design was made to provide a basis for the economic evaluation. This is presented in Section III. The in-vessel processes were evaluated by gathering information from site visits to working facilities and from literature sources. The information from each process was then modified in a theoretical way, as if the process were to be used to treat NC, to produce an economic evaluation of each process. This is presented in Section IV.

III. STATIC PILE PROCESS DESIGN AND ECONOMIC EVALUATION

3.1 Design Basis and Assumptions

The quantity of waste NC fines requiring compost treatment at RAAP is not currently well defined. USATHAMA, in conjunction with RAAP personnel, has been examining various process options for capturing and recycling waste nitrocellulose fines from internal streams in the NC production process. Depending on the option selected and the degree to which it is successfully applied, the quantity of NC fines that will ultimately require composting is varied. If no waste fibers can be recycled and the NC production facility operates at full capacity, it is expected that the total quantity of NC (on a dry basis) requiring composting will be about 6000 pounds per day. Alternatively, a reasonably successful recycling program or production at less than full capacity is expected to leave about 2000 pounds per day of NC still requiring composting for disposal. For comparison of costs and land space requirements, both of these waste rates were evaluated in this study.

All of the information relating to the specific compost properties of NC was obtained from a USATHAMA report prepared by Roy F. Weston, Inc., (Weston) entitled "Field Demonstration-Composting of Propellants Contaminated Sediments at the Badger Army Ammunition Plant" (Report Number CETHA-TE-CR-89061). This report details pilot-scale tests to compost NC in a soil matrix.

Additional information of a general nature was also needed regarding good compost practices. This was obtained from open literature sources regarding the composting of more conventional substances such as sewage sludge. Information was also obtained from contact persons inside and outside TVA who are experts in the fields of composting and microbiology.

Although the Weston study is thorough in its presentation of NC composting in a soil matrix, additional information was still needed to produce a complete conceptual design. It is generally recognized that even after this feasibility study and economic evaluation is complete and accepted by USATHAMA, lab-scale and pilot-scale composting studies will be required to prove the basis for the full-scale facility at Radford. In the absence of this information, several assumptions were made using engineering judgment, indirect evidence, and theoretical considerations. These assumptions are enumerated below.

1. A primary assumption is that the Weston composting test results using NC in a soil matrix are also applicable to NC composting outside of a soil matrix. None of the literature sources that were reviewed presented any information to refute this assumption.

2. The most critical and perhaps weakest assumption is that a 40-day compost retention time will be sufficient in length to reduce the NC down to a concentration less than the targeted level of 50 mg/kg. This assumption is critical because the size of the composting facility is proportional to the retention time required. It is clear from the Weston data that most of the NC is destroyed within this timeframe. In one Weston test, the concentration of NC was lowered from 5 percent by weight to 378 mg/kg in 42 days, a 99.2 percent loss (Table 4-7, page 4-18 of the Weston report).

   Although this level is still above the 50 mg/kg target, two other assumptions must be taken into account. First, in a full-scale continuous operation, the microbial population in the compost will be highly acclimated toward the degradation of NC due to repeated cycling through seeding. In the Weston study the microbes, which were contributed to the compost system by manure, were initially more adapted to the use of readily available carbon sources in the manure. Based on generally accepted principles of composting, it is likely that the presence of a microbe population fully acclimated to NC will be sufficient to overcome the small quantity of additional compost destruction that will be needed to achieve the 50 mg/kg target. Second, as the finished compost is loaded, hauled, unloaded, and spread during disposal, it will receive additional aeration and thus additional compost time to lower the NC content.

3. It is assumed that the initial concentration of NC in the compost should be about 5 percent dry solids by weight. This is less than the typical dry solids concentration range of 7-10 percent used in sewage sludge composting operations. Although the Weston report indicates that initial concentrations greater than 5 percent are compostable, the report also indicated that higher concentrations will require longer periods of composting. This will, in turn, tend to offset the advantage of using higher concentrations. However, the main barrier against raising the concentration above 5 percent is the difficulty in achieving an acceptable carbon-to-nitrogen (C/N) ratio. This is discussed in detail in the next item.

4. It is assumed that the C/N ratio in the initial compost mixture can be as low as 10:1, instead of the more typical values found in sewage sludge composting which range from 15:1 to 30:1. This assumption is based on the fact that nitrogen in NC exists in an oxidized form, quite different from the reduced organic nitrogen forms that exist in most composted materials. Compounds containing reduced nitrogen, when composted at a low C/N ratio, tend to release large quantities of ammonia that retard microbial action and also produce an odor problem. Conversely, it is assumed that the oxidized nitrogen in NC will not convert to ammonia as quickly as the reduced forms, and thus a lower C/N ratio can be tolerated.

Being able to operate at a low, 10:1 C/N ratio is an important factor in holding down capital costs. If the C/N ratio is raised to 15:1 for example, system constraints will force the percentage of NC to fall to about 4 percent in the initial compost mix, or else the proportion of recycle material in the mix will have to be lowered. However, the recycle proportion used in this design is already much lower than is normal for composting (27 percent versus a typical range of 50-60 percent). If the percentage of NC in the initial mix must be lowered to accommodate a higher C/N ratio, the facility size and the capital cost will rise accordingly. Therefore, the C/N ratio limitation is a key factor that must be known to produce a final composting design, and thus C/N ratio should receive significant attention in future lab-scale and pilot testing.

It is believed that a lower than normal recycle proportion can be tolerated with NC composting because of a relatively higher usage of fresh amendments, sawdust, and wheat straw. These materials should provide the bulk porosity and moisture absorption that the recycle normally provides. However, with NC composting, as opposed to sewage sludge composting, the recycle material is a critical source of microorganisms for the next static pile in the compost cycle. Therefore, the low proportion of recycle material used in this design (27 percent) remains a concern. Actual testing will be required to determine the minimum recycle proportion needed to perform this function.

One final assumption must be made regarding the C/N ratio. It is assumed that about 67 percent of the carbon in the wood sawdust will be available to the microbes. Essentially, this includes all cellulosic forms of carbon, leaving only lignin behind. Wood cellulose is slow to release carbon, but the lengthy (40 days) composting time proposed for this design should make all of it available. If necessary, wood carbon may be made more readily available by composting at a temperature a little lower than 55°C.

5. It is assumed that the concentration of NC in the waste stream will be 10 percent by weight. This concentration is roughly equivalent to the concentration obtained when settled fibers in holding lagoons are slurried and pumped out. This is one method of recovery that has a good probability of being used according to RAAP personnel. However, there are many possible ways in which a NC fines waste stream could be generated, depending on the type of NC recycling and recovery process (if any) that is chosen to be installed. At present, there is a very wide range of possible concentrations, ranging from a low of 143 parts per million (poacher settling pits overflow) to a high of 25 percent (based on a stream concentrated by microfiltration). (See section 3.2.4 for a discussion of the minimum and maximum stream concentrations acceptable for composting with this design.)

6. It is assumed that destruction of pathogens will not be required for NC composting. A pathogen destruction cycle is generally required during sewage sludge composting because of the presence of disease-causing bacteria in sewage. Usually, this means that the compost mix undergoes restricted aeration for several days, allowing the compost temperature to rise to 70°C or more for sterilization. In terms of process equipment, pathogen destruction time adds to the size of the facility as either additional static pile length or as a special set-aside area for the pathogen cycle.

   Since NC fines contain no pathogenic bacteria, no pathogen cycles should be required, although this may have to be proved to the appropriate regulatory agency. Since the NC facility will be started up using sewage sludge or horse manure in the initial mix, a pathogen destruction cycle may be needed at that time.

7. It is assumed that no curing cycle will be required for NC composting. Generally, after aeration and pathogen destruction, compost is stacked in the open for several days to cure it, i.e., allow it to stabilize. For NC composting, the long 40-day composting time should provide sufficient time for curing.

3.2 Process Description

Two static pile designs were cre... one capable of composting 6000 pounds per day dry NC and th... ...ble of composting 2000 pounds per day dry NC. The two de...s are similar, differing only in number of static piles and ...ces of equipment but not in operating philosophy. For brevity, the 6000 pound-per-day process is described below, and the essential differences of the 2000 pound-per-day process in terms of equipment, labor, etc., are discussed in Section 3.4, Economic Evaluation.

Because of the large land area required for composting, it is assumed that the compost facility will be located at a significant distance from the NC production area, which is located inside a congested plant area. According to RAAP personnel, the most likely site for the facility is a flat, open field just east of the Continuous Automated Single Base Line (CASBL). This site is roughly 1.4 miles in a straight line from the farthest portion of the NC production area (C-Line). Most of the other potential sites would be in the Horseshoe Area of RAAP north of the New River and would also be about the same distance away from the NC area as the field east of CASBL.

At this stage of the design, it was indeterminate which method of transport would be used to carry NC slurry to the composting area--pipeline transfer, truck hauling, etc. In order to include estimated transport costs in the design, pipeline transfer was arbitrarily chosen as the transport method. A 4-inch pipeline having an estimated length of 2 miles, plus a 100 gallon-per-minute booster pump is included in the design. It was estimated that about one mile of new pipe rack would also be needed.

3.2.1 Equipment Layout

The 6000 pound-per-day compost design contains a total of 20 static piles, each static pile 60 yards in length. Each static pile is supported by a separate diked concrete pad and has a panel roof to keep rainfall or snow off the pile. A panel roof design was selected to provide access along all sides of the static pile for moving equipment and personnel and to provide air flow to disperse odors. The diked pad is considered necessary to prevent NC-contaminated leachate from escaping to the ground environment. (Leachate handling is discussed later in section 3.2.2.)

The 20 static piles are divided among 4 identical operating units, each having 5 static piles. Each operating unit contains its own separate set of operating equipment which includes (1) a 20,000-gallon NC slurry holding tank and pump, (2) a 15,000-gallon leachate holding tank and pump, and (3) an 8,000-gallon in-ground leachate sump and pump. These figures as well as other design details presented in this section were calculated to allow for normal, smooth operation of the facility plus upset conditions. For example, a full charge of NC slurry to a single static pile is about 14,800 gallons (assuming the NC slurry concentration equals the design value of 10 percent). However, a 20,000-gallon capacity was provided for each unit's NC slurry holding tank to accommodate unusual operating requirements such as the need to make a larger than normal transfer of slurry from the NC area, a slurry weaker than 10-percent solids, pipe line flushings, etc.

Figure 3.1 depicts a single static pile and shows how it is interconnected to its operating unit's equipment. Also, to aid the reader in visualizing the equipment, Appendix A contains an end-view drawing of a static pile and a layout drawing for a single operating unit. (Static piles are shown as Buildings A through E.) Each operating unit has a separate motor control center which also houses the instrumentation.

3.2.2 Normal Operation

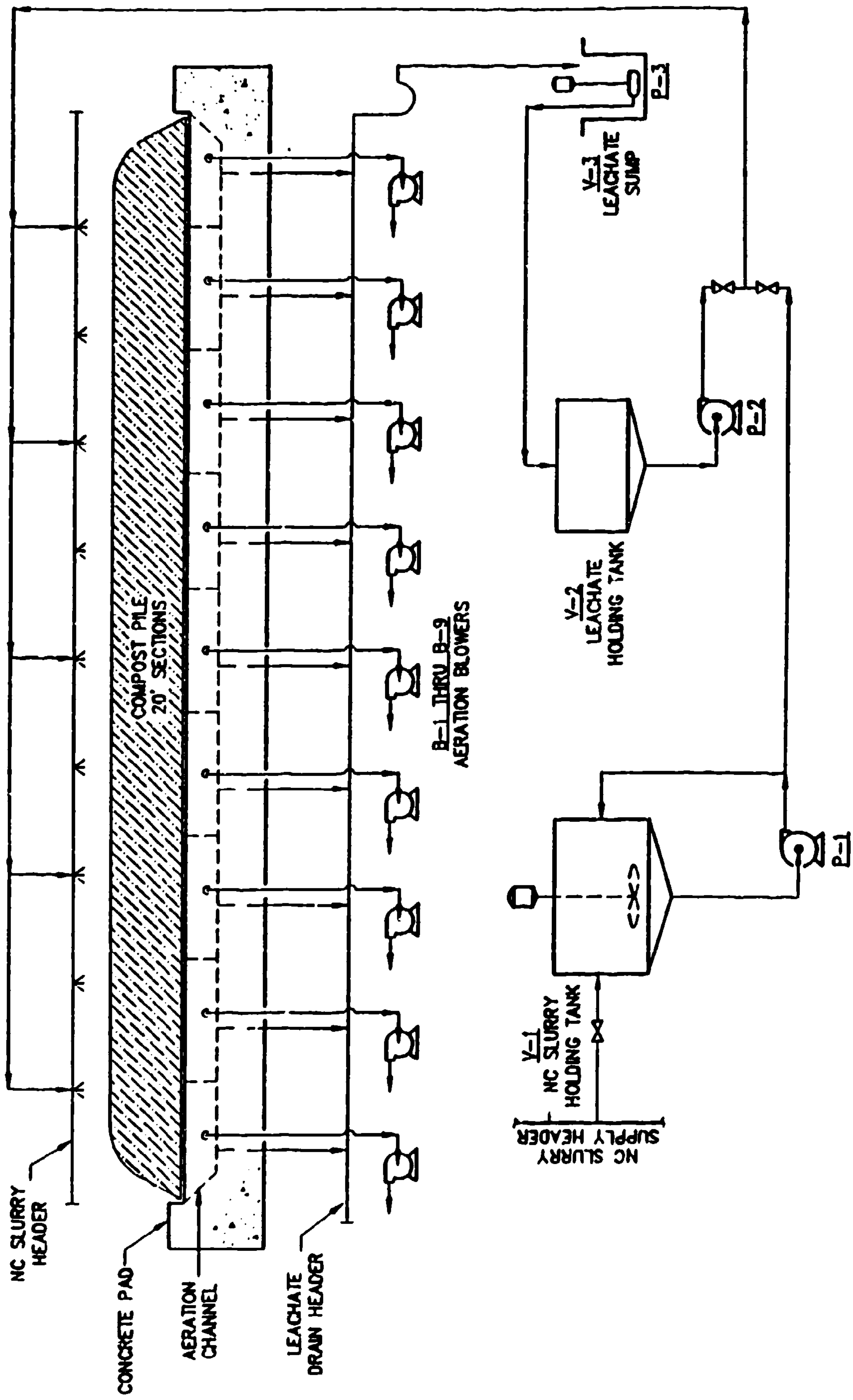
Each static pile is operated in 40-day batch cycles as follows. A portion of compost from the previous composting cycle is retained as recycle material to provide microorganisms to the compost. The recycle material is spread out using a front-end loader or 3/4-yard garden tractor to the normal length (60 yards) and width (9 feet) dimensions of the static pile. Fresh NC fines slurry is pumped from the NC slurry holding tank (V-1) to a spray header located above and along the length of the static pile. The header has spray nozzles spaced along its length to distribute the slurry evenly over the pile. The recycle material acts as a filter to capture the NC fines. Excess water drains through a support screen beneath the pile into a collection channel (aeration channel on Figure 3.1) where it flows by gravity to the leachate sump (V-3). The leachate is re-used as will be discussed later.

After the NC slurry has been added to the pile, two compost amendments, sawdust and wheat straw, are added on top of the pile using a front-end loader and/or garden tractor. The sawdust adds bulk to provide voids in the pile to facilitate good aeration. It is also a source of slowly released carbon during the long compost retention time (40 days). The wheat straw provides a source of quickly available carbon to initiate composting. The newly formed pile now contains materials which have been added in the following proportions:

FIGURE 3.1

COMPOSTING OF NC FINES

STATIC PILE METHOD



50 percent NC slurry (equivalent to 5 percent dry NC in the compost)

27 percent Recycle compost

15 percent Sawdust

8 percent Wheat straw

It should be noted that wheat straw may be replaced with any readily compostable cellulosic material. RAAP's waste cotton linters or wood pulp may be acceptable replacements.

The pile materials are next blended in place to form a homogeneous mixture by using a compost turning machine such as a Cobey composter. This type of machine straddles over the static pile so that it may move along its length. Whirling blades below the cab of the machine mix and chop the compost materials as it moves. At this point, the pile is now prepared for its 40-day composting retention time.

The use of the Cobey composter machine would have to undergo a safety hazard analysis. The SCAT windrow system, a similar compost turning system, has already undergone a hazard analysis with favorable results. The following description is from SCAT's brochure: "Hundreds of small teeth on an elevating face lift the materials in the pile and carry it over the top of the machine. It is at this time that the mild shredding action of the face takes place. As the material passes through the air, it is thoroughly aerated before being gently deposited in the next windrow."

Referring again to Figure 3.1, each static pile, as shown, is aerated by nine vacuum air blowers (capacity 300 cfm each) located along its length. Each blower is dedicated to a separate 20-foot section of the static pile. Although there is no actual division in the static pile itself, the aeration channel beneath the static pile is blanked off every 20 feet to direct the air flow through that section of the pile into the aeration channel and on to the vacuum blower. The static pile is sectioned off in this manner in order to maintain more even temperature control throughout the length of the static pile. Each 20-foot section has a separate temperature probe wired to a central controller housed in the motor control center. The controller maintains the temperature set point in each section by alternatoly turning the blower on and off. (The normal set point temperature is expected to be 55°C to provide thermophilic compost conditions.) In addition to temperature control, aeration is also necessary to provide aerobic conditions for the microorganisms.

The aeration channel also serves as a drain point to capture leachate during NC slurry addition to the pile. The leachate flows by gravity to the leachate sump (V-3) from where it is pumped to the leachate holding tank (V-2).

Good composting conditions require that the moisture content of the pile be maintained in a range between 40 percent and 60 percent moisture.

The initial mix of compost materials, if applied all at once into a single mixture, would contain about 66 percent moisture, which is too high for good composting. However, since the NC slurry is applied only to the recycle material prior to adding the sawdust and wheat straw, it is expected that the recycle material will become saturated and allow a significant portion of the water in the slurry to pass through as leachate. The leachate can then be added back to the static pile over time by pumping out of the leachate holding tank into the same spray header used to apply the NC slurry.

Any NC fines that managed to pass through the recycle material bed would also be reapplied in this manner. It is likely that due to the lengthy composting time, additional water beyond what is collected as leachate will be required to maintain moisture conditions.

Typically, with sewage sludge composting, the compost will dry from 60 percent moisture to 45 percent moisture in a 14-day period. Once the moisture content drops below 40 percent and stored leachate has been depleted, an outside source of water will be needed. Additional water can be made available at essentially no cost using the equipment arrangement in this design. For example, the 2-mile long slurry transfer line will require periodic flushing to prevent settling and subsequent pluggage of the line. The flushing water could be supplied from the abundant excess of process water in the NC production area. This same process water could also be pumped directly to the composting area using the transfer line if more water was needed.

At the end of the compost cycle, about half of the finished compost (roughly 19 tons/day; equal to about 42 cubic yards/day) cannot be recycled and must be disposed. Compost is a valuable soil amendment used in gardening and nursery operations. However, because of liability concerns, it cannot be sold or freely distributed to the public. Instead, it is suggested that compost be retained for landscape use or disposal on site at RAAP. There are a number of possible disposal options such as spreading it around shrubbery and trees in landscaped areas, spreading it onto grassy or wooded areas, filling in low-lying areas or ravines, or simply stacking it for later use. Sufficient equipment and labor are included in this estimate to handle hauling, unloading, and coarse spreading. (Landscape or gardening use would require additional personnel and equipment which, it is assumed, would not need to be provided by the composting facility.)

3.2.3 Start-up

The waste NC stream does not contain the necessary ingredients to initiate and sustain composting, as do other commonly composted materials such as sewage sludge. In particular, the waste NC stream lacks a consortium (wide variety) of microorganisms and probably contains no microorganisms of any composting benefit. A consortium of microorganisms is needed so that there are at least a few species present having a greater natural tendency to break down NC. These species can then multiply and become more acclimated to performing their task. The engineers at Weston recognized this in planning their composting studies of NC-contaminated soil. They provided a microorganism-rich, nutrient-rich environment in their research compost piles with the amendments they selected.

The initial static piles at the RAAP compost facility should be composed of materials similar to those used in Weston's research. For the 6000-pound-per-day process, these materials include 508 tons of high protein horse feed, 254 tons of sawdust, 1414 tons of sewage sludge, and 300 tons of alfalfa. The compost retention time required to destroy the NC in this initial pile is expected to be longer than 40-days, perhaps exceeding 100-days as was experienced by Weston in tests using similar amendments to those listed above. After this initial charge, the next static pile in the cycle can begin normal operation, although the compost retention time may still exceed 40-days for a few cycles. The switch from start-up operation to normal operation should take place quickly once the microorganisms have adapted to the degradation of NC, thereby helping to quickly lower the compost retention time to its minimum.

3.2.4 Maximum and Minimum NC Slurry Concentration

To assist USATHAMA and Radford AAP personnel in selecting and costing process equipment which will be used to collect the waste NC fines, it is useful to determine the maximum and minimum NC concentrations acceptable for composting with the static pile design proposed in this report.

The maximum concentration that can be composted is unlimited, i.e., 100 percent, because water can always be added to the compost to achieve the proper moisture content for good composting. As a practical and economic matter, however, there is no need to concentrate the NC waste stream beyond a value, which when added to the other compost amendments (recycle, sawdust, wheat straw) produces a compost mix containing more than 40-percent solids (a good starting percentage). This value is calculated to be about 14-percent NC by weight.

The minimum NC concentration in the waste stream can only be estimated. The minimum NC concentration must be based on the total quantity of water evaporated during the full 40-day compost retention time. If there is too much water in the waste stream, the quantity of recovered leachate from the piles will exceed the amount that can be added back to the pile and evaporated during the 40-day cycle. Excess leachate will then begin to accumulate in holding tanks, increasing in volume during each composting cycle. This excess must eventually be discharged. Presumably, the excess leachate would contain NC fibers from the compost pile, and thus discharge would be environmentally unacceptable.

Rough calculations show that the NC slurry concentration in the waste stream should be no lower than about 4.5 percent, in order for all of the excess water to be evaporated during a 40-day cycle.

3.3 Economic Evaluation

Capital and operating costs were estimated for both the 6000-pound-per-day process and the 2000-pound-per-day process. Based on each of the two process designs, the process equipment (including general piping arrangements) and the support facilities were specified in detail. Therefore, the accuracy of these estimates is in the region of plus or minus 20 percent. However, it must be re-emphasised that even though the equipment is sized, the process design contains many assumptions (as previously discussed) that could greatly alter the costs after the process is fully developed. The potential cost impact of some of these design assumptions is discussed later.

For cost purposes, it was assumed that the compost facility would be a stand-alone facility. However, water and electrical hookups were assumed to be available within a distance of one mile and also some pipe rack (about one mile) was assumed to be available for use in the vicinity of the NC production facilities. Also, it was assumed that there would be no charge for the land.

For comparison purposes, Table 3.1 lists all the major equipment pieces utilized in both size processes.

3.3.1 Capital Costs

Based on the static pile process conceptual design, the sketches presented in Appendix A, and the major equipment list itemized in Table 3.1, a capital cost estimate was prepared and is shown in Table 3.2 for both the 6000 lb/day process and the 2000 lb/day process. Total estimated costs were $7.77 million and $3.65 million, respectively. The estimates have been divided into six categories as described below.

1. Construction costs - The sum of all costs inherent in converting a design plan for material and equipment into a project ready for start-up. This includes all construction labor (salary and benefits), process equipment (delivered to jobsite; includes items 1 through 11 in Table 3.1), and other building materials (concrete, steel, lumber, piping, valves, electrical supplies, and instrumentation). Normally, part of this work will be accomplished by a general contractor but other specialized areas

TABLE 3.1

Static Pile Process Major Equipment List

		6000 lb/day process	2000 lb/day process
1.	Static piles, 60 yd concrete pad with roof	20	7
2.	Fiberglass tanks, 20,000 gallon	4	3
3.	Fiberglass tanks, 15,000 gallon	4	0
4.	In-ground sumps, 8' deep x 7' x 7'	4	1
5.	NC slurry pumps, 100 GPM @ 60' head	4	2
6.	Leachate pumps, 50 GPM @ 30' head	4	1
7.	Leachate sump pumps, 100 GPM @ 50' head	4	1
8.	Blowers, 300 CFM	180	63
9.	Booster pump, 120 GPM @ 260' head w/2 miles of 4" dia. transfer line	1	1
10.	Mobile home trailer office	1	1
11.	Motor control centers	4	1
12.	Compost turning machines	2	1
13.	Front-end loaders, standard	2	1
14.	Dump truck, standard	1	1
15.	SCAT-type loader, 3/4-cu. yd. scoop	1	1

TABLE 3.2

Static Pile Process Capital Cost Summary

Category	Capital Costs: (1990 $) 6000 lb/day process	2000 lb/day process
1. Construction costs (direct)	$5,382,219	$2,318,383
2. Indirect and start-up expense	459,622	209,221
3. Profit and performance bond	679,206	293,098
4. Engineering	416,640	408,240
Total Fixed Plant Costs	$6,937,687	$3,228,942
5. Material handling equipment	665,067	369,897
6. Initial charge of materials	167,521	56,008
Total Cost	$7,770,275	$3,654,847

of work such as the electrical installation, piping systems, and erection of buildings will be done by subcontractors working for the general contractor.

2. Indirect and start-up expense - Includes costs which do not become a final part of the installation but which are required for the orderly completion of the installation. They may include, but are not limited to, field administration, direct supervision, contractor's fees, insurance, and taxes. Start-up costs are those costs that are incurred to bring the plant to full production. This may include employee training, process adjustments and/or capital expenditures to correct a problem, report writing, and travel of consultants. The indirect and start-up expense was estimated as 10 percent of the subcontract costs (which are part of the construction cost category, item 1, above) plus 2 percent of the total construction costs.

3. Profit and performance bond - For these estimates, the construction cost and indirect expense were summed, with the general contractor's profit calculated as 10 percent and the performance bond as 1.5 percent of that sum.

4. Engineering - Includes the cost for the design and engineering, drafting, purchasing, accounting, reproduction, travel, and home office expense to produce documents and plans for the facility, and to supervise the construction and start-up process. Engineering cost was calculated by actual estimates of the work required for the job (number of drawings, manhours of engineering calculations, etc.).

5. Materials handling equipment - The cost for all compost turning and moving equipment. The number of pieces of equipment required for each of the two process sizes is shown in Table 3.1 as items 12 through 15. This equipment was capitalized, rather than

expensed (i.e., rented or taken from RAAP's motor pool) because it will be utilized nearly 100 percent of the time by the composting operation. The cost of a single piece of each type of equipment is listed below.

(a) Compost turning machine - self propelled
Written price quote: $185,000
Vendor: Eagle Crusher Co., Inc., Galion, Ohio

(b) Dump truck
16 cubic yard, tandem axles, diesel, 16-foot bed
Telephone Price Quote: $51,363
Vendor: Anderson Ford, Florence, Alabama

(c) Front-end loader
Caterpillar 936 E, 3 cu. yd. bucket, cab with air conditioner
Telephone price quote: $110,170
Vendor: Thompson Tractor & Equipment Co., Decatur, Alabama

(d) Scat-type front-end loader
3/4 cu. yd. wheeled/diesel
Estimating Manual: $23,364
Englesman's Heavy Construction Cost File

6. Initial charge of materials - Includes the cost of compostable materials to be used in start-up of the static piles. Costs per ton were derived as shown below.

(a) Alfalfa, $114.28/ton quote from Lauderdale and Colbert County, Alabama farmer's co-operative.

(b) High-protein horse feed, $240/ton quoted from same source as alfalfa above.

(c) Sawdust, free to haul according to local sawmill operators, \$9.46/ton estimated hauling charge (assumed 50 miles one-way at \$1.00/mile using dump truck).

(d) Sewage sludge, free to haul according to sewage plant operators, \$6.25/ton estimated hauling charge (same hauling assumption as for sawdust).

The total materials required for each size process are listed below.

	6000 lb/day process	2000 lb/day process
-Alfalfa	508 tons	169 tons
-Horse feed	254 tons	85 tons
-Sawdust	1414 tons	471 tons
-Sewage sludge	300 tons	100 tons

For purposes of cost projection, it is useful to develop a mathematical equation relating the economy of scale to capital costs. By utilizing the cost figures from both facility sizes, an equation having a standard exponential format (often used to relate economy of scale) can be constructed as follows:

$$\text{Estimated capital cost, \$, million} = 7.77(R)^{0.68}$$

$$\text{where } R = \text{Ratio: } \frac{\text{NC Flow Rate, lb/day}}{6000 \text{ lb/day}}$$

It should be noted that the exponential factor in the equation (0.68) is close to the factor widely used by the chemical industry to estimate overall plant economy of scale (0.6).

This equation can also be used to approximately determine the impact that a change in design assumptions would have on the capital cost of a 6000 lb/day process. In this case, the value of "R" is substituted with a value equal to the relative impact of the design change on the size of the facility. For example, if experimental research shows that the compost retention time can be reduced from 40 days to 20 days, the number of static piles can be cut in half. Hence the new capital cost estimate can be determined:

$$\text{Capital cost} = 7.77\ (20/40)^{0.68} = \$4.85 \text{ million}$$

Similarly, an increase in initial NC concentration in the compost from 5 percent up to 10 percent (without changing the compost retention time) would also halve the facility size and would have the same impact on capital cost as the above example.

As a further example, this equation can be used to estimate the capital cost of a 6000 lb/day NC composting facility on the basis that it could be operated at conditions typically used for sewage sludge composting (14 day compost retention time and 8 percent initial concentration):

$$\text{Capital cost} = (7.77)\ [(14/40)(5/8)]^{0.68} = \$2.76 \text{ million}$$

Although this equation is only an approximation, it can be seen in the above calculation that the unusual operating conditions employed to compost NC have a large impact on the capital cost ($7.77 million versus $2.76 million).

3.3.2 Operating Costs

The operating costs for both facility sizes are shown in Table 3.3. The total operating costs are estimated to be $455 per ton of NC for

TABLE 3.3

Static Pile Process Operating Cost Summary

	6000 lb/day process		2000 lb/day process	
	Annual Cost	Cost Per Ton of NC Fines	Annual Cost	Cost Per Ton of NC Fines
Personnel 1-Supervisor (1/4 time) 4-Operators (6000 lb/day) 2-Operators (2000 lb/day) 1-Maintenance	\$278,500[a]	\$254[a]	\$176,300[a]	\$483[a]
Compost Materials -Wheat Straw -Sawdust	89,600	82	29,868	82
Utilities	85,200	78	44,134	121
Fuel, Vehicle Maintenance	25,400	23	15,200	42
Miscellaneous	19,000	18	9,500	26
Total	\$497,700	\$455	\$275,002	\$754

[a]Includes 50 percent of salary in benefits plus 35 percent contractors overhead and profits.

the 6000 lb/day process and $754 per ton of NC for the 2000 lb/day process. All operating costs are expressed on a dry ton of NC basis. Both cost estimates are significantly lower than USATHAMA's estimate for incineration ($2000 per ton of NC). Incineration is an alternative destruction method being examined by USATHAMA. The $2000 per ton estimate is a rough estimate since there are no data available regarding incineration of NC slurried in water.

In both cases the largest expense category is labor, accounting for about 56 percent of the cost for the larger process and about 64 percent for the smaller. The operating crew shown on both tables is figured on day shift only (40 hours per week). All manual activities can be done during these hours. At night and on weekends, the only ongoing activity, temperature control of the static piles, can be maintained by the automatic instrumentation system.

The assignment of labor to a conceptual process can be rather difficult without having had the benefit of actual operating experience, so this is one cost category in which the estimate may have a fairly wide range of error. The remaining cost estimate categories have an accuracy of plus or minus 15 percent.

It should be noted that there is potential for cost savings in the category of compost materials. Waste cotton linters or wood pulp from the NC production area may be suitable to substitute for wheat straw. (Any soft cellulosic material such as grass clippings or food waste may also be substituted). The quantity of wheat straw to be replaced every day is quite large, amounting to 4.8 tons per day. The potential savings are about $53 per ton of NC fines.

As with capital costs, an economy of scale equation can be devised for the operating costs. However, when the operating costs are expressed on a per-ton-of-NC basis, the exponential scale factor becomes negative (i.e., operating costs on a per-ton-of-NC basis increase with decreasing facility capacity).

$$\text{Operating cost, \$ per ton of NC} = 455\ R^{-0.46}$$

$$\text{where } R = \text{Ratio: } \frac{\text{NC Flow Rate, lb/day}}{6000 \text{ lb/day}}$$

This equation should not be used to estimate the impact of proportional changes in the design assumptions (as was done with capital costs). A new equation was devised by analyzing the impact of design changes on each operating cost category:

$$\text{Operating cost, \$ per ton of NC} = 455\ R^{0.36} \text{ (6000 lb/day size)}$$

where R = Proportional change in facility size brought about by changing the design assumptions.

In the previously used example where the compost retention time was theoretically reduced from 40 days to 20 days, the new operating cost can be estimated:

$$\text{Operating cost} = 455\ (20/40)^{0.36} = \$355 \text{ per ton of NC}$$

Utilizing the above equation to estimate the theoretical operating cost for NC composting using the same operating basis as most sewage sludge facilities (14 day retention time, 8 percent initial concentration), the cost becomes:

$$\text{Operating cost} = 455\ [(14/40)(5/8)]^{0.36} = \$263 \text{ per ton}$$

3.3.3 Land Requirements

By its nature, composting in static piles requires considerable land space. Land requirements are mentioned to aid in future planning and layout. The 6000 lb/day process is composed of four distinct units, each having five static piles plus dedicated equipment. Each unit covers an area with dimensions of approximately 80 yards by 100 yards. Each unit is independently operable so the layout does not necessarily have to be contiguous. However, the units should be within a reasonable distance from each other to allow moving equipment (composters, front end loaders, etc.) to be shared by the units. In the case of the 2000 lb/day process, there is only one unit containing seven static piles. The overall dimension of the unit is about 80 yards by 140 yards.

IV. IN-VESSEL PROCESS FEASIBILITY AND ECONOMIC EVALUATION

4.1 General Evaluation

A quite different approach was taken in the evaluation of in-vessel composting systems versus the approach used for the static pile system. In-vessel composting systems, as a class, are generally automated package equipment designs developed by independent process developers. It is outside the scope of this study to reconstruct design details of these systems and modify them for NC composting. Furthermore, it was learned from visiting with system operators that the state of the art in in-vessel system composting has not yet matured to full commercial viability. Operators are still experiencing difficulties and there are relatively few systems in commercial operation in the U.S. According to the December 1989 issue of BioCycle magazine, out of 115 fully operational sludge composting facilities in the U.S., only 21 are in-vessel type. However, far more in-vessel systems are in various stages of planning, design, or construction than static pile and windrow systems. This indicates that in-vessel systems are emerging as the preferred method of composting for the future.

The approach taken in this study was to evaluate specific in-vessel composting systems by answering three basic questions about each system:

1. Can this in-vessel system design be modified to compost 6000 lb/day or 2000 lb/day of NC fines in the form of a 10 percent slurry?

2. What is the approximate capital cost and operating cost of this in-vessel system after being modified for NC fines composting?

3. Does this in-vessel system have advantages or disadvantages compared to the static pile system design or compared to other in-vessel systems?

Before discussing specific in-vessel systems, it must be stated that the answer to question 1 for all of the in-vessel systems that were studied was generally yes, these systems can be modified for NC composting. All of the systems can be re-sized to handle the long 40-day retention time for NC. The only system that may have a problem in this area is the Fairfield system. The Fairfield design utilizes a circular vessel geometry in which the fresh compost begins at the outside of the circle and moves toward the discharge point in the center. Over a 14-day compost period, the compost pile shrinks as it loses water and carbon dioxide, closely matching the change in circumference as it moves inward. With a longer retention time the ratio between the outer diameter and inner diameter of the discharge port may have to be altered during design.

Two other areas of concern are (1) the use of large particle size wheat straw as an amendment (not commonly used in in-vessel sludge composting) and (2) excess moisture in the initial compost mix. Wheat straw can be ground or chopped separately and then added to the mix to achieve good particle size. If excess moisture is a problem, the NC slurry can be partially filtered (using any type of conventional filtration equipment) leaving a low volume of milky filtrate with a relatively low NC fines content. This filtrate can then be injected into the compost downstream at a point where compost has had sufficient time to partly dry. (In effect, the filtrate fills the same role that the leachate plays in the static pile system.)

In estimating the capital costs of the in-vessel processes, it was assumed that the added cost of equipping the process for NC composting would be completely offset by the deletion of sewage sludge handling equipment (storage bins, belt haulers, trucks, etc.).

Three in-vessel composting facilities were evaluated for this study. Two of these processes, Metcalf & Eddy and Ebara, were recommended by USATHAMA for study. The third, Fairfield, was selected by TVA on the basis that it has been widely discussed and analyzed in recent literature.

A fourth process, Royer (Royer Industries, Kingston, Pennsylvania), was scheduled for visit and evaluation, but was subsequently dropped from consideration. Royer does not currently have a working prototype or a full-scale process, although a facility is scheduled to begin construction soon in South Carolina. However, since it appeared from Royer advertisements that their process was potentially less costly and more compact in size, TVA requested that they provide an informal capital and operating cost estimate based on process conditions provided by TVA. Initially Royer agreed, then later stated that the long retention time would make the compost reactor channel length too long to be practical. (With the Royer design, the compost is gradually moved down long pre-fabricated channels.)

One final point should be made before discussing the merits of the individual processes. The cost estimates for the three processes should be considered to be rough estimates at this stage of evaluation. It would seem improper to use these estimates for comparisons among the three individual processes. Rather, the estimates should be considered as three data points that can collectively represent a range of in-vessel processing costs.

4.2 Evaluation of Specific In-Vessel Systems

4.2.1 Metcalf and Eddy

Approximately 155 tons per day of sewage sludge from the city of Baltimore is composted at a facility operated by Metcalf and Eddy

(M&E), an environmental services company. The facility sits on about seven acres of land on the southeast side of Baltimore near the Chesapeake Bay. It employs 20 people and was built in 1985 at an original cost of 13 million dollars.

4.2.1.1 Process Description

The heart of the M&E facility (also known as a Paygro facility) consists of two long metal wall channels that hold the compost mixture during aeration. Since each channel is operated batchwise, the operation is not continuous as are many other in-vessel processes, rather it more closely resembles an in-vessel version of an aerated static pile operation. The channels sit side-by-side in an enclosed building.

Each batch begins by continuously mixing fresh sewage sludge with recycle compost and sawdust in a pug mill. The compost mixture travels on belts to an automated loading machine which fills a channel by traversing the width and length of the channel. The channel depth is about 10 feet. Aeration is provided by blowers that force air upward through the mix. The aeration rate is regulated to control the compost temperature at a constant 50°C. Periodically, the compost mixture is stirred using a machine called an extractovator. The extractovator moves down the length of the channel, picking up small amounts of compost and then returning it to the pile. The retention time in the channel is normally 14 days.

The completed compost is removed by the extractovator and carried on belts outside the channel building to a holding area. Here, it undergoes restricted aeration to raise the temperature for pathogen destruction. After pathogen destruction, the compost is hauled by front end loader to a stacking area for curing. The finished compost is then sold to distributors outside the Baltimore area.

4.2.1.2 Capital Cost

A simple approach was taken to estimate the capital cost of a conceptual M&E facility modified for NC composting. First, the relative size of the NC facility, as compared to the Baltimore M&E facility, was calculated by ratio of the two compost reactor volumes. On this basis, composting 6000 lb/day of NC (at conditions of 40-day retention time and 5 percent initial mix concentration) would require a facility about equal to 69 percent of the size of the Baltimore facility.

Second, the inflation factor for construction costs must be taken into account. The Baltimore facility was built in 1985 at a cost of $13 million. Using an economy of scale factor of 0.6, and escalating the cost into 1990 dollars using a construction cost index factor of 1.17, the following is obtained:

$$\text{Estimated cost of an M\&E NC facility} = (\$13 \text{ million})(0.69)^{0.6}(1.17) = \$12.2 \text{ million (1990 cost)}$$

This cost is higher than the estimated capital cost of the 6000 lb/day static pile facility, which was estimated to cost $7.77 million.

4.2.1.3 Operating Cost

The M&E personnel provided TVA with a complete breakdown of their operating costs. However, these costs cannot be directly adjusted and applied to a 6000 lb/day NC facility in the absence of specific information as to how the expenses were incurred. Therefore, some simplifying assumptions were made in adjusting these costs. These are discussed briefly below before presenting the results.

The Baltimore M&E facility directly employs 20 people, including operators, foremen, managerial staff, office personnel, and one full time analytical chemist. There are eight operators out of these 20. For the 6000 lb/day NC facility, it was assumed that these eight people could reasonably be cut to four, due to the smaller size of the facility and the longer retention time (i.e., fewer loadings and unloadings of the reactors). As with the static pile estimate, it was assumed that the occasional need for managerial, clerical, and analytical support could come from sources already at Radford AAP without having to actually hire additional persons. Therefore, with four persons forming the core operating crew, it was assumed that the same crew that was proposed for the static pile facility could also handle a similar size M&E facility: one supervisor (1/4 time), four operators, and one maintenance.

The cost of compost materials (sawdust, wheat straw) was assumed to be the same as for the static pile facility since it is likely the same materials would be used. For the remaining cost categories of utilities, maintenance, technical services, and miscellaneous, it was assumed that these costs would be about 83 percent of the Baltimore M&E costs (assuming cost reduction will roughly follow a square root function, i.e., $0.69^{0.5} = 0.83$). Sludge transportation was assumed to be zero for the NC facility since long distance trucking would not be required for NC.

Table 4.1 shows a cost breakdown by category of the operating costs for the full-size Baltimore M&E facility and for the theoretical M&E facility composting 6000 lb/day NC. The total operating cost for the theoretical M&E facility was about 70 percent higher than the static pile estimate ($772 per ton of NC versus $455 per ton).

One cost category that was much higher for the conceptual M&E facility was maintenance costs ($182 versus $23 for static pile). Higher maintenance costs could be expected for an automated compost handling facility.

TABLE 4.1

Actual Operating Cost Summary for the Baltimore Metcalf and Eddy Composting Facility Conceptual Costs for a Facility Composting 6000 lb/day NC

	Annual Operating Cost		
	Baltimore M&E Facility	Theoretical M&E 6000 Lb/Day NC Facility	Cost Per Ton of NC Fines
Personnel	$ 600,000[a]	$278,500[b]	$254
Compost Materials	120,000	89,600	82
Utilities	168,000	139,400	127
Maintenance	240,000	199,200	182
Technical Services	48,000	39,800	36
Sludge Transportation	180,000	0	0
Miscellaneous	120,000	99,600	91
Total	$1,476,000	$846,100	$772

[a]The personnel cost figure for the Baltimore M&E facility does not include benefits or contractors profit.

[b]Includes 50 percent of salary in benefits plus 35 percent contractors overhead and profit.

4.2.1.4 Discussion

TVA's overall impression of the Baltimore M&E facility is that it is a basically sound commercial operation. There are some mechanical problems that are relatively minor and are still in the process of being corrected. These problems mainly involve plugging at various points, generally bins and hoppers. If in the future USATHAMA selects a compost facility contractor, then, as with any contractor, it is recommended that USATHAMA obtain a mechanical performance guarantee. (A process performance guarantee may not be easily obtained because NC is unusual as a compost material.)

There also appears to be a fairly severe corrosion problem on the building structural beams and other points except for the composting equipment itself. Apparently, this problem results from operation of the aeration blowers in an updraft mode, which pushes ammonia and moisture into the internal building atmosphere. In the winter, moisture condenses on the walls and ceilings. Originally, the aeration was designed to be operated in a downdraft mode (i.e., vacuum), but the 10-feet deep compost beds tended to pack down, restricting air flow. If the facility had been originally designed for updraft operation, I-beams and other metal parts could have been specified with the appropriate corrosion protection measures.

If land space becomes a limiting factor at RAAP, an M&E compost process would be ideal due to its compact channel geometry and its bed depth, which is twice that of typical static piles. M&E personnel stated that their site space of seven acres was rather limiting for their operation, but this was due to the space needed to stack and hold the compost during curing. A curing cycle would not be required for NC composting due to the long composting time required.

4.2.2 Fairfield

Approximately 100 tons per day of sewage sludge from Clinton County, New York, and the city of Plattsburgh is composted in a facility designed by the Fairfield Engineering Company. The Fairfield facility, completed in 1986 at an approximate cost of $7 million, was funded by a grant from the U.S. Environmental Protection Agency as an innovative technology demonstration project. Fairfield Engineering maintains an active role in the operation, maintenance, and ongoing modification of the facility, and has a full-time engineer on site.

At the time of TVA's site visit, the facility was down for repair and equipment clean-out.

4.2.2.1 Process Description

The Fairfield system utilizes two 116-foot diameter circular shaped digesters in which the compost mixture is aerated (14-day retention time). Operation is continual. A system of overhead mounted augers are used to periodically mix and move the compost from the outside of the circular bed to the discharge port at the center of the bed. As the compost bed moves inward, fresh compost mix is loaded along the outside circumference of the circular bed. Bed depth is approximately 9-10 feet. The circular geometry enables the bed to stay level as the compost mix moves inward and loses mass due to normal composting action.

4.2.2.2 Capital Cost

The Fairfield facility in Plattsburgh is very close to the size that would be required if the Fairfield equipment were employed to compost 6000 lbs/day of NC. The capital cost was estimated by applying the construction cost index for 1986 (1.19) to the original cost of \$7 million. This gives an estimated cost in 1990 dollars of \$8.3 million. (Note that the cost index in 1986 (1.19) was actually higher than the cost index for 1985 (1.17) used in the M&E cost estimate. This was due to disinflation in the construction industry during that time period.)

4.2.2.3 Operating Cost

The Fairfield personnel provided TVA with a complete breakdown estimate of their operating costs. However, as with the M&E facility, these costs cannot be directly adjusted and applied to a 6000 lb/day NC facility in the absence of specific information as to how the expenses were incurred. Therefore, some simplifying assumptions were made as discussed below.

The Fairfield facility employs a full-time operating crew of nine people plus a full-time representative from Fairfield. Using the same logic that was applied to the M&E facility, it was estimated that the number of operators could be reduced to four because of the longer retention time (fewer loadings and unloadings of the reactors). Therefore, the same crew (one-fourth supervisor, four operators, and one maintenance) that was proposed for the static pile facility was assumed to be able to handle a similar size Fairfield facility.

The cost of compost materials (sawdust and wheat straw) was assumed to be the same as the static pile facility since is it likely the same materials would be used. (It should be noted that Fairfield's wood chip cost, \$74,000 per month, appeared to be very high, but since Fairfield's cost was not used to estimate this cost category, it has no impact on the NC facility cost estimate.)

Fairfield's utility cost was reduced for the NC facility estimate because of climatic difference between Plattsburgh, New York, and

Radford, Virginia. Fairfield often has to preheat their air during the winter prior to compost aeration. This practice would not be required as often at Radford. Accordingly, the cost for fuel was reduced from $24,000 per month to $12,000 per month. The remaining utilities costs were assumed to be the same.

The last two cost categories, maintenance and miscellaneous, were assumed to be the same as currently experienced in Plattsburgh.

Table 4.2 shows a cost breakdown by category for the current Fairfield facility and for the theoretical Fairfield facility composting 6000 lb/day NC in the same size equipment. As with the M&E facility, the operating cost was much higher than the static pile estimate ($712 per ton of NC versus $455 per ton). The operating cost of the theoretical Fairfield NC facility was comparable to the estimate for the theoretical M&E facility ($712 per ton of NC versus $772 per ton).

4.2.2.4 Discussion

TVA's overall impression of the Fairfield facility is that it is still in the demonstration (or pilot) stage of technology development. Some of the problems they are experiencing are directly related to the extremely cold climate in Plattsburgh, which is near the Canadian border. However, many of the problems are systemic in nature. For example, the augers used to move compost through the circular digesters wear out at the tip and have to be replaced frequently. New auger designs are still being tested.

The Fairfield representative was particularly candid when discussing the problems that the facility was experiencing. Some problems, such as the auger problem, would likely have gone unnoticed if he had not volunteered the information. This must be taken into account when

TABLE 4.2

Actual Operating Cost Summary for the Plattsburgh Fairfield Composting Facility and Conceptual Operating Costs for Composting 6000 LB/DAY NC

	Annual Operating Cost		
	Plattsburg Fairfield facility	Theoretical Fairfield 6000 lb/day NC facility	Cost per ton of NC Fines
Personnel	$ 480,000	$278,500*	$254
Compost Materials	984,000	89,600	82
Utilities	334,000	190,200	174
Maintenance	192,000	192,000	175
Miscellaneous	30,000	30,000	27
Total	$2,020,000	$780,300	$712

*Includes 50 percent of salary in benefits plus 35 percent contractors overhead and profit.

making relative comparisons of the in-vessel facilities. The representatives from M&E and Ebara (Section 4.3.3) did not volunteer information about problem areas, although when questioned they were very open to providing this information. Nevertheless, TVA's impression of the Fairfield facility is that many problems must be overcome before it can be considered commercial.

Like the M&E facility, the Fairfield facility offers an advantage of reduced land space requirements as compared to a static pile facility due to its use of large vessels to retain the compost mixture.

4.2.3 Ebara

Approximately two tons per day of food waste is composted in a demonstration-scale composting facility operated by Ebara Environmental Corp., the process developer. The facility is located in the mountains of southwest Pennsylvania near the Seven Springs Mountain Resort. The large restaurant facilities at the resort are the source of food waste for the process. The process is fully operational although some minor process modifications are still being made as might be expected for a demonstration unit. The facility was constructed in early 1990 at a cost of $500,000. Ebara employs two engineers on site to oversee data collection, engineer process modifications, and troubleshoot process problems. One operator is employed.

4.2.3.1 Process Description

The Ebara compost reactor is an open top channel made with concrete block walls to retain the compost mixture. Overall dimensions of the channel are approximately 7 feet wide by 45 feet long with a 5 foot depth. The reactor is housed in a metal building.

The Ebara process uses a unique processing method in which the compost mixture is continually moved along the length of the reactor by a traversing paddle wheel. A typical compost cycle proceeds as follows: Food waste is hand loaded from plastic tubs into a short (2-3 feet) empty zone at the front end of the reactor channel. A small amount of recycle compost and fresh wood chip amendment are also loaded into the front end zone with the food waste. The food waste contains about the right combination of moisture, nutrients, and porosity to be compostable, so very little additional material is needed. The remainder of the reactor channel contains compost mix from previous operating cycles. The mixture at the rear end of the channel has been retained for 12 days and is fully composted. After the fresh materials are loaded, the operator initiates operation of the traversing paddle. The paddle first traverses the width of the channel at the rear end, picking up and tossing the compost onto a moving belt. The belt carries the compost mix outside to the curing area. The paddle continues to traverse and move inward, mixing and tossing compost into the zone previously vacated by the tossing action. When the paddle reaches the front end, it leaves an empty zone where fresh material can be added.

Air is pulled by a vacuum blower through the compost mixture to control temperature and provide oxygen for biological degradation. The vacuum blower pumps the air into an underground soil/gravel mix to remove ammoniacal odors.

The finished compost is used in the many flower and shrub gardens at the resort.

4.2.3.2 Capital Cost

The Ebara demonstration facility is significantly smaller than the facility size that would be required to compost 6000 pounds per day of NC. Having a total volume of only 58 cubic yards, the Ebara unit is about 93 times smaller than the 5400 cubic yard requirement for NC composting. Such a difference in size is likely to induce a large error when the capital costs are scaled upward to represent the full size facility. This should be taken into account when weighing the Ebara capital cost estimate with other in-vessel system estimates.

Since the Ebara demonstration facility was completed in 1990, no inflation factor was needed to make the capital cost estimate. Only the scale-up in size was used. Applying the standard scale-up factor of 0.6, capital cost is obtained:

Capital cost, theoretical = $(\$500{,}000)\,(93)^{0.6} = \$7.6$ million for a 6000 lb/day NC Ebara facility

This estimate is quite close to the estimated cost for the static pile system, $7.77 million and is not far from the estimate for the Fairfield facility, $8.3 million.

Because the scale-up factor for the Ebara facility was so large, TVA asked Ebara officials to make a rough theoretical estimate of the capital cost of a 5400 cubic yard facility that utilizes Ebara equipment. Ebara responded with an estimate of $4.5 million, which included the installed cost of the basic equipment: fermentation reactors with rotating paddle wheel, crane, aeration system, drainage system, temperature control system, soil odor filter, discharge conveyor, curing yard, and all necessary buildings. To this cost TVA added two front end loaders, a dump truck, utility hook-ups (service water, electrical), service road, and fencing. This brought the total capital cost estimate to a figure of $5.8 million. It must be emphasized that this figure is based on rough calculations, not the cost of a working facility.

4.2.3.3 Operating Cost

The operating philosophy of the Ebara demonstration unit is typical of that found in pilot-plant operations. Thus Ebara's current operating costs would not translate to a commercial operation. When Ebara personnel made the above described capital cost estimate, they also roughed out some of the operating costs for a full-scale facility. Their estimate for labor included one manager and four operators. (No maintenance personnel were included.) Therefore, it seemed reasonable that the standard crew (one-fourth supervisor, four operators, and one maintenance) proposed for all the other estimates could be used for the Ebara estimate. Ebara also provided figures for power (350,000 KWH) and maintenance costs ($90,000). The remaining cost categories were predicted by using costs from the 6000 lb/day NC static pile estimate.

Table 4.3 shows an operating cost breakdown for a conceptual Ebara facility composting 6000 lb/day of nitrocellulose. The total estimated operating cost is $471 per ton of dry NC. This is comparable to the estimated operating cost of the 6000 lb/day static pile process ($455), but significantly lower than estimates for the two other in-vessel processes, Metcalf & Eddy ($772) and Fairfield ($712).

4.2.3.4 Discussion

The Ebara engineers arranged a demonstration run for the TVA investigative team during the site visit. The operation appeared to be mechanically sound. According to Ebara engineers, most of the equipment development is complete and the focus now is to fine-tune the process. Overall, the operation was impressive. Discussions with the Ebara engineers revealed that they were confident that the Ebara process could be adapted and scaled-up to compost 6000 lb/day NC. A pilot facility similar in size to the Ebara facility would be appropriate to test NC composting to determine the potential commercial-scale viability of the process.

TABLE 4.3

Operating Cost Summary for a Conceptual Ebara Facility Composting 6000 lb/day

	Annual Operating Cost	Cost Per Ton of NC Fines
Personnel	$278,500[a]	$254
Compost Materials	89,600	82
Utilities	23,350	21
Maintenance	90,000	82
Fuel, Vehicle	15,750	14
Miscellaneous	19,000	18
Total	$516,200	$471

[a]Includes 50 percent of salary in benefits plus 35 percent contractors overhead and profit.

V. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- It is technically feasible to compost RAAP's waste NC fines using either (1) a static pile type of composting operation that has been specifically designed to handle NC fines such as that described in Section III, or (2) a modified in-vessel facility such as one of those described in Section IV.

- Based on research work conducted by Roy F. Weston, Inc., on composting of NC in soils and the current state of composting technology, it is assumed (1) that the length of time to compost NC down to a target concentration of 50 mg/kg (ppm) will be longer for NC (estimated 40 days) than for most compostable materials such as sewage sludge (14 days), and (2) the maximum initial concentration in the freshly mixed compost will be lower for NC (about 5 percent by weight) than for sewage sludge (about 8 percent by weight).

- The capital cost of a static pile composting facility that can process 6000 pounds per day of NC will be about $7.77 million. For a smaller facility that can process 2000 pounds per day NC, the capital cost is estimated to be $3.65 million.

- The operating cost to compost 6000 pounds per day of NC in a static pile facility is estimated to be $455 per dry ton of NC. For a 2000 pound per day facility, the operating cost is estimated to be $754 per dry ton of NC. These costs are significantly lower than the estimated cost of incineration ($2000 per dry ton of NC), based on USATHAMA's incineration estimate.

- The operating conditions required to compost NC (see item 2 above) have a major impact on the estimated capital and operating cost. If NC could be composted at conditions similar to those used for sewage sludge, then it is estimated that the capital cost of a 6000 lb/day NC facility could be reduced from $7.77 million to about $2.8 million, and the operating cost could be reduced from $455 per dry ton of NC to about $263.

- The capital cost of a 6000 lb/day NC in-vessel composting facility that utilizes commercially-licensed technology will roughly range from $5.8 million to $12.2 million. The operating cost will roughly range from $471 to $772 per dry ton of NC.

5.2 Recommendations

- Laboratory and pilot-scale research should be performed on nitrocellulose composting. The research work should focus on finding ways to reduce the length of composting time and/or increase the initial concentration of NC in the compost mix. Listed below are some recommendations for future testing.

  (a) Determine the lowest carbon-to-nitrogen ratio that will not produce ammonia odor problems or retardation of the composting rate.

  (b) Examine the effect of pile temperature as a variable. Temperature should be studied at levels held constant throughout the composting time period and also studied by varying the temperature during the composting period.

  (c) Examine the effects of changing the relative proportions of amendments (wheat straw, sawdust, etc.) in the compost mix. In particular, the possibility of reducing wheat straw usage should be examined. The cellulose in wheat straw is so readily available that the microorganisms may tend to use it exclusively instead of NC, if too much straw is present. However, at least some readily available cellulose is needed to encourage rapid growth of the microorganism population early in the compost cycle. A balance is needed to maximize the overall consumption rate of NC.

An additional concern is that carbon sources in the pile may be consumed well before the end of the 40-day cycle, and the pile will run out of energy to maintain the operating temperature. Thus, the system may benefit from small additions of amendments during the compost cycle. This should be tested.

Also, the selection of amendment materials should undergo testing. In particular, there is a concern that recycle compost will not provide adequate reseeding of the next static pile in the cycle. An outside microbe source, such as manure, may be needed as an amendment for each new static pile.

(d) Perform routine testing of standard compost system variables, i.e., moisture content, pH, supplemental nutrients (phosphorous and nitrogen).

(e) Examine the possibility of using anaerobic conditions (i.e., restricted aeration) during some portion of the compost cycle. Anaerobic conditions may be able to rapidly denitrate NC by reducing the oxidized nitrogen into ammonia, thereby leaving a cellulose molecule that is easily broken down. However, since ammonia may tend to retard microorganism activity during subsequent aerobic conditions, the anaerobic cycle must be tightly controlled to avoid excessive ammonia production.

(f) Determine the sequence of reactions which NC undergoes during biological breakdown by identifying the intermediate molecular species. At this time, the breakdown process of NC during composting is not well understood. (Current literature suggests the possibility that NC simply undergoes a partial loss of nitrate groups (denitration) instead of a complete breakdown to carbon dioxide, water, and nitrates). By obtaining a fundamental understanding of the NC composting process, the search for optimum composting conditions should be aided.

- A research study should be completed to determine the maximum concentration of undecomposed NC that can be left in the finished compost and not cause an environmental problem when the compost is disposed. The concentration limit adopted for composted soils by Roy F. Weston, Inc., used by TVA for this study was 50 mg/kg, a limit that appears to be very stringent considering that NC's main hazard is its flammability. This work should be done in conjunction with the compost research work recommended above.

- If in the future the Army chooses commercially licensed in-vessel technology to compost NC, mechanical performance guarantees should be obtained by contract from the licensor. At this time, in-vessel composting technology has not fully matured to commercial applicability, and it must be insured that the contractor be responsible for on-site mechanical changes. Furthermore, if the licensor performs NC composting tests in their equipment for the Army and makes claims regarding the effectiveness of their process, a process performance guarantee should also be obtained.

APPENDIX A

STATIC PILE PROCESS DRAWINGS

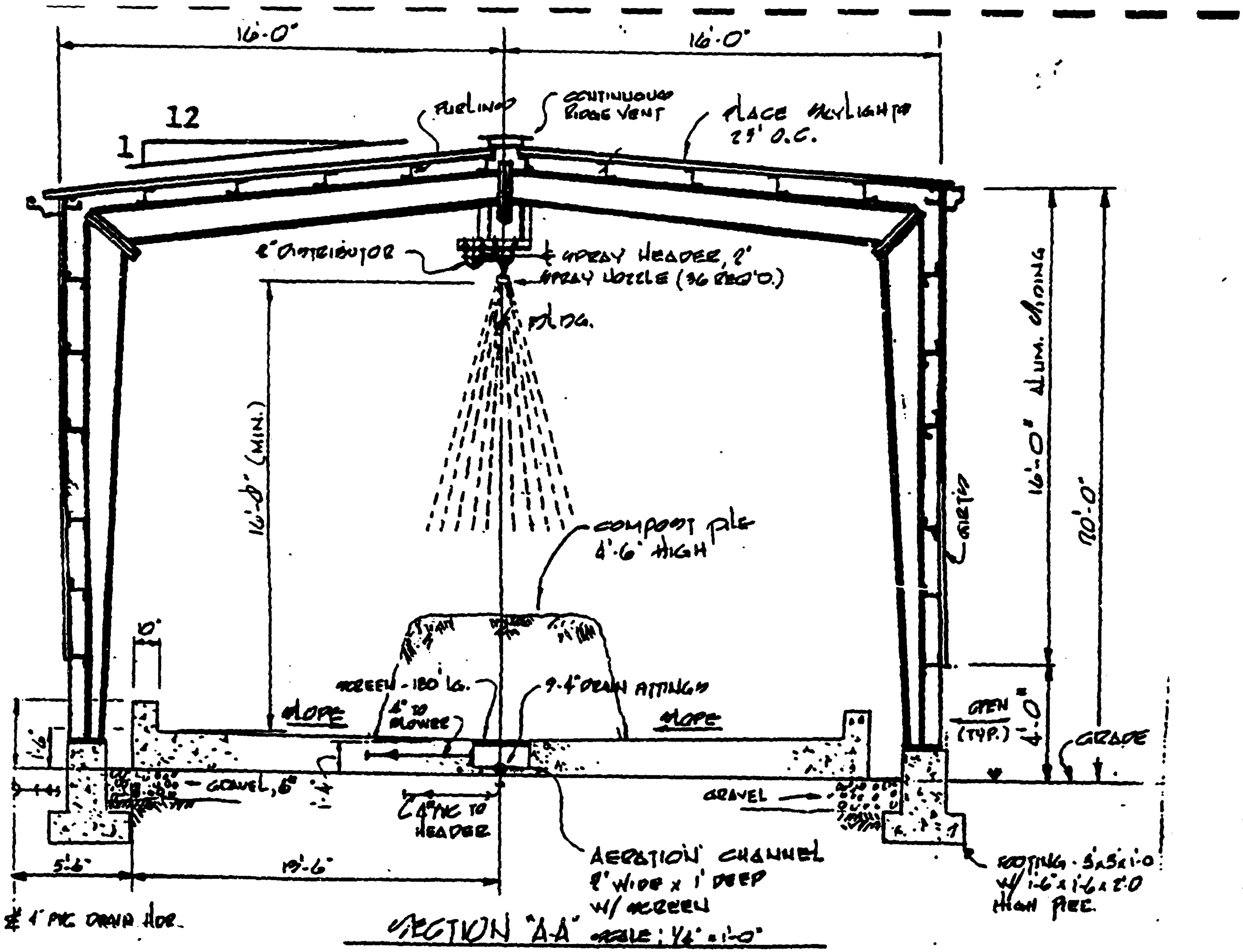


FIGURE A-1

End view of a static pile

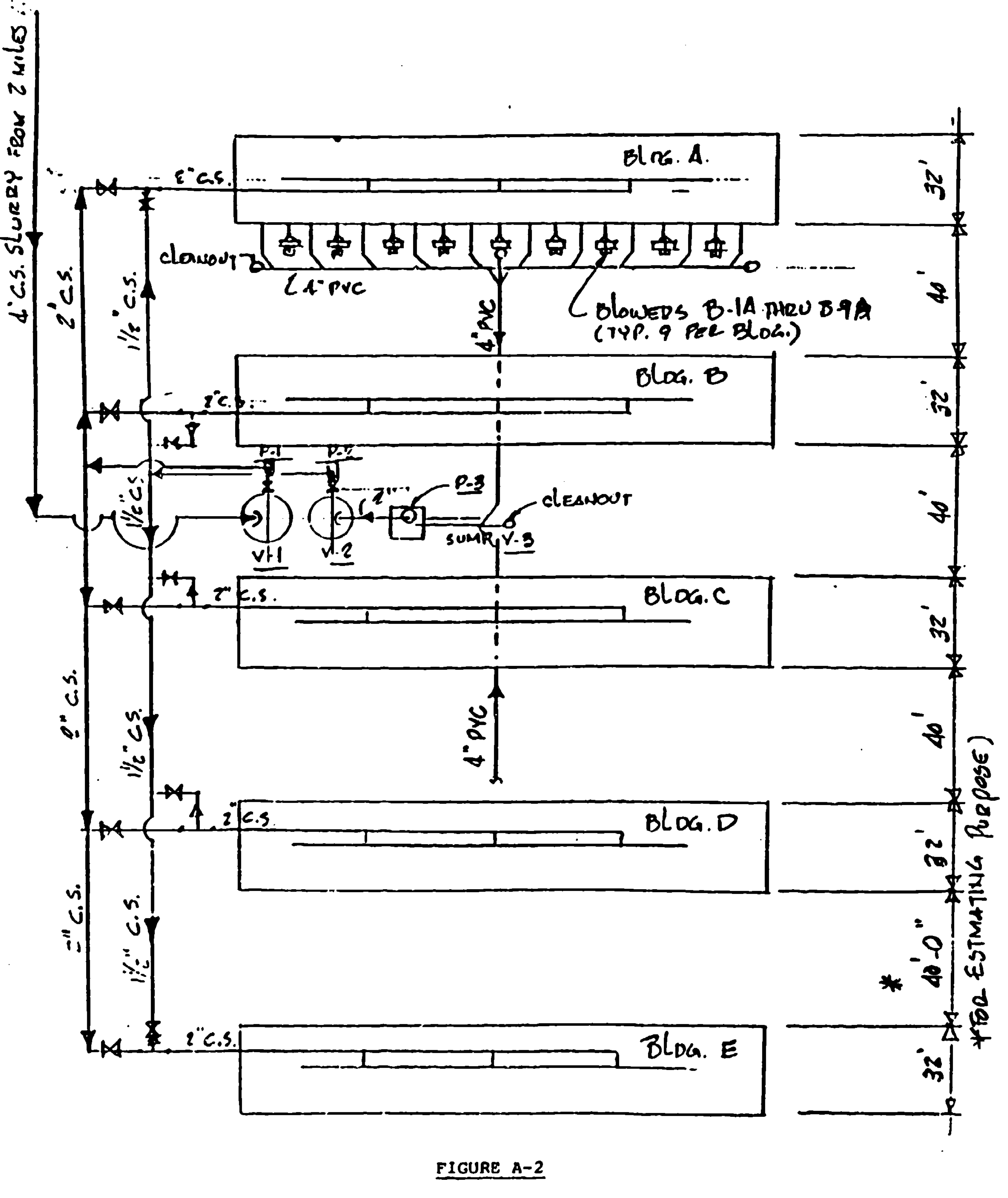


FIGURE A-2

Equipment and piping layout for a five static pile unit