TNT-CONTAMINATED SOILS REMEDIATION FOR

VOLUNTEER ARMY AMMUNITIONS PLANT

[redacted]

A Thesis

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[redacted]

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I am submitting a thesis written by Janice Tevonia Russell Horn entitled "TNT-Contaminated Soils Remediation for Volunteer Army Ammunitions Plant". I have examined the final copy of this thesis and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science with concentration in chemical engineering.

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James Cunningham, Major Professor

We have read this thesis and recommend its acceptance:

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[redacted]

Assistant Provost for Graduate Studies

DEDICATION

This thesis is dedicated to my family,

especially my husband Darryl and my children

Arlyn and Darryl Jr.

for without their help, encouragement and patience

I would never have conquered this challenge.

ACKNOWLEDGEMENTS

There are many people to whom I am thankful for making my time at the University of Tennessee at Chattanooga rewarding. I am particularly thankful to my Dissertation Committee, Doctors James Cunningham, Michael Jones, Phil Kazemersky and Chris Mawata for their support, suggestions, and encourgement.

ABSTRACT

Many facilities involved in the production of munitions, or with a history of munitions production or storage, are faced with the remediation of residual explosives in soil, groundwater and process wastewater. This requirement has become particularly prevalent with the closing of many military installations across the country.

The Volunteer Army Ammunition Plant (VAAP) is a 6,681 acre Government owned and contractor-operated facility for the production and storage of trinitrotoluene (TNT).

Two (2) technologies were investigated for TNT (nitroaromatic explosive) contaminated soils remediation. The technologies are phytoremediation and thermal incineration. Phytoremediation is an in-site wetlands-type remediation which uses plants. Thermal incineration (mobile) treatment achieves complete destruction of the organic portion of the contaminated soil using heat.

After evaluation of both phytoremediation and thermal incineration (mobile), thermal incineration was chosen as the optimum remedial technology for TNT contaminated soils remediation at the VAAP Facility.

The evaluation of the technologies include but is not limited to: the following regulatory requirements, technology and design parameters for remedial activities at VAAP, costs and environmental impact. An International Technology Corporation countercurrent rotary kiln incineration is recommended for soils at the VAAP facility with a total remedial cost of approximately $12,822,000.

The Technology Background, Technology Applications, Technology for Soils Remediation, Remedial Design and Enviro-Economic Analyses are outlined and detailed in Chapters One, Two, Three, Four, and Five, respectively.

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CHAPTER ONE - TECHNOLOGY BACKGROUND

2,4,6-Trinitrotoluene has been one of the most commonly used high explosives among those derived from aromatic hydrocarbons. In recent investigation of federal facilities contaminated with explosive or radioactive wastes reported by the Environmental Protection Agency, trinitrotoluene (TNT) was found at 85% of the investigated sites in one study, and at 76% of investigated sites in another study. [7] TNT has been popular due to its relatively safe and simple manufacturing process, its high explosive power, and its high chemical stability/low sensitivity to impact and friction. Two technologies were chosen for further research to remediate nitroaromatic explosive soil contaminantion.

PHYTOREMEDIATION

Illya Raskin, a professor of plant biology at Rutger's University in New Jersey, first coined the term "phytoremediation". Raskin defines phytoremediation as the use of plants for environmental remediation, which involves removing organics and metals from soils and water.

Phytoremediation is gaining attention because it is potentially cheaper than conventional treatment approaches such as incineration and soil washing which are chemically based and energy intensive. Phytoremediation is also being explored because it may speed up the slow pace of hazardous waste cleanup.

In 1948 Italian researchers first reported nickel hyperaccumulation in the Italian serpentine plant Alyssum Bertolonii. The discovery was all but forgotten until 1977, when researcher Robert Brooks, of Massey University in New Zealand, reported similar findings. Researchers in the United Kingdom then began to study hyperaccumulator plants. Three years later, Rufus Chaney, a US Department of Agriculture agronomist became the first US scientist to publish on hyperaccumulator plants potential as toxic site cleaners. So far, almost all phytoremediation experiments have taken place in the laboratory where plants are grown in a hydroponic setting.[2]

Plants remediate organic pollutants via three mechanisms: direct uptake of contaminants with subsequent accumulation of nonphytotoxic metabolites into plant tissue; release of exudates and enzymes that stimulate microbial activity and biochemical

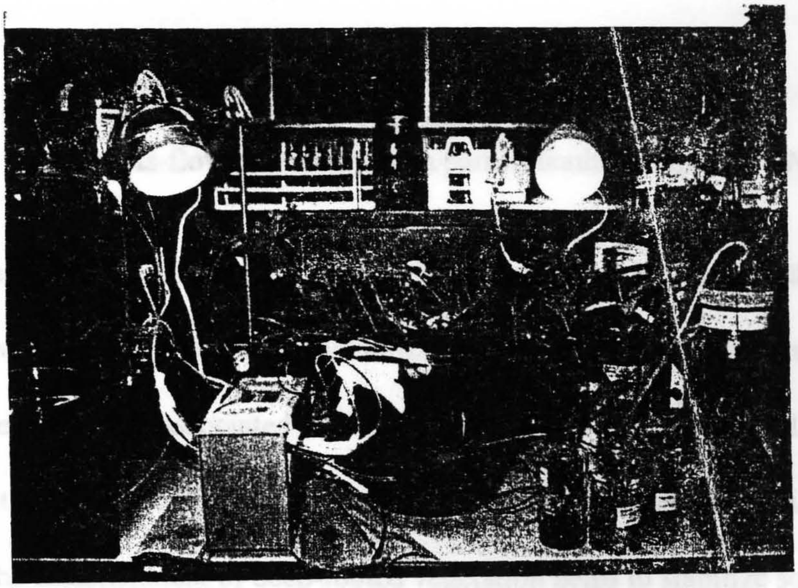

Figure 1
Nature's kidneys. Plants such as parrot feather can absorb metals, solvents, explosives, and pesticides from soil and water.

Figure 2
Continuous-flow pilot study with parrott feather degrading TNT.[3]

transformations; and enhancement of mineralization in the rhizosphere (the root-soil interface) which is attributable to mycorhizal fungi and the microbial consortia.

The vegetation associated with phytoremediation at contaminated sites increases the amount of organic carbon in the soil which in turn stimulates microbial activity. In addition, the establishment of deep-rooted vegetation helps to stabilize soil. When windblown dust is controlled, it reduces an important pathway for human exposure via inhalation of soil and ingestion of contaminated food. Plants also transpire large amounts of water. This loss of water can reverse the downward migration of chemicals by percolation and lead to absorption of surface leachate.

A potential application of phytoremediation would be bioremediation of petrochemical spills and contaminated petrochemical storage areas, ammunition wastes, fuel spills, chlorinated solvents, landfill leachates, and agricultural nonpoint source runoff (i.e. pesticides and fertilizers). Generally, phytoremediation is used in conjunction with other cleanup approaches.

Direct intake of organics by plants is an efficient removal mechanism for hydrophobic organic chemicals in shallow contaminated sites. Once an organic chemical is taken up, a plant can store the chemical and chemical fragments in new plant structures via lignification; or it can volatilize, metabolize, or mineralize the chemical all the way to carbon dioxide and water. Detoxification mechanisms may transform the parent chemical to nonphytotoxic metabolites, including lignin, that are stored in various places in the plant cells.[1]

The direct uptake of a chemical through the roots depends on the plants uptake efficiency and transpiration rate as well as the concentration of the chemical in soil and water. Uptake efficiency, in turn, depends on the physico-chemical properties of the contaminant, chemical speciation, and the plant itself. Transpiration is a key variable that determines the rate of chemical uptake for a given phytoremediation scheme.

Enzyme reactions in plant sediment, plant soil, and exudate systems are also key variables. Wherever significant natural activity in the transformation of contaminants mixed with sediment and soil is observed, plant enzymes have been determined as the cause. Five enzyme systems have been identified -- dehalogenase, nitroreductase, peroxidase, laccase, and nitrilase. Tracing natural processes to plants provides strong evidence of the potential for phytoremediation and also indicates that future development must revolve around discovering which enzyme systems will degrade the chemicals of concern.

Nitroreductase and laccase enzymes break down the ammunition waste 2,4,6-trinitrotoluene by incorporating the broken ring structure into new plant material or organic detritus, which becomes a part of sediment organic matter. Although enzymes such as nitroreductase rapidly transform TNT, remediation should involve whole plants and not just the enzymes. Isolated enzymes are destroyed and inactivated by low pH, high concentrations of metals, and bacterial toxin associated with contaminated sites. When plants are grown in soil or sediment slurries, pH is neutralized, metals are biosorbed or chelated, and enzymes remain protected inside the plant or sorbed to plant surfaces.[1]

THERMAL INCINERATION

Thermal incineration is the controlled high-temperature oxidation of primarily organic compounds to produce carbon dioxide and water. Additional inorganic substances, such as acids, salts, and metallic compounds, may also be produced from the wastes. Incineration processes for the management of hazardous wastes are highly complex and require control of the kinetics of chemical reactions under non-steady-state reaction conditions. All of the mechanisms of heat transfer--including conduction, convection, and radiation--will take place among solids, liquids, and gases under high-temperature reaction conditions involving high rates of heat release. Another factor that must be considered in incineration operations is the frequent and somewhat unpredictable shifting in the chemical and physical composition of the hazardous waste itself that is being fed into the incineration system.

The chemistry of incineration represents a combustion process applied to the destruction of unwanted hazardous substances. It should be noted that the chemistry of combustion and the chemistry of incineration are interchangeable. Both combustion and incineration are used to define a thermal oxidation process. The distinction between combustion and incineration lies in the chemical relation to the desirable effects of resource conversion versus the destruction of undesirable substances. All combustion and incineration of organic substances is a highly complex sequence of reactions that ultimately result in similar final products. The heat transfer objectives in hazardous waste incineration are 1) maximization of the heat transfer rates, compatible with economic factors, 2) utilization of heat exchange whenever practical, and 3) minimization of heat loss to the surroundings by the use of insulation. The three modes of heat transmission that interact in the thermal destruction of hazardous waste are conduction, convection, and radiation. Conduction is the transfer of heat from one element to another by means of a temperature gradient, but without displacement of the adjacent elements themselves. Convection is the transfer of heat by the mixing motion of one fluid with another or the movement of one fluid. In radiation, heat transmission results from transfer between particles not in physical contact with each other, but at different temperatures. The particle with the higher temperature will radiate more energy than it will absorb, and the cooler particle will absorb more than it radiates.

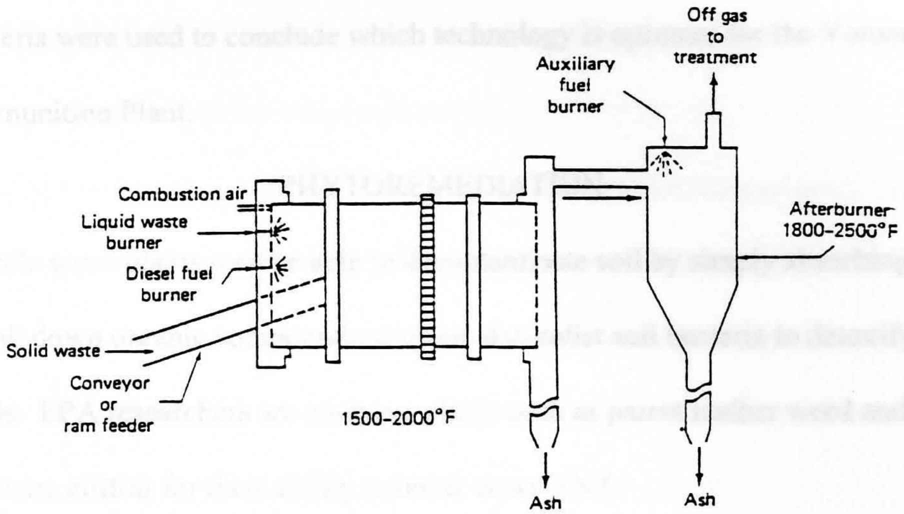

Figure 3
Rotary kiln for hazardous waste incineration.[3]

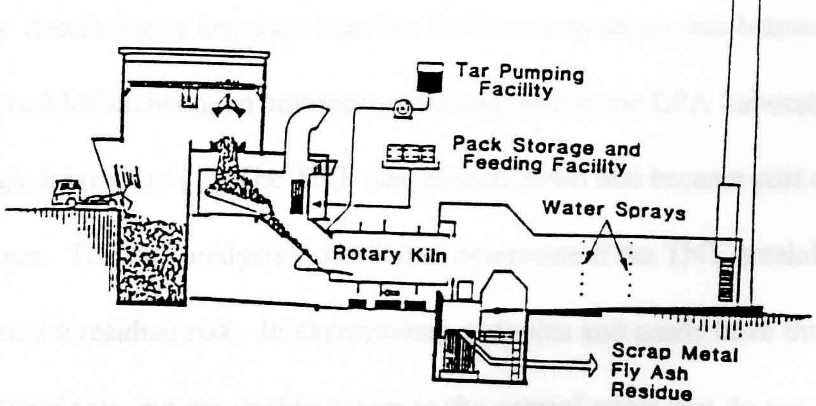

Figure 4
Rotary kiln design. Source: U.S. EPA Hazardous Material Design Criteria, October 1979.

CHAPTER TWO - TECHNOLOGY APPLICATIONS

The application(s) for remediation using both phytoremediation and thermal incineration were compared. This comparison along with the technology meeting the design criteria were used to conclude which technology is opimum for the Volunteer Army Ammunition Plant.

PHYTOREMEDIATION

While some plants may be able to decontaminate soil by simply absorbing metals, others break down organic compounds and can also enlist soil bacteria to detoxify these compounds. EPA researchers are studying plants such as parrot feather weed and Eurasian water milfoil for their ability to break down TNT.

Researchers at Auburn University have tested Eurasian milfoil on 2-4 inches of soil from the Alabama Army Ammunitions Plant contaminated with 5,000 ppm of TNT. At 5,000 ppm TNT the soil, which is essentially sterile, was put in small plastic pools, covered with water, and the plants were added. Within a week the dissolved TNT was barely detectable; a few days later the TNT concentration was below detection, according to Steve McCutcheon, an environmental engineer at the EPA Laboratory in Athens, Georgia laboratory.[1] The TNT was broken down and became part of the lignin or plant structure. Toxicity analysis is needed to determine if the TNT breakdown products represent a residual risk. In experiments, tadpoles and snails have thrived in the pool with the plants, but are unable to live in the control pools that do not contain the plants.

Another pilot test was conducted at Auburn University, where parrot feather was introduced into flooded mesocosms of TNT-contaminated soil at 5,000 ppm TNT. In the initial sampling after one week, dissolved TNT-contaminated soil concentrations decreased from 128 ppm (saturation) to 10 ppm. The disappearance of TNT attributable to parrot feather was rapid enough to support snails and tadpoles. However, new roots grew only along the edge of the contaminated soil, avoiding hot spots while breaking down the dissolved TNT in the water column.[1]

Phytoremediation is most effective at sites with shallow contaminated soils, where nutrient and organic contaminants can be treated in the rhizosphere and by root uptake. Although deep-contaminated sites and those with deep pools of nonaqueous-phase liquids are not good applications, deep groundwater contaminants or leachate pond effluent may be treated by pumping and drip irrigation on plantations of trees.[4]

According to Edward Gatliff, founder of Applied Natural Sciences, Hamilton, Ohio, the most effective role of phytoremediation is as a long-term solution once mechanical systems have taken care of the more urgent situations. Phytoremediation, the technology of using plants to clean up organic and inorganic contaminants, is in its infancy. Although many demonstration projects are under way, most of the test sites are small, covering less than one-half acre. Most scientists agree, that the success of phytoremediation will depend on how it can be interfaced with other approaches.[5]

THERMAL INCINERATION

The thermal destruction of hazardous waste involves the controlled exposure of the waste to elevated temperatures, typically above 1600° F. When properly designed and operated, thermal destruction systems offer the opportunity to destroy hazardous organic wastes and significantly reduce their volume.

All hazardous waste incineration systems are normally governed by RCRA (Resource Conversation and Recovery Act) or TSCA (Toxic Substance Control Act) regulations. These regulations typically specify a minimum destruction temperature that must be maintained for a required residence time in the presence of excess oxygen. Hazardous waste incineration normally occurs during the flow of hot, turbulent substances within a refractory-lined incinerator. The design of the incinerator plays a key role in ensuring adequate destruction of the waste. There are many factors of incinerator design that can significantly affect the thermal destruction of hazardous waste, including the following:

Factor	Effect on Incineration
1) Temperature	The destruction and removal efficiency (DRE) of the incineration operation depends upon the incinerator temperature.
2) Residence time	The volume of the incinerator determines the residence time for any given flow rate, sufficient residence time must be allowed in order to achieve DREs as well as to assure conversion to desirable incinator product.
3) Turbulence	The degree of turbulance may be used effectively to attain desirable DREs and lessen the severity of operating temperature and residence time requirement.

4) Pressure	Most incinerator operations are designed to operate at slightly negative pressure to reduce fugitive emmissions.
5) Air supply	The incinerator operations require sufficient oxygen to ensure complete combustion.
6) Materials of construction	The materials of construction for the incinerator must provide a 10 ng operating life for the incinerator and minimize potential maintenance problems.
7) Auxiliary features.	Incinerators must operate with numerous additional features to provide effective thermal destrictopm.

On-site treatment by a mobile thermal treatment system may be considered for a site which contains several thousand tons of materials which are considered toxic, reactive, or not readily amenable to treatment by other technologies. Examples of such wastes include materials contaminated with PCBs, dioxins, chlorinated phenols, pesticides, herbicides, and explosives and propellants. Thermal treatment can destroy organic substances but does not destroy inorganic substances including heavy metals.

The following chemical characteristics of the waste being treated are key design criteria for waste treatment systems by thermal technologies: (1) the presence of high concentrations of organic chlorine, sulfur, or phosphorus (due to acid-gas removal capabilities and corrosion considerations); (2) the presence of alkali metal salts (leading to formation of submicron particulates and problems with the formation of low-melting slag eutectics and metal-corrosion); and (3) the presence of heavy metals (preventing delisting of ash and delisting of residues from the gas-cleaning system).

Mobile thermal treatment systems are utilized for site-remediation activities rather than commerical fixed thermal systems or landfilling for several reasons. Among these reasons are:

- Lack of available capacity and the high cost of using commercial fixed incineration facilities to handle large quantities of bulk wastes (especially contaminated soil).
- High cost, risk of accidents, and public opposition to the transportation of hazardous wastes to commerical fixed incineration facilities.
- 1984 Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act (RCRA) requiring the EPA to consider restricting certain types of wastes from land disposal encourages incineration systems.
- Decreasing availability and rising disposal costs at permitted landfill facilities encourages incineration systems.
- Perpetual generator liability if wastes are stored rather than destroyed encourages incineration systems.[6]

CHAPTER THREE -TECHNOLOGY FOR SOIL REMEDIATION

Both the technologies research may be applicable to remediation of nitroaromatic explosives; however, site specific and former processing operation at Volunteer Army Ammunition Plant helps to optimize the phytoremediation and thermal incineration technologies.

VAAP SITE DESCRIPTION

The Old TNT Area consists of Batch Lines 1 through 16 and covers approximately 330 acres. Currently only Batch Lines 1 through 6 still remain. A fire caused major damage to Batch Line 3 in 1969 and the line was demolished by 1983. Current investigative activities are in the Old TNT Area, with the remedial design focused on Batch Lines 4 and 5. [8,9]

FORMER PROCESS DESCRIPTION

The batch process was used in the Old TNT Area. Each Batch Line had a mononitration house (mono-house), a binitration house (bi-house), a trinitration house (tri-house) and wash house. Pairs of Batch Lines shared a toluene day tank, and acid fume recovery unit, and a case house. [9]

The mono-house received the toluene from a day tank. The production process begins with mononitration of toluene in the monohouse tank using nitric acid. During this process, excess nitric acid is recovered and sent to the acid fume recovery unit. The mononitrotoluene is pumped to the tank in the bi-house where it undergoes the second nitration to 2,4 and 2,6 dinitrotoluene. The dinitrotoluene then is pumped into the tri-house tank where a third nitration takes place to yield the final product 2,4,6 trinitrotoluene. [9]

Next to each tri-house was a limestone-lined acid pit. The acid pit collected spills and runoff from the tri-house. The acid pit was dug into the residuum and was located south and east of the tri-house. Presently, the pits have been graded level and filled in with soil to the surface. [8]

The primary emphasis of investigative research was on defining the nature and extent of contamination in the Old TNT Area. Abundant surface soil field samples were collected by International Technologies Corporation to estimate the internal extent of surface explosives contamination. Batch Lines 1 through 6 compromise the largest and most intact site within the Old TNT Area. [8]

Out of a total of 174 surface soil samples collected in the vicinity of the tri-nitration houses located on Batch Lines 1 through 6, there were fifty (50) samples in which 2,4,6-TNT was detected. The 2,4,6-TNT detection's ranged from 0.9 to 9,500 μg/g. A total of thirteen(13) of the samples collected had 2,4,6-TNT concentrations greater than one hundred twenty (120) μg/g, and a total of four (4) of the samples collected had concentrations of 1,800 μg/g or above. Nineteen (19) of the samples were field screened for DNT but DNT was detected in only four (4) samples with concentrations ranging from less than eight (8) μg/g to between eighty (80) and eight hundred (800) μg/g. [8]

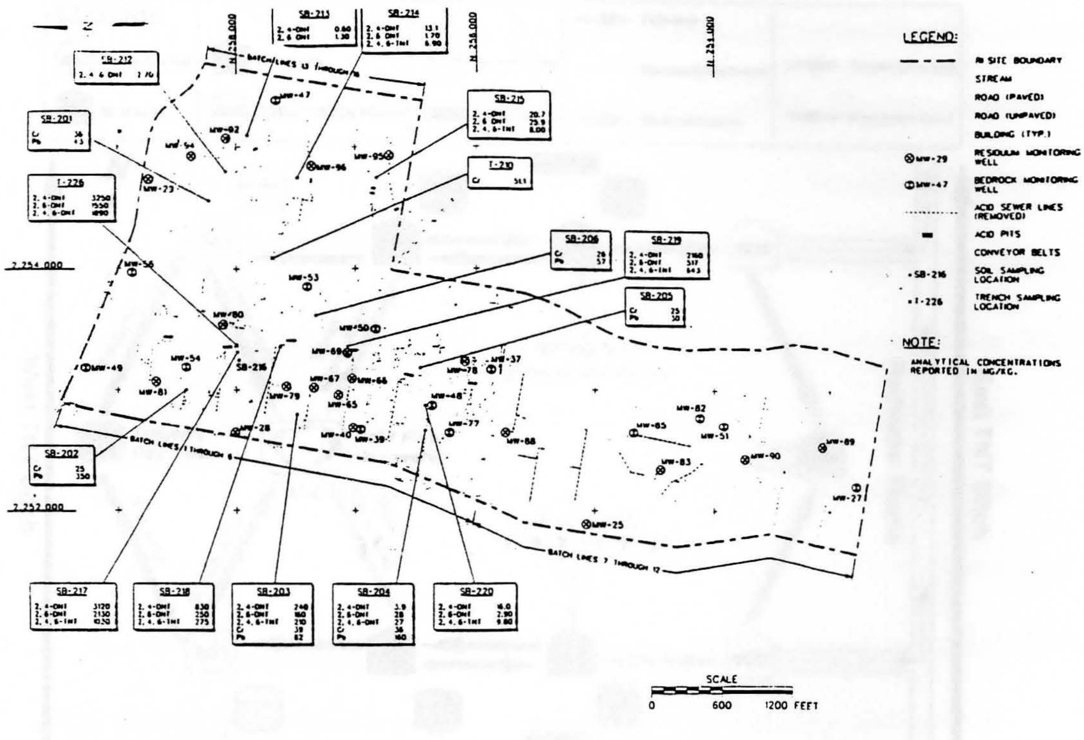

Figure 5
VAAP Old TNT Area Site Map. Source: International Technology Corporation.

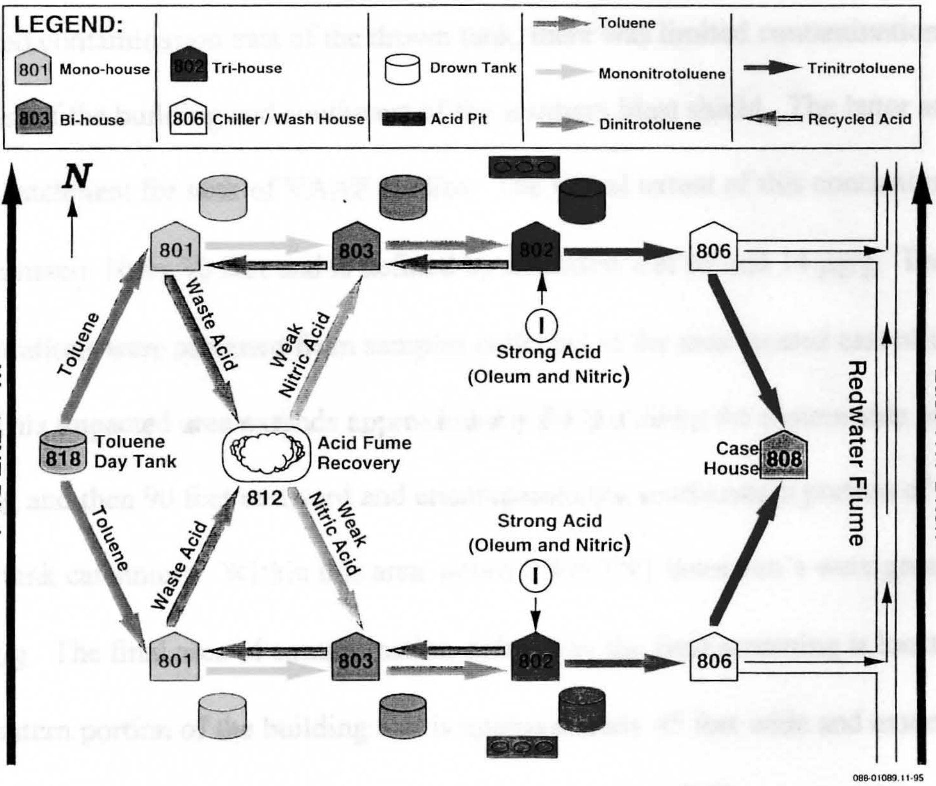

Figure 6
TNT Batch Process
Tri-Nitration Houses Soil Contamination

(1) Batch Line 4 - Nitration House Soil/Sampling

A total of fifty-eight (58) samples were collected from the area around Batch Line 4 Tri-Nitration House. Field screening revealed 2,4,6-TNT in eighteen (18) of these at concentrations ranging from 1 to 2,200 μg/g. DNT was detected in two samples (SE5383 and SE5384) at a concentration range less than 80 μg/g and greater than 8 μg/g. This tri-house exhibited an atypical pattern of contamination because in addition to an area of suspected contamination east of the drown tank, there was limited contamination located northeast of the building and southwest of the southern blast shield. The latter area is a walled catchment for tank of VAAP cradles. The lateral extent of this contamination is approximately 30 by 30 feet and is defined by detection's of 63 and 14 μg/g. The highest concentrations were screened from samples collected in the area located east of the drown tank. This impacted area extends approximately 60 feet along the eastern side of the building and then 90 feet eastward and encompasses the southeastern portion of the drown tank catchment. Within this area seven 2,4,6-TNT detection's were greater than 170 μg/g. The final area of contamination defined by the field screening is located off the northeastern portion of the building and is approximately 45 feet wide and extends approximately 60 feet northward from Batch Line 4. 2,4,6-TNT concentrations screened within this area range between 2 and 5.3 μg/g. [8]

The tri-nitration houses are built on stilts and do not have cement slabs below the structure. Two soil samples were collected from the soils below the tri-house building at this batch line. Screening concentrations from one of these samples is below detection

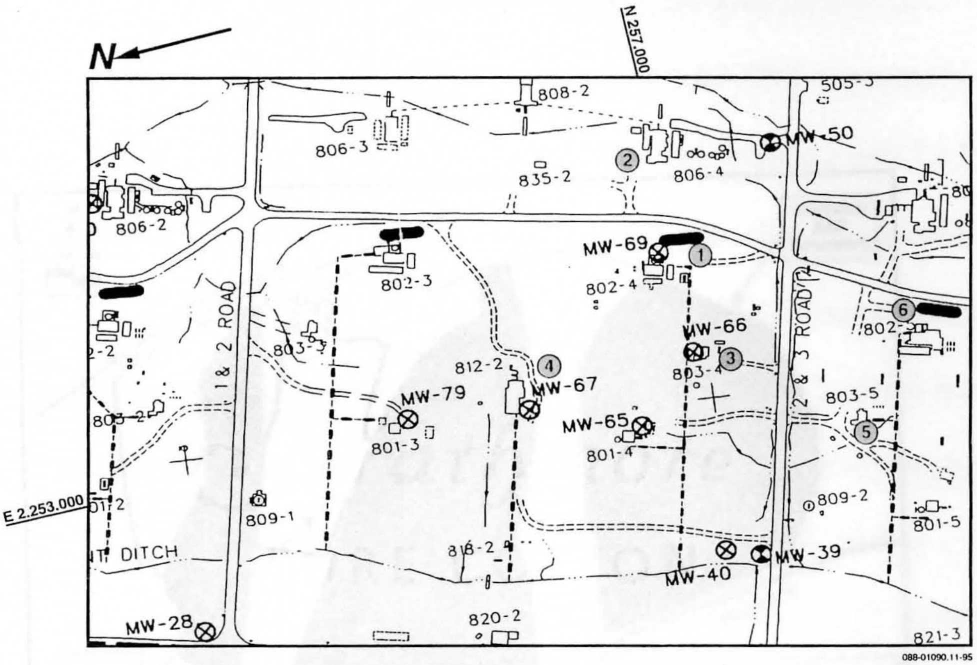

Figure 7
Site Characterization Locations Within Old TNT Area

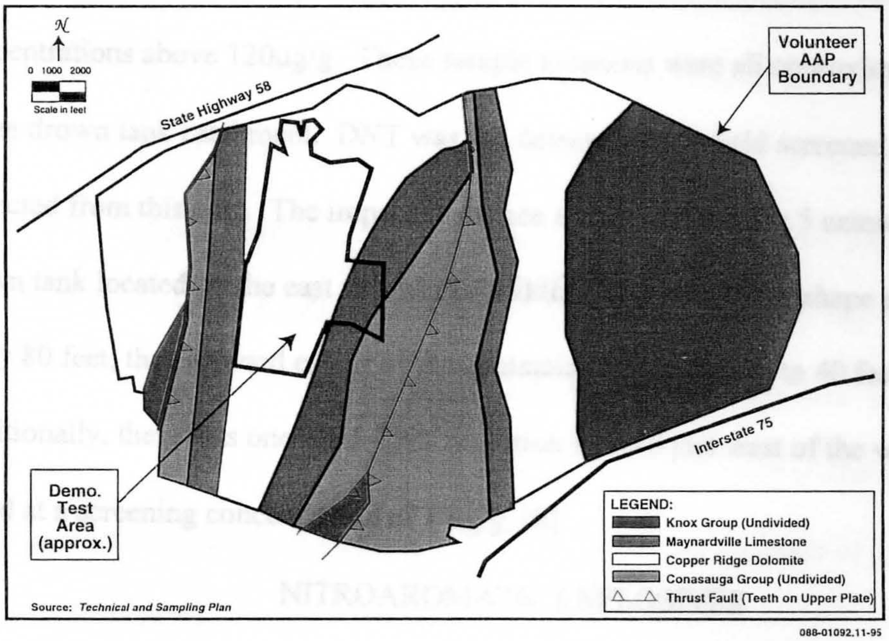

Figure 8
Geological Map

and the other is 41 μg/g, although this sample was collected 2.5 feet below the surface and will be discussed later in the medium depth soils section. Samples were not collected from below the second floor of the tri-houses on any of the other batch lines due to structural instability. [8]

(2) Batch Line 5-Tri-Nitration House Soil Sampling

A total of thirty-seven (37) samples were collected from the area surrounding the Batch Line 5-Tri-Nitration House with 8 detection's of 2,4,6-TNT concentrations ranged from 1 to 410μg/g. Two samples (C1005 and C1006) were screened with 2,4,6-TNT concentrations above 120μg/g. These sample locations were all approximately 5 feet east of the drown tank catchment. DNT was not detected in the field screened samples collected from this area. The impacted surface soils at Batch Line 5 extend from the drown tank located on the east side of the building in a rectangular shape approximately 40 by 80 feet; the eastward extent of the contamination is limited to 40 feet. Additionally, there was one 2,4,6-TNT detection located just west of the western blast shield at a screening concentration of 1 μg/g. [8]

NITROAROMATIC EXPLOSIVES

Four (4) nitroaromatic explosive compounds were detected above their Certified Reporting Limit(CRLs) in the surficial soils of the tri-nitration house areas:

- 1,3,5-TRINITROBENZENE(TNB)
- 2,4,6-TRINITROTOLUENE(TNT)
- 2,4-DINITROTOLUENE(DNT)
- 2,6-DINITROTOLUENE(DNT)

2,4,6-TNT and 2,6-DNT exceeded their Chemical Screening Concentration(CSCs) of 190 and 8.4 μg/g.

1,3,5-TNB was detected in 5 of 17 samples at concentrations ranging from 1.82 μg/g to 5.23 μg/g with an average concentration of 2.9μg/g. These results are two orders of magnitude less than the 100 μg/g CSC for 1,3,5-TNB. 2,4,6-TNT was detected in 11 of 17 samples at concentrations ranging from 3.28 μg/g to 4,100 μg/g with an average concentration of 715 μg/g. These results range from two orders of magnitude less than the CSC to one order of magnitude greater than the 190 μg/g CSC for 2,4,6-TNT. The CSC for 2,4,6-TNT was exceeded by analyzed concentrations in four samples. 2,4-DNT was detected in 2 of 17 samples at concentrations ranging from 5.97 to 20.1 μg/g, respectively. These results are from three orders of magnitude to two orders of magnitude less than the 4,100 μg/g CSC. The presence of 2,4-DNT was confirmed for both samples by the Semivolatile Organic Compound(SVOC) analysis. 2,6-DNT was detected in 1 of 17 samples at a concentration of 27.6 μg/g, which is one order of magnitude greater than the 8.4 μg/g CSC for 2,6-DNT. The presence of 2,6-DNT in this sample was confirmed by the SVOC analysis. [8]

BATCH LINE 4 VOLUME MEASUREMENTS

Analyte	Volume Ft^3	Volume Yd^3	Highest Reading
135 TNB>0 ppm	365.79	13.55	16.9 ppm
246 TNB>100 ppm	223.78	8.29	2300 ppm
24 DNT>10 ppm	7101.69	263.03	9143 ppm
26 DNT>10 ppm	2161.66	80.06	2667 ppm
Combined	5384.08	199.41	- - -

TRW[9]

BATCH LINE 5 VOLUME MEASUREMENTS

Analyte	Volume Ft^3	Volume Yd^3	Highest Reading
135 TNB>0 ppm	106.03	3.93	48.8 ppm
246 TNT>100 ppm	106.03	3.93	1803 ppm
24 DNT>10 ppm	106.03	3.93	2335 ppm
26 DNT>10 ppm	106.03	3.93	848 ppm
Combined	106.03	3.93	- - -

TRW[9]

The soil phase contaminate distribution observed at VAAP is high variable and heterogeneous. The variable nature of contaminates may result from historical spills, leaks or accidents rather than continuous discharges from the TNT batch lines. Another factor contributing to the variable nature of the contamination may be the clay content in the residuum soil. Clays have the capacity to absorb nitroaromatic explosives. The soil at VAAP is a clay with chert fragments and localized cherty soil layers with Karst features.[9]

CHAPTER FOUR - REMEDIAL DESIGN

This chapter optimizes both phytoremediation and thermal incineration technologies based on technology and design parameters as well as information gained in previous chapters

TECHNOLOGY AND DESIGN PARAMETERS

The initial design parameters for the remedial technology are as listed:

- Remedial technology shall be mobile (able to move from batch line area to batch area line).
- Remedial technology shall be cost efficient.
- Remedial process time for each Batch Line shall be <1 yr.
- Land Usability shall be immediate upon completion of remediation.
- Non climate dependent (technology may be used at other ammunitions plant throughout the U.S).

Both technologies were evaluated and compared to the technology and design parameters. The optimum technology is now selected based on Chapter Two, Chapter Three and technology and design parameters.

(1) Phytoremediation

Phytoremediation has proven effective in several applications for treatment of shallow contaminated soils. Phytoremediation is most effective at sites where nutrient and organic contaminants can be treated in the plant rhizosphere and by root uptake. Deep contaminated (>5 feet) sites are not good candidates for phytoremediation. Phytoremediation may require more time to achieve cleanup standards since the technology currently faces some limitations. A better understanding of the role of metabolites, enzymes, and the selection of plant systems for various waste is needed.

The wetlands-type environment needed for application of phytoremediation technology may be its primary limitation. Cost associated with phytoremediation can not at this time be compared to other standard remedial technologies because phytoremediation research has only been performed in the laboratory. Issues such as the effect on animals and insects that eat toxic plants, carrying toxins through the food chain; how to dispose of toxic/contaminated biomass; and contaminants that lie out of reach beneath the plant root zone are a few of the issues that must be resolved before phytoremediation evolves.[4]

(2) Thermal Incineration

Thermal incineration is one of the most effective measures for the disposal of hazardous wastes. During thermal incineration a reduction in the volume of wastes and virtually complete destruction of organic compounds occur. Incineration is attractive economically because of limited regulatory permitted landfill space. A mobile thermal incinerator meets technology and design parameters for mobility. Also, land usability will be immediate since the mobile incinerator can be moved from Batch Line Area to Batch Line Area. [10]

REMEDIAL TECHNOLOGY - THERMAL INCINERATION

The remedial technology, thermal incineration, depends on several variables; (1) Performance requirements for the mobile thermal treatment unit, (2) preparation and thermal process functions and (3) type of thermal prossing unit used and design features.

(1) Performance Requirements

Performance requirements for mobile thermal treatment systems are imposed by federal, state, and local regulations. The RCRA requires:

(a) 99.99% destruction and removal efficiency (DRE) for principal organic hazardous constituents (POCHs).

(b) A particulate emission rate of less than 180 mg/m^3 0_2.

(c) 99% HCl (Hydrochloric Acid) removal or an HCl emission rate of less than 1.8 kg/h (4.0 lb/h).

The Comprehensive Environmental Response Compensation and Liability Act (CERCLA) requires no federal permits for remediation of CERCLA (Superfund) sites. However, it is likely that testing will be required to verify compliance with TSCA (Toxic Substance Control Act) and RCRA performance criteria. The primary factors determining the throughput of processing capacity of a thermal treatment system are the waste characteristics, which are heterogeneous for the VAAP nitroaromatic explosives contaminated soils [6]

(2) Preparation and Thermal Process Functions

The nitroaromatic explosives contaminated soil from each Batch Line Area will be excavated and stored in a designated waste preparation area in its Batch Line Area. The bulk soil will be sampled and stored for treatment. Soils will be conveyed to the thermal treatment unit under monitored and controlled conditions. The thermal processing will occur in two stages. The primary stage should treat the bulk soils. The secondary stage should treat the gases produced in the primary stage. Because of cost, complexity, and fouling considerations, the mobile thermal treatment unit will not have any type of energy-recovery equipment. [6]

(3) Rotary Kiln with Secondary Combustion Chamber

Mobil treatment units utilizing rotary kilns with secondary combustion chambers have proven very successful in the remediation of explosive contaminated soil in studies performed at Army Ammunitions Facilities. Rotary kilns are typically used for mobile thermal treatment units because they offer flexibility in their ability to handle a wide variety of physical forms of waste materials with little or no feed-stock pretreatment and they provide good mixing and long residence time for solids. The flow of waste-feed materials and combustion gases for rotary kiln incinerators are counter current with tight control on the supply of combustion air. IT Corporation has commercialized and patented a mobile rotary kiln for site-remediation activities involving thermal treatment of contaminated soils and hazardous waste. [6]

PROJECT PHASES AND ACTIVITIES FOR SITE REMEDIATION

The major objectives of the project phases is to determine which specific activities are required for each project phase and to select specific activities that will ensure that the site remediation meets the technology and design parameters.

PROJECTS PHASES	SPECIFIC ACTIVITIES
1. Planning/Procurement	Survey the site and develop layout drawings, design and waste-disposal systems, plan transportation and

mobilization, plan health and safety program and QA/QC program, implement, public relations program, develop site-security plan, develop operations plan and procedures, develop environmental monitoring plan.

Comment:

- Facility drawings are included in Appendix A.
- Rotary Kiln incinerator design schematic with parameters in Appendix A.
- Transportation and mobilization shall be minimal since the incinerator unit is mobile.
- The health and safety program and QA/AC program shall be designed as per RCRA guidelines. RCRA guidelines located in Appendix B.
- Site security shall be performed as required by the U.S. Department of Defense (present facility owner).
- Operations plan and procedures are discussed in Chapter 4 (2) Thermal Processing Functions and (3) Rotary Kiln with Secondary Combustion Chamber.
- Environmental monitoring shall be within the thermal treatment unit design to meet. RCRA requirements DRE of 99.99% particulate emission rate of less than 180 mg/m^3 corrected to 7% 0^2 and HCl emission rate of less than 1.8 kg/h (4.0 lb/h) TSCA regulatory compliance shall also be performed, if necessary.

2. Permitting — Identify permits and specific information requirements, prepare draft permit applications and trial burn plans, client and agency review, finalize permits applications,

	conduct public hearings, negotiate final operating permits.

Comment

- It is the intent that VAAP site shall be a CERLA site, not requiring any permitting. However, thermal unit design, processing, operation and environmental monitoring will be in compliance with RCRA and TSCA regulations.

3. Site Preparation	Mobilize site-preparation equipment; set up site containment and security; connect utilities; install environmental monitoring system.

Comment

- Excavation equipment shall be provided by a contractor chosen by the U.S. Army. The contractor shall mobilize to the equipment site. Site preparation equipment shall be mobilized to Batch Line 4 Area.
- The IT Corporation mobile counter-current rotary Kiln incinerator shall be mobilized and installed by contractor at the VAAP facility under the U.S. Army contract. This unit shall be located at the Batch Line 4 Area.
- Utilities are available at VAAP. An extended connection shall be required for site remediation. This shall be performed by an utilities contractor chosen by the U.S. Army.
- This phase will be performed by the equipment contractor. See the Enviro-economic Analyses, Chapter 5.

4. Equipment mobilization — Unload equipment, erect all equipment modules, interconnect instruments and control systems, interconnect electrical distribution system, connect emission-monitoring system, interconnect all utility systems.

Comment

- This phase will be performed by the equipment contractor. See the Enviro-economic Analyses, Chapter 5.

5. Commissioning — Conduct site personnel training, check out electrical instrumentation systems, conduct hydrostatic testing, align rotating equipment, check containment systems, check winterization systems, check fire protection systems, check emergency procedures, start up the plant and bring the process into equilibrium.

Comment

- The aforementioned activities are included in the rotary kiln incinerator installation. See Enviro-economic Analyses; Chapter 5.

6. Trial Burns — Check out monitoring systems; deploy sampling teams; prepare waste feeds; excavate and execute trial burns; conduct laboratory analyses of feeds, treated ashes and wastewater, gaseous emissions; analyze results and prepare report to agency.

Comment

- The trial burn phase shall be performed by the site remediation contractor. These cost are estimated in the Enviro-economic Analyses Section, Chapter 5.

7. Operation — Excavate waste; analyze waste; pretreat wastes, if needed; thermally treat wastes; store and analyze residuals; dispose of treated ashes and residuals from the gas-cleaning system.

Comment

- Operations at the facility are included in the scope of work performed by the site remediation contractor. These cost are estimated in the Enviro-economic Analyses Section, Chapter 5.

8. Equipment demobilization — Clean and decontaminate equipment; dispose of wastes generated during decontamination; conduct require

equipment maintenance; disconnect power, electrical, utility, and stack monitoring systems; disassemble process modules; load and transport equipment to next site.

Comment

- Equipment demobilization shall be performed by the site remediation contractor. These cost are estimated in the Enviro-economic Analyses Section 5.

9. Site Disassembly and Closure

Disconnect and remove site utilities, remove personnel support facilities, remove waste-handling facilities, grade and vegetate the site.

Comment

- Site disassembly and closure shall be performed by the site remediation contractor after remediation of each Batch Line Area. An estimate of these cost are included in the Enviro-economic Analyses Section, Chapter 5.

The aforementioned project phases and activities for site remediation are evaluated in the enviro-economic analyses with the estimated environmental impact as a major component.

CHAPTER FIVE-ENVIRO-ECONOMIC ANALYSES

The enviro-economic cost analyses are costs which have been developed with consideration of environmental impact. Phytoremediation costs are not included. The only available cost involved with phytoremediation at present is the planting cost which is approximated $10,000 per acre. This cost does not include monitoring cost. The enviroeconomic analyses presented is for thermal incineration which is the optimum remedial technology for remediation of contaminated soils at the Volunteer Army Ammunition Plant.

ITEM	COST ESTIMATE		TOTAL
(1) IT Corporation Countercurrent Rotary Incincerator			
(a) Design and Plans			$500,000
(b) Mobilization			$3,000,000
(c) Demobilization/ Decontamination			$750,000
(d) Testing (prior to Trial Burn)			$1,000,000
		(1)	5,250,000
(2) Trial Burn This is anticipated to be only a one time need, with a 3 day test period			$1,000,000
		(2)	1,000,000
(3) Permits, if needed It is not anticipated that permits shall be needed.			0
		(3)	0
(4) Annual Operations Includes manpower, utilities, and maintenance	$50,000 per day for 120 days		$6,000,000
		(4)	$6,000,000

(5) Environmental Monitoring and Sampling	2,000 samples x $250		$500,000
			$72,000
(a) Monitoring-Sampling Soils		(5)	$572,000
(b) Monitoring-Sampling Emissions			

TOTAL PROJECT COST

$12,822,000 [15]

NOTE: The Regulatory Agency providing oversight shall in conjunction with the US Army obtain contractors at the reasonable rates mandated by the Tennessee Department of Environment and Conservation.

The environmental impact and cost estimate for the thermal treatment of soils at VAAP is $12,822,000. This estimate is inclusive of design parameters, project requirements as well as environmental monitoring and sampling.

CHAPTER SIX - CONCLUSIONS/RECOMMENDATION

Phytoremediation technology does not meet all of the technology and remedial design parameters required for site remediation at the Volunteer Army Ammunition Plant. Phytoremediation is not mobile, non-climate dependent and the remedial process time will most likely exceed one year. Also, enviro-economic analyses could not be determined for this technology.

Incineration is an expensive alternative in the choice of remedial measures to eliminate hazardous materials, however, it is the most effective method of disposal. Thermal incineration achieves the complete destruction of the organic portion of the waste and limits possible future liabilities of the generator.

The major costs in incinerating waste are the cost of energy and the cost of air pollution control equipment. Although the rotary kiln incineration system at the VAAP facility shall not require permitting, the kiln incineration system must meet all RCRA and TSCA regulatory requirements. Advantages of the rotary kiln include its ability to handle a variety of waste, its high operating temperature and continuous mixing of incoming wastes. Rotary kilns have high capital and operating costs and require trained personnel. Maintenance cost can also be high because of the abrasive characteristics of the waste and exposure of moving parts to high incineration temperatures.

The IT Corporation countercurrent rotary kiln incinerators meets all technology and design parameters for remediation of contaminated soils at the VAAP facility. After analyzing the problem, along with its many interrelationships, I have selected thermal incineration . Thermal incineration is the optimum commercially available technology and equipment to abate the contaminated soil problem at the VAAP facility. This decision was made considering all the economics involved, whether it be immediate, short or long range and environmental impact.

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