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LOW TEMPERATURE THERMAL DESORPTION PROCESSES FOR THE REMEDIATION OF SOILS CONTAMINATED WITH SOLVENTS, HYDROCARBONS, AND PETROLEUM PRODUCTS

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In December, 1991 the United States Army undertook a full-scale effort to remove Volatile Organic Compounds (VOCs) from contaminated soils at the Industrial Waste Treatment Plant (IWTP) Lagoon at Letterkenny Army Depot (LEAD) near Chambersburg, Pennsylvania. The Low Temperature Thermal Treatment process used had previously undergone successful pilot studies in the K-area. It is the objective of this report to review data from both the studies and the full-scale operation at LEAD for the purpose of evaluating those factors that may influence the selection of this technology for the remediation of soils elsewhere. Included in this report is scale-up efficiencies, costs, physical parameters and comparisons of low temperature thermal stripping technologies used in soil remediation. This report is designed to disseminate practical, implementation-related information to minimize, selection, design, costing, and construction problems associated with Low Temperature Volatile Systems (LTVS).

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LIST OF ACRONYMS

AFB	Air Force Base
APG	Aberdeen Proving Ground
ARAR	Applicable or Relevant and Appropriate Requirements
BAT	Best Available Technology
CDHS	California Department of Health Services
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
DA	Disposal Area
EPA	Environmental Protection Agency
FC	Fort Campbell
ISV	In Situ Volatilization
IWTP	Industrial Waste Treatment Plant
LEAD	Letterkenny Army Depot
LEL	Lower Explosive limit
LT^3®	Low Temperature Thermal Treatment
LTVS	Low Temperature Volatile Systems
NEESA	Naval Energy and Environmental Support Activity
PADER	Pennsylvania Department of Environmental Resources
PPM	Parts Per Million
QC/QA	Quality Control/Quality Assurance
R&D	Research and Development
RCRA	Resource Conservation and Recovery Act
SE	Southeastern
SEI	Southeast Industrial

SHAD	Sharp Army Depot
USATHAMA	United States Army Toxic and Hazardous Materials Agency
USAEC	Unites States Army Environmental Center (formally USATHEMA)
VISITT	Vendor Information System for Innovative Treatment Technologies
WESTON	Roy F. Weston, Inc.

LIST OF CHEMICALS

BTEX	Benzene, Toluene, Ethyl Benzene, Xylene
CH_2Cl_2	methylene chloride
$CHCl_3$	chloroform
CTC	carbon tetrachloride
C/T12DCE	cis/trans-1,2-dichlorethylene
11DCE	1,1-dichlorethylene
12DCE	1,2-dichlorethylene
11DCE	1,1-dichlorethane
MEK	methyl ethyl ketone
HEL	Hydrocarbon Emissions Limit
PCB	polychlorinated biphenyl
PNA	Polynuclear Aromatics
POL	petroleum, oils, lubricants
111TCE	1,1,1-trichloroethane
1122TCE	1,1,2,2-tetrachloroethane
TCL	tetrachloroethylene (tetrachloroethene)
TCLP	toxicity characteristic leaching procedure
T12DCE	trans-1,2-dichloroethylene (trans-1,2-dichloroethene)
TCLP	Toxic Characteristic Leaching Procedure
TPH	total petroleum hydrocarbon
TCE	trichloroethylene (trichloroethane)
VOC	volatile organic compounds

EXECUTIVE SUMMARY

In December, 1991 the United States Army undertook a full-scale effort to remove Volatile Organic Compounds (VOC) from contaminated soils at the Industrial Waste Treatment Plant (IWTP) Lagoon at Letterkenny Army Depot (LEAD) near Chambersburg, Pennsylvania. The Low Temperature Thermal Treatment process used had previously undergone successful pilot studies in the K-area. It is the objective of this report to review data from both the studies and the full-scale operation at LEAD for the purpose of evaluating those factors that may influence the selection of this technology for the remediation of soils elsewhere. Included in this report is scale-up efficiencies, costs, physical parameters and comparisons of low temperature thermal stripping technologies used in soil remediation. This report is designed to disseminate practical, implementation-related information to minimize, selection, design, costing, and construction problems associated with Low Temperature Volatile Systems (LTVS).

LOW TEMPERATURE THERMAL DESORPTION PROCESSES FOR THE REMEDIATION OF SOILS CONTAMINATED WITH SOLVENTS, HYDROCARBONS, AND PETROLEUM PRODUCTS

1.0 INTRODUCTION

In December, 1991 the United States Army undertook a full-scale effort to remove Volatile Organic Compounds (VOCs) from contaminated soils at the Industrial Waste Treatment Plant (IWTP) Lagoons Letterkenny Army Depot (LEAD) near Chambersburg, Pennsylvania. The Low Temperature Thermal Treatment process used had previously undergone successful pilot studies in the K-area. It is the objective of this report to review data from both the pilot studies and the full-scale operation at LEAD for the purpose of evaluating those factors that may influence the selection of this technology for the remediation of soils elsewhere. Included in this report are scale-up efficiencies, costs, physical parameters and comparisons of other low temperature thermal stripping technologies used in soil remediation.

1.1 PURPOSE AND AUDIENCE

This report is designed to:

- Disseminate practical, implementation-related information for selection, design, costing, and construction problems associated with Low Temperature Volatile Systems (LTVS).
- Help Project Managers evaluate soil remediation technologies using LTVS.
- Help Engineering Field Division personnel write statements of work and remedial design plans for the application of LTVS to soil clean-up projects.
- Enable field personnel such as Project Managers/Officers, Project Superintendents, Engineers in Charge, On-Scene Coordinators, and Resident Officers in Charge of Construction to become familiar with the LTVS technologies.

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- Present selected case study information about successful LTVS so that engineers and decision-making personnel can better evaluate the appropriateness of this technology to the remediation of soils contaminated with petroleum products and hydrocarbons.

1.2 BACKGROUND

A number of methods for removing VOCs from soils have been proposed over the last decade. Some involve in-situ techniques such as in-situ volatilization (R.F. Weston, Inc., 1991) while others employ ex-situ processes such as either naturally aerated processes (NEESA, 1992) or heat treatment. Included in this latter category are high temperature incineration and low temperature volatilization technologies. The primary objective of this paper is to consider soil remediation processes utilizing low temperature volatilization.

In general these processes utilize a purge gas—nitrogen, a combustion stack gas, or other gases that do not support combustion—to entrain VOCs released by thermal desorption from contaminated soils. Typically desorption temperatures run around 230°C to 260°C (450° F to 500°F). The purge gas then is subjected to particulates removal in a bag house or scrubber system after which the VOCs are removed either through condensation and carbon adsorption or incineration at temperatures between 760°C and 980°C (1,400°F and 1,800°F) in an afterburner.

Significant differences between the various LTVSs lie in the choice of methods for heating the soils and the management of the contaminated and decontaminated soils. Fuels for these processes typically are fuel oil, natural gas, or propane. Heat may reach the soil either directly through radiant heat from the flame and convection transfer from the combustion gas or indirectly such as the use of thermal screws heated with hot oil (or sometimes molten salt) circulating through the shell and/or hollow screw auger. Electricity and Infrared radiation also have been a source of heat (Tool, 1991). Four general types of commercially available equipment for this work that have been used for full-scale remediation of VOC-contaminated soils are:

Thermal Screw
Asphalt Plant Aggregate Dryer
Rotary Dryer
Conveyor Furnace

The general tendency in the development of these systems has been to construct equipment out of high temperature alloys which allow operating temperatures of newer systems to range between 315°C and 650°C (600°F and 1,200°F). This permits the treatment of soils contaminated with higher molecular weight hydrocarbons such as crude oil and No. 6 fuel oil. Brief summaries of these systems are given below and some specific general comparisons are compiled in **Table 1**.

1.2.1 Thermal Screw Design:

Sometimes called the "Hollow Screw", this indirect heat exchange processor has been successfully used in cooling and drying conveyable bulk solids, slurries, and viscous liquids for thirty-two years in the food chemicals and minerals industries (Erdman, Jr., 1988). The primary areas of application lie in hazardous and non-hazardous waste sludge volume reduction and low temperature volatile organic compound vapor exclusion or recovery. In soil remediation efforts, soils are brought to these mobile units and fed through a hopper into a jacketed trough where the soils are moved by one to four screw augers configured either in series or parallel. The augers have hollow flights through which hot oil, steam, or possibly molten salt circulates. The return flow is through the hollow shafts. The troughs also may be heated by a flow of hot heat-transferring liquids. It is possible to have electricity or infrared radiators heat the trough and auger(s), but it is more usual to heat the transfer liquid with propane, fuel oil, or natural gas. Auger temperatures of around 340°C (650°F) are reached with circulating oil and up to 590°C (1,100°F) with molten salt.

Exit flue gases from the heater may be vented concurrently or counter-currently through the thermal screw enclosure to provide an inert purge gas and keep the purge gas temperature above 140°C (280°F) (to prevent premature condensations of VOCs). Soils typically reach temperatures up to 260°C (500°F) (with oil heated flights) to 480°C (900°F) (with circulating molten salts) and may reach 870°C (1,600°F) with electrically heated thermal screw systems. Normally thermal screw systems have capacities from 2.7 megagrams (Mg) to 9 Mg (3 tons to 10 tons) contaminated soil per hour. Treated soils can be returned to the excavation for recompaction depending on treatment levels and applicable laws.

Purge gases must be filtered to remove entrained particulates. Often this is done using a bag house, a cyclone, or a scrubber. VOCs entrained in the gases then may be incinerated in an afterburner or condensed and then adsorbed onto activated carbon columns.

TABLE 1
Comparisons of Low Temperature Thermal Stripping Technologies Used in Soil Remediation
(Troxler, et al., 1991; Ellison, 1991)

Characteristics	Thermal Screw	Rotary Dryer	Conveyer Furnace	Asphalt Plant
Estimated Number of commercial systems	18 to 22	40 to 60	1	100-150
Typical soil quantity/site (Megagrams)	455-4540	455-22700	455-4500	<=9000
(tons)	500-5,000	500-25,000	500-5,000	<=10,000
Maximum soil size (cm)	2.5 - 5	5 - 7.5	2.5 - 5	5 - 7.5
(inches)	1 - 2	2 - 3	1 - 2	2 - 3
Soil mixing method	Auger	Shell rotation and lifters	Soil agitators	Shell rotation and lifters
Discharge soil temp. °C(°F)	150(300) to 260(500)(a) 315(600) to 480(900)(b) 540(1,000) to 870(1,600)(c)	150(300) to 315(600)(d) 315(600) to 650(1,200)(e)	150(300) to 430(800)	150(300) to 315(600)
Average Soil residence time (minutes)	30 - 70	3 - 7	3 - 10	3 - 7
Heat up time (hrs) and cool down time (hrs)	not reported not reported	0.5 - 1.0 1.0 - 2.0	0.5 - 1.0 1.0 - 2.0	0.5 - 1.0 not reported
Removal efficiency (%)	64 - 99	95 - 99.9	not reported	>99.9
Soil throughput (Mg/hr)(f,g)	2.7 - 14	9 - 45	23 - 91	4,5 - 9
(Tons/hr)	3 - 15	10 - 50	25 - 100	5 - 10
Mobility	Mobile	Fixed & Mobile	Mobile	Mobile
Costs ($/Mg)(h)	73 - 110	22 - 88	58	not reported
($/ton)	66 - 100	20 - 80	53	not reported

(a) Hot oil heat transfer
(b) Molten salt heat transfer system
(c) Electrically heated system
(d) Carbon steel materials of construction
(e) Alloy materials of construction
(f) Mg = megagrams = 1,000,000 g = 1.102 short tons
(g) Mean range given by 13 vendors, all LTVS: 16-36 kg/hr (15-32 tons/hr)(VISITT, 1992)
(h) Costs do not necessarily reflect all considerations given in **Table 3**. See **Table 2** for more "realistic" values.

Limiting factors: The only critical criterion for these systems is their need to be serviced by a continuous feed system: batch or semi-batch loadings are unacceptable. These systems remove only those organics with comparatively high vapor pressures at the temperatures employed and are most effective for lighter hydrocarbon compounds (gasoline, jet fuels, diesel, chlorinated solvents). Equipment atmosphere must be controlled to prevent explosions. Soils identified to contain environmentally unacceptable levels of metals, fluorides, chlorides, and/or sulfur or total petroleum hydrocarbon concentrations (TPH) exceeding 10,000 ppm may be insufficiently remediated by LTVS protocols (because these protocols are not designed to remove such contaminants) and further treatment—or ultimate disposal—of such soils may be necessary. Soils with pH levels <5 or >11 may cause corrosion and high soil moisture content and tightly packed soils content will reduce heating/removal efficiencies significantly (as will high percentages of clay and/or silt) and may lead to sticking to machinery and the clogging of moving parts.

Agronomists identify four edaphological categories of mineral soils: platelike, prismlike, blocklike, and spheroidal (Brady, 1974). These same concepts have a certain applicability to LTVS treatment of soils. Platy (found in some subsoils and surface regions of virgin soils), Prismatic (more characteristic of soils found in arid regions), and blocklike soils (usually subsoils that strongly control drainage, aeration, and root penetration) all tend to strongly influence the manageability of soils—for both agronomists and LTVS system managers—by tending to clump, be excessively moist and sticky, or be dry and either dusty or brick-like. As agronomists prize the stable granular soil structure for arable topsoils, LTVS system managers also find such soils ideal in terms of their manageability. Typically the granular soil will have the more ideal proportions of sand, clay, and silt that identifies the "loam" soil.

Organic soils typically are obtained from peat bogs, estuarian deposits, and some fresh water swamps and sloughs. Such soils may be very hard to manage because of their tendency to resist dewatering and to clump and stick. Dredged sediments may be high in silt content and while they may dewater reasonably well, may tend to be dusty and hard to keep properly moist for clean handling and storage. Such materials also may be chunky, even blocky and may need to be reduced by mechanical means before LTVS treatment.

Material extracted from the lower regions of the soil column, from river bottoms and bars, and from sites which had been used for human waste disposals, may contain unsuitable debris such as rocks, waste wood, discarded materials of all sorts, and even bones. It may be necessary to screen the soil before putting it through the LTVS. Permissible sizes for solids (rocks and so forth) may range up to 5 cm (2 in) depending on the capacity of the machinery, but soil

clumps may need to be less than 0.6 cm (0.25 in) or so to ensure proper heating and VOC removal. Discarded material may have to be consigned to hazardous waste disposal sites. Rocks may have to be crushed and fed through the LTVS: the permissible size for the crushed rock would depend on the physical limitations of the machinery, but it must be remembered that sometimes added rock can help scour sticking soils from the machinery and thus this can be a benefit for a given operation.

1.2.2 Rotary Dryer Design:

The Rotary Dryer is a kiln or cylindrical metal drum, lying at a slight angle to the horizon. It is mounted to slowly rotate around its longitudinal axis and is heated by a flame from the outside. Heat can be applied either to the upper or lower end of the kiln and purging gases can be made to flow either co-currently or counter currently to the flow of the soil. The soil is loaded at the higher end and allowed to move under gravity while being lifted and mixed by internal flights within the kiln. Because the Rotary Dryer has no refractory material on the inside, internal soil temperatures can not reach temperatures in excess of 315°C (600°F). If the kiln is made of special alloys, however, discharge temperatures can be as high as 650°C (1,200°F). The basic technology is well known having been adapted from kilns operating at higher temperatures (650°C to 1650°C [1,200°F to 3,000°F]). Those are lined with refractory material, are heated internally, and have been used for years to incinerate sediment-born organics (viz. Department of Defense (DoD) remediation of TNT-contaminated soils at Grand Island, Nebraska; and Shreveport, Louisiana)(Anon., EPA, 1991).

The LTVS Rotary Dryer design treats for a wide range of contaminants including gasoline, diesel, waste oil, slop oil, lube oil, crude oil, oil contaminated soils, acid sludges, tars, solvents, and PCBs. Because this process also may cause at least some heavy metals to bind with soil materials especially when the system is run at its higher temperature ranges, some immobilization of heavy metals may accompany LTVS treatment: any binding of metals to soils may affect subsequent solubilities of cations hence this process has some marginal advantages for remediation of some metal-contaminated soils. However, any such immobilization need not be permanent: cations may adhere to fine soil granules that escape dust entrapment or are eroded from the storage pile of remediated soils by wind and/or rain. Also, once the remediated soil has been backfilled and the site closed, subsequent groundwater leaching may remobilize these cations. Gases from the Rotary Dryer LTVS may be treated in the same way mentioned for the Thermal Screw design.

Limiting factors: The future use of these soils may be limited because weathering may, in time, cause heavy metals to again become mobile. If these soils are used as aggregate for concrete, fine organic particles may weaken cement bonds and other chemicals, notably any soluble metal salts, sulfates, semi-volatile organics, cyanides and so forth may affect the curing of the concrete and the ultimate strengths achieved. However, specific experience with these soils is limited and information on the long-term fate of such soils is poorly documented. Therefore, regulating agencies may require that these decontaminated soils be consigned to an appropriately designed landfill.

Remediated soils may, in some cases, be returned to forestry and/or agricultural-recreational activities. Suitable vegetation for the specific soils would have to be determined on a site-specific basis by a competent agronomist because the remediation processes will have altered many characteristics of the soil including soil aggregation, soil organics, soil life forms (fungi, bacteria, and so forth) and other relevent parameters.

1.2.3 Asphalt Plant Aggregate Design:

The aggregate dryer typically is a rotary counter-current dryer with a cyclone or bag house and no afterburner. Historically the Asphalt Plant has no treatment of gaseous by products, but air quality standards of many states now require that these units be retrofitted at least with afterburners to reduce hydrocarbon emissions. The soil may or may not be used as a partial substitution for the stone aggregate for the asphalt. Soils contaminated with petroleum hydrocarbons are best suited for this type of remediation.

Limiting factors: Most asphalt plants do not operate during cold weather and off-site transportation may be needed since the asphalt plant often is not located where the contaminated soil resides. The soil particles need be approximately the same as the stone aggregate being used and must satisfy asphalt mix requirements.

1.2.4 Conveyer Furnace Design:

There is very little information about this design. It consists of a flexible conveyor belt upon which soil is placed and moved through a primary furnace fired by propane burners. Soil agitators are used to lift the conveyor belt and turn the soil over to enhance heat transfer. The gases are treated in an afterburner then through a quench chamber, a duel-venturi collision scrubber, a mist eliminator, an induced draft fan, an exhaust stack, and a flue gas analysis system. The

scrubber blowdown is added to the dry processed soil in the discharge screw. This cools and moisturizes the soil and minimizes dust formation.

Limiting factors: The paucity of information about these facilities precludes comments about limiting factors other than speculating that maintenance of the moving belt, scoured as it must be by abrasive soils, may be high.

1.3 PERFORMANCE FACTORS:

A number of factors which affect the performance of LTVS projects may be considered elements of system operating parameters, contaminant characteristics, and soil characteristics. The following will expand on each of these categories.

1.3.1 Equipment Operating Parameters:

The primary equipment related factors affecting performance include the maximum soil temperature achieved, soil residence time, oxygen content of the purge gas, heating method, and the mode of operation.

Maximum Soil Temperature and Residency Time: The maximum temperature achieved by the soil is influenced by the heat capacity of the soil, average particle size of the soil, and the heat transfer and mixing characteristics of the thermal desorption device. The soil moisture content is another significant factor: it is desirable to keep soil moisture between the dust-hazard lower limit of around 5% moisture and the generally upper limit of around 40%. Ideally it should be between 20% and 25%. In general, soil must be heated to the temperature which would achieve a contaminant vapor pressure of between 0.5 and 2.0 atmospheres in a closed system. The treatment time also is significant: Thermal screw devices usually require 30 to 70 minutes residency time while other LTVS systems generally require less than 10 minutes.

Characteristics of the Purge Gas: The purge gas may be oxidative or inert, but it should stay below 2% to 3% oxygen to prevent an explosion. If the treated soils are very high in organic material, it will be necessary to keep the oxygen concentration below 2%, but such restraints allow the treatment of soils contaminated with as much as 50% organics. In some systems a nitrogen blanket is used to keep the oxygen concentration below 4% which reduces the necessity to keep the organic concentration below the lower explosive limits (LEL) applicable to air.

Heating Methods: If a burner is mounted inside the desorption chamber, heating is direct and up to 10 times more volatile gas can be released than if the burner is mounted outside the chamber and heating done through indirect methods. Indirect fired systems generally are limited in size and generally have lower waste processing capacities than comparatively sized directly heated systems.

Flow of Purge Gases: Purge gases may flow either co-currently or counter-currently. The arrangement affects the temperatures of exit gases, the efficiency of contaminant removal, and the arrangement of downstream facilities.

If the purge gases flow co-currently, exit gases have high temperatures (10°C to 38°C [50°F to 100°F] over counter-current flows) and typically are followed by an afterburner then a bag house. Particles contaminated with organics will be treated in the afterburner hence bag house contents need no further decontamination. The higher temperatures of purge gases in this mode of operation results in higher exit temperatures for soils.

Counter-current flowing purge gases typically pass through a bag house before entering the afterburner. Dusts there may need to be recycled through the LTVS system to eliminate surface adsorbed organics. Because exit gases under this system have less energy, smaller downstream gas cleaning equipment is needed compared to co-current systems

1.3.2. Soil Contaminant and Treatability:

Except for certain circumstances where low temperature thermal treatment may cause at least some metals to bind with soil chemicals, metal removal is not achieved through these processes. Similarly high molecular weight organics (viz. most organo-phosphate and chlorinated hydrocarbon pesticides) may be unaffected. However most hydrocarbon contaminants with sufficient vapor pressures can be removed. Since vapor pressure increases exponentially with temperature, removal of most hydrocarbons is possible through a careful selection of the appropriate LTVS. Other factors affecting treatability are the volume of purge gas flowing through the system, the oxygen content of that gas, and the exit temperature of the gas.

The potential for explosions in LTVS is limited by keeping the oxygen level in the purge gas to less than 25 percent of the lower explosive limit when the gas temperature is above the autoignition temperatures of the hydrocarbons being vaporized. Typically the lower explosive

limits of hydrocarbons are in the range of 1% to 2% of hydrocarbon by volume and autoignition temperatures range from approximately 260°C to 650°C (500°F to 1,200°F). Soils contaminated with high concentrations of hydrocarbons may, because of these considerations, have to be treated by alternate technology or significant modifications in the choice of and/or volume of the purge gas. One particular advantage of the Thermal Screw system is that the purge gas—composed as it is of nothing but flue gases from the furnace—is essentially oxygen free and these systems, therefore, are better adapted for use with high concentrations of hydrocarbons.

1.3.3 Soil Characteristics:

Soil particle size can influence the performance of thermal desorption systems in several ways. If the soil particles are primarily clay to silt in size, a large portion (1% to 30%) may be entrained as dust in the purge gas flow and thereby escape the necessary residence time in the LTVS needed to effect adequate treatment. Such dusts, collected in the bag house, would have to be recycled through the system and this would reduce the efficiency of the process. Furthermore, there may be significant losses of such soils from stockpiles of both pretreated and post-treated soils leading to significant on-site soils management problems in wind and rain storms.

On the other hand, excessively large blocks of soil aggregate will not heat uniformly or to high enough temperatures and may tend to "clinker" into unmanageable and ineffectively treated nodules. Typically thermal desorption devices require soils to be mechanically reduced and screened to a size not larger than 2.5 cm to 5 cm (1 in to 2 in).

Thermal desorption of fine-grained soils with a moisture content above the plastic Atterberg limit[1] is difficult. Such soils tend to stick to rocks, soil debris, and the surfaces of both moving and stationary parts of the machinery leading to jamming problems. These soils also can become molded into large blocks having a comparatively low surface area per unit volume that would contribute to an ineffective transmission of heat. These soils would need pre-treatment steps such as air drying, mixing with drier soils or other inert waste materials, and/or mechanical size reduction using power screens or crushing operations. Pozzuolana, a siliceous volcanic ash, is often used to absorb moisture and gypsum is used to chemically change the binding characteristics of clay. A ploy used in some sludge treatments systems is to mix hard, multifaceted particles of limestone (0.5 cm to 1.0 cm [0.25 in to 0.5 in] diameter) with the feed. These "scour"

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[1] The Atterberg limits identifies the boundaries between the semiliquid and plastic states (known also as the liquid limit) and between the plastic and semisolid states (known as the plastic limit).

sticking material from the auger surface and help transfer heat to the matrix. As products are discharged from the unit, screening separates these limestone particles from the residue and the particles then can be recycled (Erdman, Jr., 1988).

Another soil factor to consider is moisture content. Soil moisture may range from 5% to 30% or higher although most soils will range between 10% to 20%. This moisture may be chemically bound in the form of hydrates or simply surface absorbed. In either form the soil moisture can be a significant heat sink affecting heating costs and the efficiencies of heat transfer. However, water forms many azeotropic[2] systems (sometimes called "steam stripping") and conceivably there will be occasions when this tendency will enhance the ability of the LTVS to remove certain contaminants (e.g. p-xylene removal is known to be enhanced through this mechanism). A completely dry feed soil would present serious handling problems and excessive losses (in the form of dust) both within the LTVS and in storage and handling processes. It may be necessary to add water to such soils before operations.

LTVSs are able to remediate soils, sludges, industrial solids, and natural sediments. Various contaminants reported by vendors listed in the U.S. Environmental Protection Agency (EPA) Vendor Information System for Innovative Treatment Technologies (VISITT), version 1.0 include:

- 4,4-methylene, bis(2-chloroaniline)
- BDAT metals/Organics
- Bis (2-ethylhexyl) Phthalate
- BTEX
- Chlorinated solvents
- Coal Gassification Products
- Creosote
- Dioxins/Furans
- Dioxin 2378-tetrachloro-dibenzodioxin (TCCD)
- Drilling Oil
- Kerosene
- Oil, Grease
- Organic Corrosives
- PAH - Total
- PCB
- Pesticide Manufacturing by-products
- Pesticides/Herbicides
- Petroleum refining/reuse
- PNA
- VOCs
- Steel Mill Rolling Mill Oil
- Toluene
- Total Cyanides

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2 Certain solutions of two or more compounds, for example ethanol (b.p. 78.5°C) and water (b.p. 100°C), have the same percent composition in the liquid and gaseous phase (viz. 4.4% water, 95.6% ethanol) at a precise boiling point (78.2°C for the ethanol-water solution). Such a solution is said to be an azeotrope system. The boiling point of an azeotrope always is lower than the boiling point of any of its constituents.

Light Petroleum Products	Toxaphene
Mineral Oil	VOCs
No. 2 Fuel Oil	Wood Preservatives
No. 6 Fuel Oil	Xylene

1.4 SYSTEM PERMITTING:

There are no Federal regulations that establish performance standards for thermal desorption systems treating petroleum contaminated soils. The Federal regulations listed in 40 CFR 261.4(b)(10) specifically exempt petroleum contaminated soils from being a Resource Conservation and Recovery Act (RCRA) hazardous waste if it fails to qualify as toxic material as determined by the benzene toxicity standards defined in the Toxic Characteristic Leaching Procedure (TCLP). This is an extremely important exemption since it has allowed the thermal treatment of petroleum contaminated soils in mobile and fixed-site plants operating under state air permits instead of the more complex and expensive RCRA regulations. Petroleum contaminated soils which contain concentrations of lead that exceed TCLP criteria are not exempted, however. Such soils are RCRA hazardous wastes and might fail to be permitted for LTVS remediation.

The effect of these factors is that permitting of thermal desorption systems for the treatment of petroleum and hydrocarbon contaminated soils is characterized to a large degree by state standards for solid wastes and air. Specific handling and clean-up protocols generally are based on the results of analytical data on a site-specific basis. Soil acceptance standards generally will be different if the soil is suspected of being contaminated with RCRA hazardous wastes or waste oil. Clean-up criteria vary widely from state to state, but the most common criteria call for a reduction of total petroleum hydrocarbons (TPH) to levels from 1,000 mg/kg to 100 mg/kg. State standards for allowable concentrations of benzene, toluene, ethyl benzene, and xylene (BTEX) usually range from 1 mg/kg to 10 mg/kg, but can extend to subparts per million or up to 200 mg/kg for individual BTEX components.

States also differ with respect to the analytical protocols deemed acceptable for these analyses and in some states, notably California, local management districts and air quality boards may vary considerably in their requirements. Numerous permits may be required from different agencies in the same district.

1.5 COSTS:

Treatment costs are highly application specific. They depend on the type and size of the thermal desorption equipment used, the type and quantity of soil at the site, the moisture content of the soil, and the type of hydrocarbon contaminant. Mobilization, permitting, site closure, and demobilization costs may be a significant fraction of the total treatment for mobile systems. Handling equipment, managing soils, equipment rental, handling fuel, labor, electricity, waste disposal, capital depreciation, maintenance, health and safety supplies, analytical costs, and profits of contractors and subcontractors all affect costs. Insurance costs are much lower if the site is handled under the auspices of Superfund or RCRA.

Some aspects of the costs (and their estimated ranges in 1990 dollars where available [see Tool, 1991]) that have to be evaluated carefully are:

-Mobilization and demobilization; erection and dismantling of equipment ($2.20/Mg to $55.00/Mg [$2.00/ton to $50.00/ton]).

-Permitting and chemical analyses (a fixed price regardless of the size of the job, hence these costs decrease with the size of the job ($1.10/Mg to $18.75/Mg [$1.00/ton to $17.00/ton]).

-Recycling of materials (including carbon columns if used ($7.72/Mg to $28.67/Mg [$7.00/ton to $26.00/ton]).

-Labor inefficiency due to the level of personnel protection required by LTVS plant operators ($1.10/Mg to $4.41/Mg [$1.00/ton to $4.00/ton]).

-Prime contractor overhead and profit ($9.92/Mg to $38.59/Mg [$9.00/ton to $35.00/ton]).

-Soil quantity to be treated (generally costs per unit of soil decrease as the amount of soil to be treated increases).

-Capacity of production.

-Level of contaminate residuals permitted.

-Fuel and electricity costs.

-Air monitoring costs.

-Site restoration costs. Wastewater-runoff sewer charges and/or containment/on-site processing costs.

-Stockpiling treated soils and preventing fugitive losses of soils from wind and/or precipitation events: Material handling area. Mechanical crushing devices (including rock crushing), screening devices, loading and unloading equipment.

-Local meteorological history and impact(s) that can be reasonably expected throughout the lifetime of the project.

-Air emission controls or abatement costs.

Examples of LTVS costs (in 1990 dollars) for four full-scale projects are given in **Table 2.**

1.5.1 Comments on Costs:

An alternate source of information on costs was obtained through the U.S. EPA VISITT data base. Thirteen vendors of LTVS technology were identified and estimated costs for these services were given as a range between a low and high values. In making these estimates, vendors were not uniform in taking into account all of the factors which influence price hence the estimated costs ranged from $16.54/Mg to $661.52/Mg ($15.00/ton to $600.00/ton).

Estimates of lowest costs ranged from $16.54/Mg to $137.82/Mg ($15.00/ton to $125.00/ton). The mean low estimate of the thirteen respondents was $79.38/Mg ($72.00/ton); the median was $71.66/Mg ($65.00/ton), and the standard deviation was $40.35/Mg ($36.60/ton). The highest estimates ranged from $33.07/Mg to $661.52/Mg ($30.00/ton to $600.00/ton): the mean was $230.43/Mg ($209.00/ton); the median was $165.38/Mg ($150.00/ton); the standard deviation was $169.79/Mg ($154.00/ton). A list of items that should be taken into consideration when working out costs for LTVS operations is given in **Table 3.**

2.0 ASSESSMENT CRITERIA:

2.1 ADVANTAGES OF LTVS:

-LTVS processes can be tailored to treat soils contaminated with either low molecular weight or higher molecular weight hydrocarbons by controlling temperatures and retention times.

-Conservative applications of heat and retention times can be used to remediate soils to permitted levels and avoid costs associated with "over-remediating".

-In many cases the LTVS can be set up on the site and treatment can be completed with a minimum of soils hauling.

TABLE 2
COMPARISONS OF COSTS BETWEEN FOUR SUPERFUND SITES: SOILS APPROXIMATELY 20% MOISTURE
(Tool, A.R., 1991)

PROJECT NAME	DESCRIPTION OF SITE	ESTIMATED	
		$/Mg	$/TON(1)
Lipari Landfill off-site	85,630 m^3 (112,000 yd^3) marsh soils: dispose on-site (Glassboro, N.J.)	252.76	229.25
Caldwell Trucking	19,270 m^3 (20,000 yd^3): dispose on-site (Fairfield, N.J.)	249.65	226.43
Metaltec(2)	5,890 m^3 (7,700 yd^3): off-site disposal (Franklyn, N.J.)	328.65	298.09
Waldick Aerospace Devices(2)	2,750 m^3 (3,600 yd^3): off-site disposal (Wall Township, N.J.)	336.95	305.61
	Average:	292.01	264.85

1. Estimates are composites from seven vendors including 4 who employ rotary dryers, 2 employing Thermal Screws, and 1 using an Infrared Furnace.
2. Note that LTVS projects have many "fixed" costs which, if not amortized over large volumes of soils, cause the price per unit of soil to appreciate rapidly.

TABLE 3

VARIOUS COMPONENTS OF AN IDEALIZED LTVS PROJECT THAT SHOULD BE CONSIDERED WHEN WORKING OUT A COST ESTIMATE

DIRECT CAPITAL COSTS:	
(Rental cost for LTVS unit including afterburner or carbon adsorption columns; Baghouse; flue gas scrubbing; Piping; Electrical instrumentation; Controls.)	
Thermal Screw	_____
Externally Heated Kiln	_____
Conveyer Furnace	_____
Asphalt Aggregate Dryer	_____
INDIRECT COSTS:	
(Site preparation/Mobilization; Construction Erection/Installation; Engineering; Permits; Start-up and Training; Spare Parts; Freight; Site closure/Demobilization; Contingency.)	_____
OPERATING COSTS:	
(Equipment; Labor; Utilities [fuel[1], electricity, water, wastewater disposal, oversized disposal]; Laboratory costs; Miscellaneous supplies; Contingency.)	_____
EQUIPMENT COSTS:	
(15.3 m^3 (20 yd^3) roll-off box dump truck(s); 3.8 m^3 (5 yd^3) front-end loader(s); Safety vehicle, Monitoring equipment, Sanitary facilities.)	_____
LABOR COSTS: (Site leader; LTVS and scrubber operators; Site safety officer; Maintenance technicians; Excavation operators; Contract mechanic/electrician; Secretarial and Security personnel.)	_____
TOTAL COSTS	_____

1. Fuels specified include those used for heating the LTVS (propane, fuel oil, natural gas etc.) and for running trucks, utility vehicle, etc. (diesel, gasoline).

-Treatment efficiencies of up to 99% and better can be obtained.

-Easy to implement because much of the technology is comparatively simple and readily available.

-LTVS treatment of most contaminated soils does not fall under Federal permitting (an important exception will be soils contaminated with RCRA wastes). Local and regional air and solid waste requirements must be met.

-Contaminants either are destroyed in an afterburner or secondary burner, absorbed onto carbon columns, or scrubbed.

-Treated soils often can be placed back into the excavation from which they came (if regulatory authorities permit it), be compacted, and continue to provide useful services as "reclaimed" land.

-There is a lower reduction of soils volume with LTVS than with incineration.

-Costs often are very competitive with other treatment technologies especially on larger projects.

2.2 DISADVANTAGES OF LTVS:

A number of considerations need to be evaluated before undertaking an LTVS project:

-Nature of contamination: Soils contaminated with heavy metals, pesticides, and high molecular weight organics may still need to be consigned to hazardous waste landfills even after LTVS treatment. Such soils may need further remediation to meet applicable landfill requirements before this ultimate disposal.

-Concentrations of contaminants: Soils contaminated with very high concentrations of hydrocarbons (50% or more) may have to be treated with high temperature systems or may have to be treated as hazardous materials.

-Safety: Hazard of explosion if temperatures are high, oxygen is present, and the concentration of organics in the purge gases becomes sufficiently high.

-Handling excessively wet soils: Soil moisture must be around 20%: higher concentrations of water due to rain, groundwater, or an attempt to treat estuary/dredging sediments may make it necessary to employ dewatering pre-treatment. Excessively wet soils consume excess heat and introduce handling complications.

-Handling excessively dry soils: Excessively dry soils present dust losses, handling difficulties, and inefficient removals of contaminants. Dry soils may have to be watered. Excessively fine-grained soils may have to be mixed with other soils or inert ingredients to prevent excessive losses to the bag house.

-Health: Large volumes of soils must be handled. This requires a careful management protocol to assure that workers and/or off-site personnel are not exposed to contaminated dusts or contaminants that outgas during handling and that soil stockpiles neither impede operations nor pose problems with respect to wind or water erosion.

-Energy: Large volumes of fuels are required. Fuel must be handled, stored, and piped. There always is a danger of spill (or venting) and fire/explosion.

-Operational track record: Of the LTVS designs reviewed here, not all have had the same amount of testing. Their technologies are in early states and their potential contributions to soil treatment may not yet be fully realized.

-Pretreatment: Soils may be chunky and have to be screened or otherwise broken down to particles between 2.5 cm to 5 cm (1 and 2 inches) in size.

-Handling non-soils: Soil debris such as rocks and human discards of all kinds need to be separated from soils and stockpiled. In some instances these may also need to undergo a decontamination process and/or disposal in a hazardous waste landfill.

3.0 CASE STUDY: LETTERKENNY army DEPOT (LEAD)

3.1 SITE CHARACTERISTICS

3.1.1 Site Location and History:

Letterkenny Army Depot (LEAD) is located in the central portion of Franklin County, Pennsylvania, about 8 kilometers (km) [5 miles (mi)] north of the city of Chambersburg. The depot is bounded by Greene, Hamilton, and Letterkenny Townships. The installation occupies 7,900 hectares (ha) [19,520 acres](See **Figure 1**).

LEAD was established in 1942 with a mission of ammunition storage, but currently its mission includes overhauling, rebuilding, and testing of wheeled and tracked vehicles; the issuance and shipment of Class III chemicals and petroleum; and the storage, maintenance, demilitarization, and modification of ammunition. Operations associated with current or prior missions have included cleaning and stripping, plating, lubrication, demolition, chemical and petroleum transfer and storage, and washout/deactivation of ammunition. Many of these activities, except those associated with ammunition, were conducted in the Southeastern (SE) area where significant quantities of trichloroethylene (TCE), other chlorinated hydrocarbons (carbon tetrachloride (CTC), chloroform, methylene chloride, 1,1,1-trichloroethane (111TCE), and tetrachloroethylene (TCL)), hydrocarbons, and other solvents were used and disposed (Anon., Final . . ., 1992) (see **Appendix A**).

Spent materials were wasted to various burial trenches, IWTP Lagoons, pits, and landfills in the Southeastern area. The SE area includes the Disposal Area (DA) and Southeast Industrial (SEI) area (**Figure 2**) of the reservation. The K-Area and IWTP Lagoons are part of the DA (see **Figures 2** and **3**). These sites became sources for VOC contaminated groundwater that has been traced offpost to private wells. Potential sources for these contaminants are the K Area and the IWTP Lagoons.

A pilot study was conducted at LEAD from August 5, 1985 to September 16, 1985 to determine the feasibility of low temperature thermal stripping of VOCs from the soils around the sites of the two K4 Area Lagoons that apparently had been used for the disposal of organic liquids. Soils were treated in a thermal processor in which an indirect heat exchanger was used to heat and dry the contaminated soil. The VOCs removed through volatilization were entrained in a carrier gas and thermally destroyed in an afterburner. This study indicated the practicality of the use of

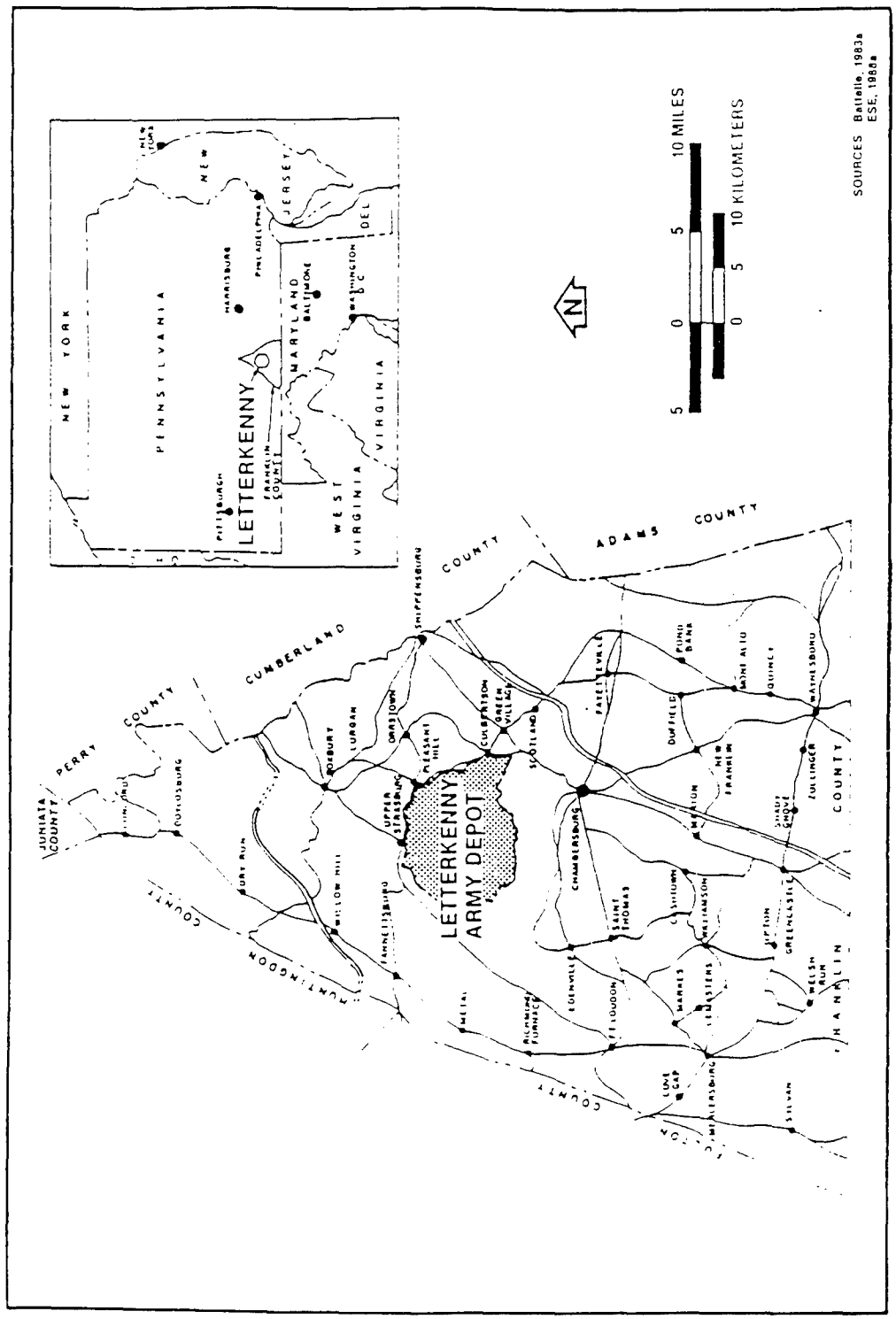

FIGURE 1

LOCATION AND MAP OF LEAD AND VICINITY

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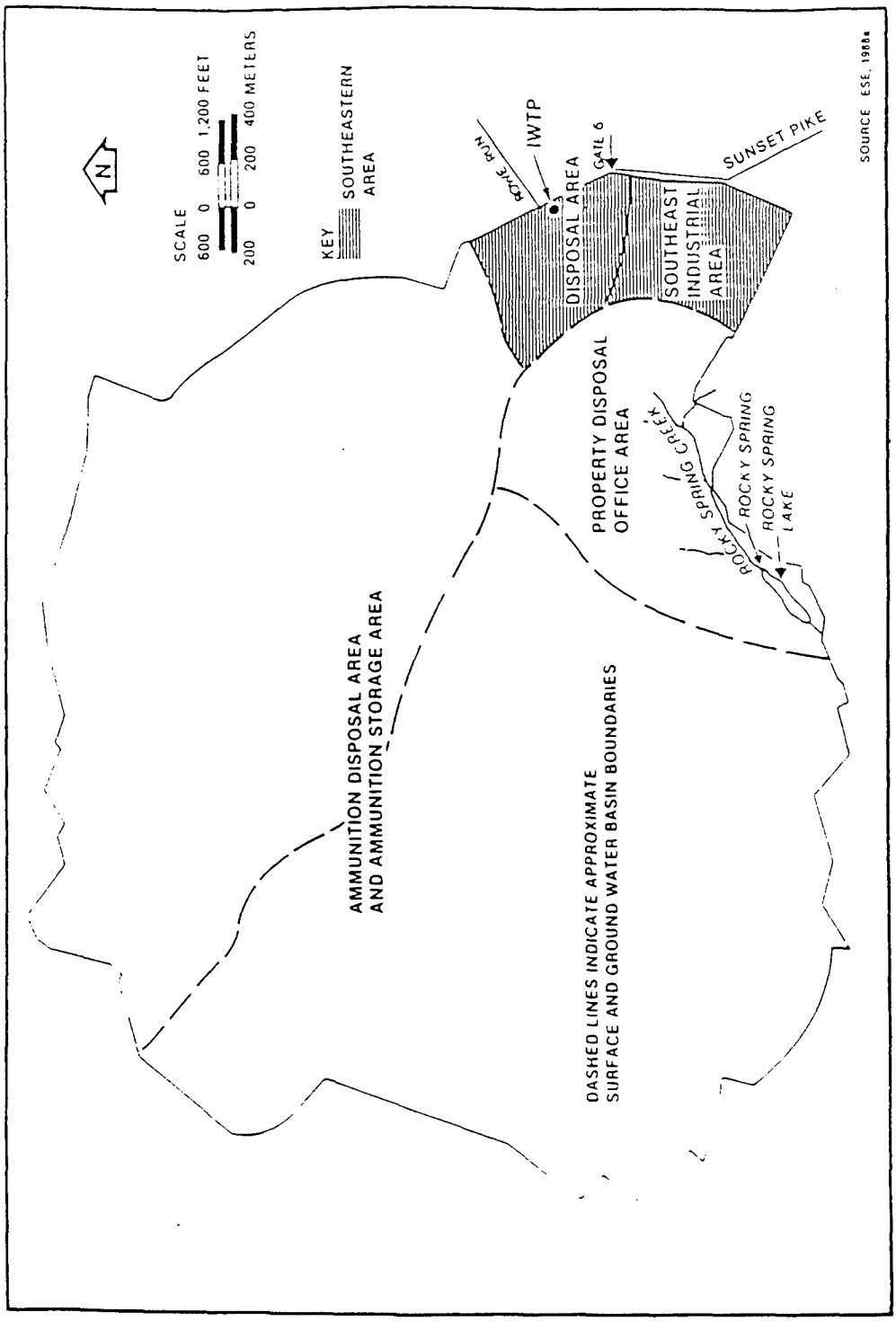

FIGURE 2

SURFACE WATER AND GROUNDWATER BASINS AND SE STUDY AREA AT LEAD

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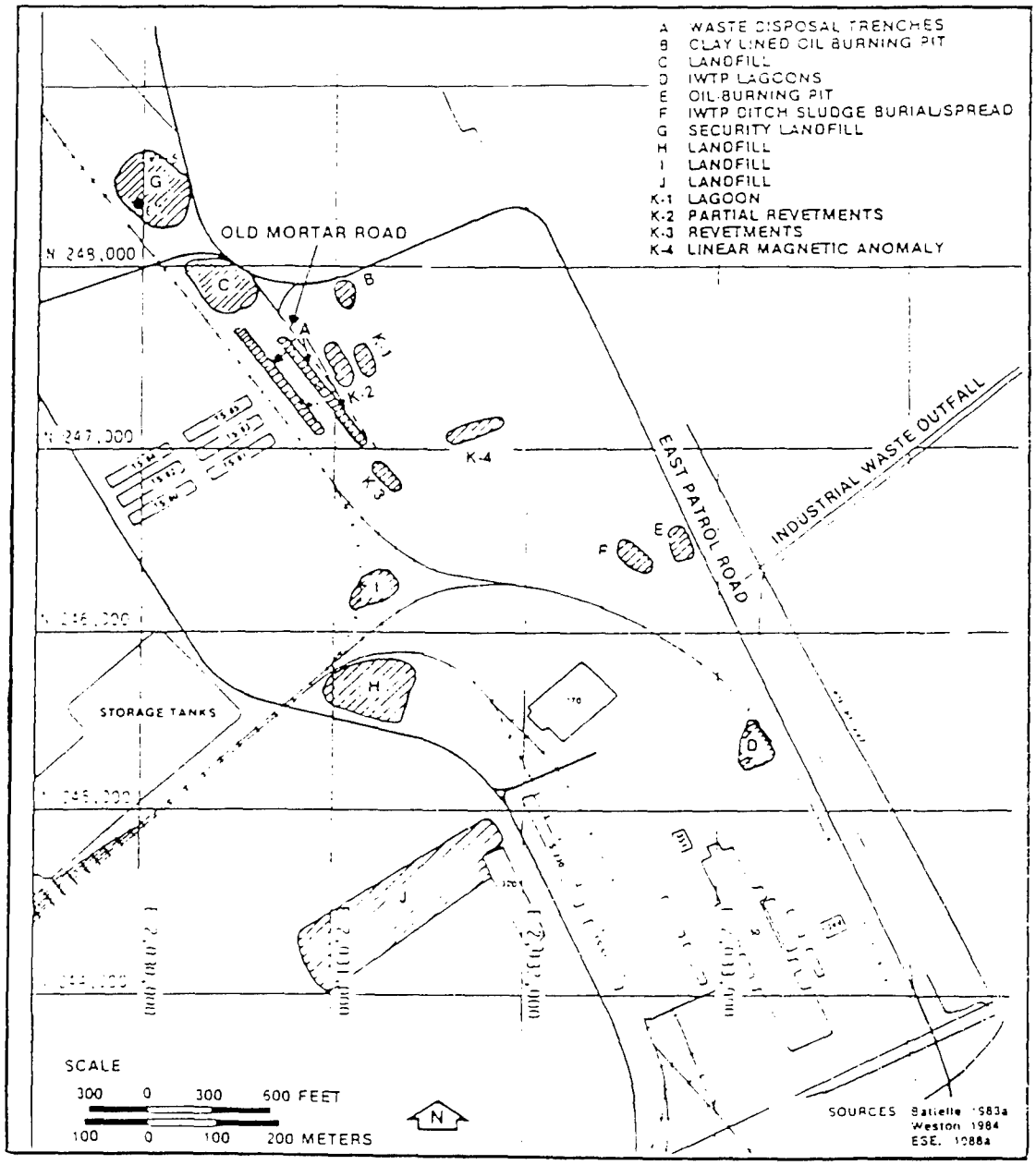

FIGURE 3

POTENTIAL CONTAMINANT SOURCE AREAS IN THE DA

this technology for soil remediation and highlighted many relevant parameters that would have to be taken into consideration during any full-scale application (Anon., Final . . ., 1992).

Between February 7 and February 27, 1989, an interim In Situ Volatilization (ISV) remediation program was conducted on the K Area. An array of 26 vents, ranging from 3 m (10 ft) to 9 m (29.6 ft) deep, in an area approximately 46 m (150 ft) by 61 m (200 ft), were connected to a pipe manifold. This in turn was connected to a particulate filter, an air vacuum pump, and two carbon units. The intent was to pull air through the soil, have that air entrain soil VOCs, and have those removed from the air stream by the activated carbon filters. Off gas sampling detected trichloroethylene (TCE), 1,2-dichloroethylene (12DCE), tetrachloroethylene (TCL), and vinyl chloride. TCE was detected in the highest concentrations (676 ppm). These efforts were terminated because seasonal wetness interfered with operations significantly, clay contents of the soil made the soils excessively nonporous to prevents adequate air flow, and soils beneath floating boulders could not be treated (Anon., Final . . ., 1992).

Between October 1985 and April 1987 a series of studies identified the IWTP Lagoons area as a major VOC contaminant source in the SE Area at LEAD. Dye tracer studies showed that the discharge area for groundwater from the IWTP Lagoons area is toward Rowe Run. By June 1989 a system of open hole recovery wells had been prepared and water recovered from them was treated by air stripping. This system has treated over 366 million liters (96.8 million gallons) of contaminated groundwater and continues to operate routinely without detectable limits of volatile organics in the groundwater and air stream effluents. Sampling of the stack emissions from the gas phase carbon offgas treatment indicates the Best Available Technology (BAT) air treatment is not allowing release of VOCs. This system continued to operate partially during the closure/remediation of the former IWTP Lagoons (site operations interfered with the operations of two wells) and is to be back in full service on the completion of this work.

IWTP Lagoons closure began in January 1992. The IWTP Lagoons concrete liner was broken up, pressure washed, and removed from the IWTP Lagoons area. The underlying contaminated soils were excavated and transported to the LT^3® unit located on a specially prepared containment pad adjacent to the DA. The VOCs were thermally removed from the soils in rotary kilns operating at 315°C (600°F) to 426°C (800°F), entrained in a gas stream within the kiln, vented to a secondary burner operating at approximately 900°C (1,650°F) where the VOCs were destroyed and only carbon dioxide, carbon monoxide, hydrochloric acid, and water were vented. All concrete and rocks that were removed, washed, and crushed along with the remediated soils were backfilled at the site, compacted, and capped.

3.1.2 Soil, Hydrogeology and Geology of Site:

The LEAD site is situated in the western side of the Cumberland Valley and is characterized by gently rolling terrain underlain by folded and faulted limestone bedrock. LEAD native soils are described by Johnson (1987) as being "clayey coarse sand and gravel" belonging to the Hagerstown-Duffield Association. These soils are described as deep-well drained, nearly level to steep soils in valleys formed in materials weathered from limestone. Specifically the IWTP Lagoons soil is a Hagerstown (HfB) silty clay loam with 2 to 8% slopes. The soil is reddish brown in color, but turns redder after low temperature thermal treatment (Bryan Hoke, personal communication). There also is fill soil at LEAD consisting of gravely sands.

LEAD is located in the Great Valley section of the Valley and Ridge physiographic province. This area, known locally as the Cumberland Valley, extends in a northeast-to-southwest direction across the central part of Pennsylvania.

LEAD straddles two major structural features, the South Mountain anticlinorium to the east and the Massanutten synclinorium to the west. These structures resulted from the folding that occurred during the close of the Paleozoic Era. High angle reverse faulting accompanied the folding of rocks in the eastern part of LEAD. Several major faults, which strike to the northeast and dip to the southeast at fairly steep angles, cross through the part of the facility where the IWTP Lagoons are located (see **Appendix A**).

The predominant faults include the Pinola and Letterkenny Faults. The Pinola Fault is reportedly located immediately north of the IWTP Lagoons and represents the structural boundary between the Martinsburg Formation and the St. Paul Group. The Letterkenny fault is also located north of the IWTP Lagoons area and represents a major structural feature between the northern boundary of the Chambersburg Formation and the St. Paul Group. One additional unnamed fault is reportedly located near the IWTP Lagoons.

Maps of the LEAD area are given in **Appendix A**. This area is underlain by rocks which have been mapped as belonging to five geologic units: The Chambersburg Formation, the St. Paul Group, the Pinesburg Station, Rockdale Run, and Martinsburg Formations. The IWTP Lagoons are underlain by rocks of the St. Paul Group (limestone) close to the contact with the Pinesburg Station Formation (dolomite). The St. Paul Group limestones have a pinnacled rock

surface and exhibit numerous healed fractures and solution openings, many of which are partially filled with wet, runny clay.

Relatively highly weathered rock underlies 2 to 10 meters (6.6 to 32.8 feet) of silty and clayey soils in the IWTP area. Rocks at greater depths (13 to 20 meters [42.6 to 65.6 feet]) are unweathered and may be less fractured than overlying rock. A sinkhole developed when the IWTP Lagoons was unlined presumably due to chemical leaching of the limestone by acidic wastewaters leaking from the storage site (Anon., Final . . .,1992).

Groundwater flow within the limestones of the Chambersburg Formations and of the St. Paul Group (the latter of which underlies the IWTP Lagoons area) is predominantly through solution channels and enlarged fractures typical of karst terrain. Groundwater also locally occurs within the weathered overburden which covers the limestones and dolomites at the site. Thickness and occurrence of overburden is variable. Fractures are predominantly aligned with the regional north-northeast strike of the formations and are relatively irregularly and widely spaced. Large solution cavities are also found the limestone; groundwater flow in these cavities would be expected to occur at significantly higher rates than in other fractures. Flow within the overburden deposits typically is at lesser rates.

Regional groundwater movement is, in general, in a northeasterly direction along the regional strike of the underlying geologic units except where influenced by the less permeable Pinesburg Station dolomites. Dye tests indicate the discharge area for groundwater from the IWTP Lagoons area to be Rowe Run spring about 3.2 km (2 mi) to the northeast.

Based on historical data, the groundwater elevation in the IWTP Lagoons area is often 3 to 4.6 m (10 to 15 ft) above the bedrock surface and was found in certain studies to vary in response to recent rainfalls as much as 3 m (10 ft) in 1 day in the IWTP Lagoons area. Highest levels occurred during spring and summer recharge seasons and lower levels during the September to November dry season.

3.1.3 Reason for Action and Permitting:

A total of 62 soil borings were completed within and around the IWTP Lagoons to define the area and vertical extent of contamination in soils. Thirty core samples were collected from 10 soil boring locations surrounding the IWTP Lagoons in January and February, 1987.

Samples were taken up to 5.5 m (18 ft) in depth and were analyzed for priority pollutants, EP toxicity (Ni, Cu, and Zn) and total cyanide.

The only chlorinated VOC found was dichloromethane, in eight of the 30 samples. PCBs, pesticides, and cyanides were below detection limits in all 30 samples. Metals contamination was widespread, with copper (Cu), chromium (Cr), lead (Pb), zinc (Zn), nickel (Ni), and thallium (Tl) detected in all 30 soil samples, and other metals being detected in many other samples. EP toxicity testing was performed on all 30 samples. All 30 samples were at least an order of magnitude below the maximum leachable concentrations as specified at 40 CFR 261.24. Metal contamination was relatively uniform, both horizontally and vertically, around the IWTP Lagoons parameter

The high levels of VOCs in groundwater around the IWTP Lagoons and the relative absence of organics in soils were interpreted as suggesting that a concentrated contaminant source may be present as a sludge or liquid-filled cavity in the limestone bedrock layer within the geological formation under the IWTP Lagoons.

The Pennsylvania Department of Environmental Resources (PADER) closed the IWTP Lagoons as a RCRA action (Annon., Final , , , 1992). State ARARs were applicable and these require that the soils be cleaned to the extent of meeting state ground water standards ("background levels"). ARARs for this alternative include: Pennsylvania Title 25; Chapters 75 (Solid Waste Management Facilities Applying for a Permit and Incinerators), 123 (EPA PM-10 Standards), 131 (Ambient Air Quality Standards), the PADER Air Toxic Guidelines, 25 Pa Code 264.90 - 264.100 (groundwater remediation to background), EPA 40 CFR Chapters 261 and 264, and technical guidelines for incinerators.

Remediation actions at LEAD were handled under RCRA and required a closure permit and air discharge permit issued under PADER.

3.2 PRELIMINARY BENCH AND PILOT STUDIES

3.2.1 Conduct of Bench Test:

A bench-scale investigation was conducted to determine the feasibility of using the low temperature thermal stripping technology. The bench study was done using K-Area soils. A Bantam Processor (Model No. D303-1 1/2) was used by R.F. Weston, Inc. (WESTON) in their

Analytical Laboratory in Lionville, Pennsylvania for the bench study. This processor consisted of a trough which housed a double auger mechanism, each auger had 7.6 cm (3 in) diameter flights and was 76 cm (30 in) long (See **Figure 4**). The augers were driven by a variable speed motor and the system provided 0.44 m^2 (4.7 ft^2) of heat transfer surface. The intermeshing fin-flight augers were electrically heated to simulate the flow of hot oil used in the Thermal Screw design and the exterior housing also was heated with two Chromolox strips to provide additional heat. The augers could receive a maximum heat input equivalent to 4 kilowatts (kw) and each strip heater was rated up to 1 kw. The covered unit was operated in a spacious laboratory hood with negative draft. Hood discharge gases were treated with carbon adsorption and high efficiency filtration then vented to the atmosphere. This work was done in 1987.

3.2.2 Pilot Scale Demonstration:

A pilot LT^{3}® unit was successfully demonstrated by WESTON in 1985 in initial field tests at LEAD under contract with USATHAMA to remediate soils contaminated with chlorinated solvents with total VOC concentrations exceeding 32,000 mg/kg (McDevitt, 1986). The contaminant levels of the treated soils were reduced to less than 5 mg/kg. A summary of the data from both the bench-scale and pilot-scale studies is shown in **Table 4**. The pilot system is depicted in **Figure 5**. After the LEAD pilot demonstration, WESTON patented a mobile Low Temperature Thermal Treatment (LT^{3}®) process to enable on-site removal and recovery of volatile and semi-volatile organic compounds from contaminated soils. This system was mounted on three trailers and required a 8 m x 19 m (26 ft x 63 ft) area, consumed about 195 kg (430 lb) of propane per hour, employed two persons for operations, had electrical service for 460 V/3 phase/60 Hz/300 amp demand, and was designed to process 6,800 kg (15,000 lbs) of soil per hour (Kostecki, 1989; Murphy, 1992).

3.2.3 Comments:

The bench test and pilot studies are not precisely comparable because the feed concentrations were remarkably dissimilar. This was caused by the sampling protocols: the bench test employed soils obtained by hand shovels from the surface while the pilot study used soils obtained with a backhoe that penetrated the more contaminated deeper soils. Nevertheless certain generalities seem to hold:

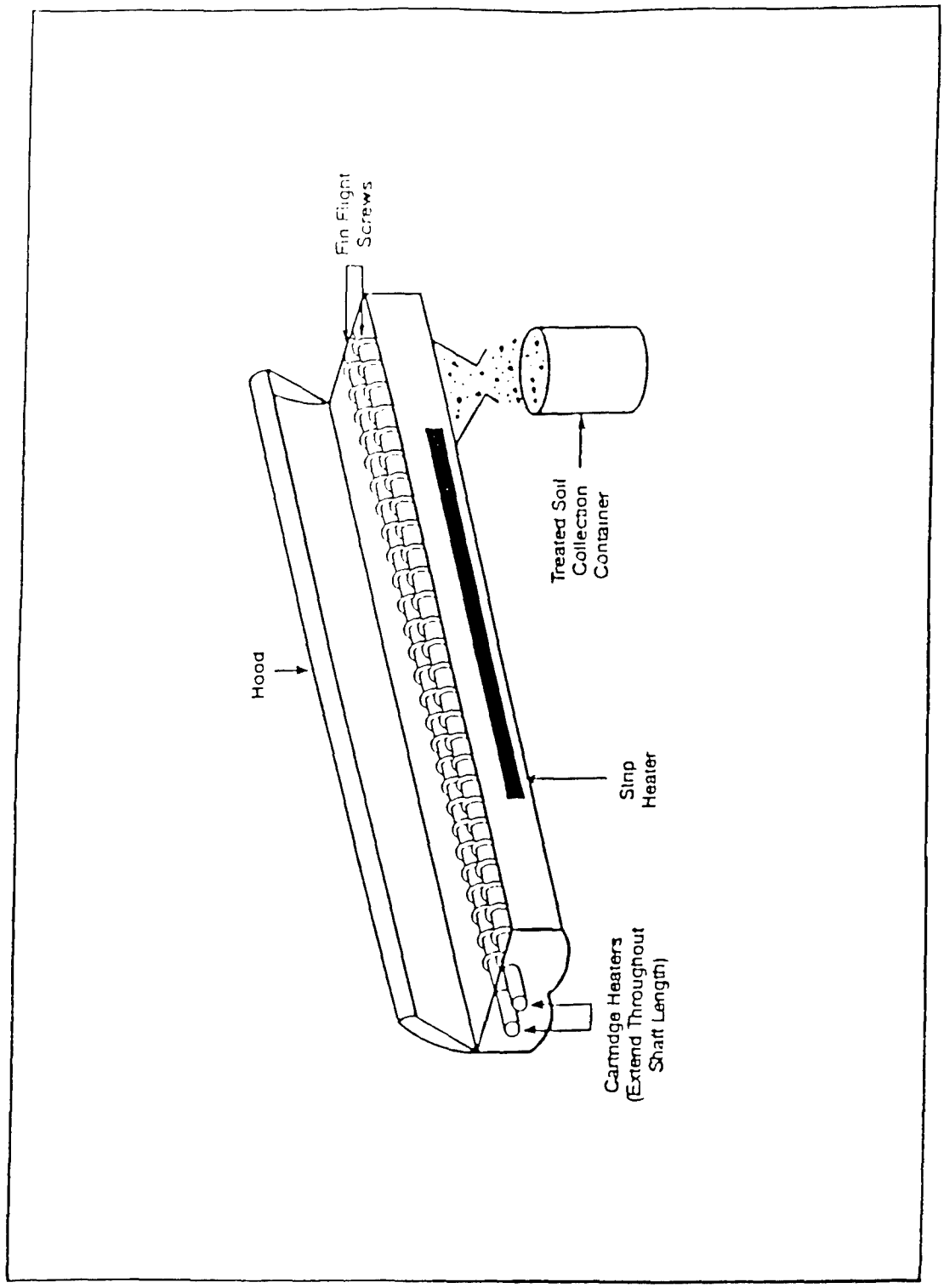

FIGURE 4

SCHEMATIC OF BENCH SCALE EQUIPMENT

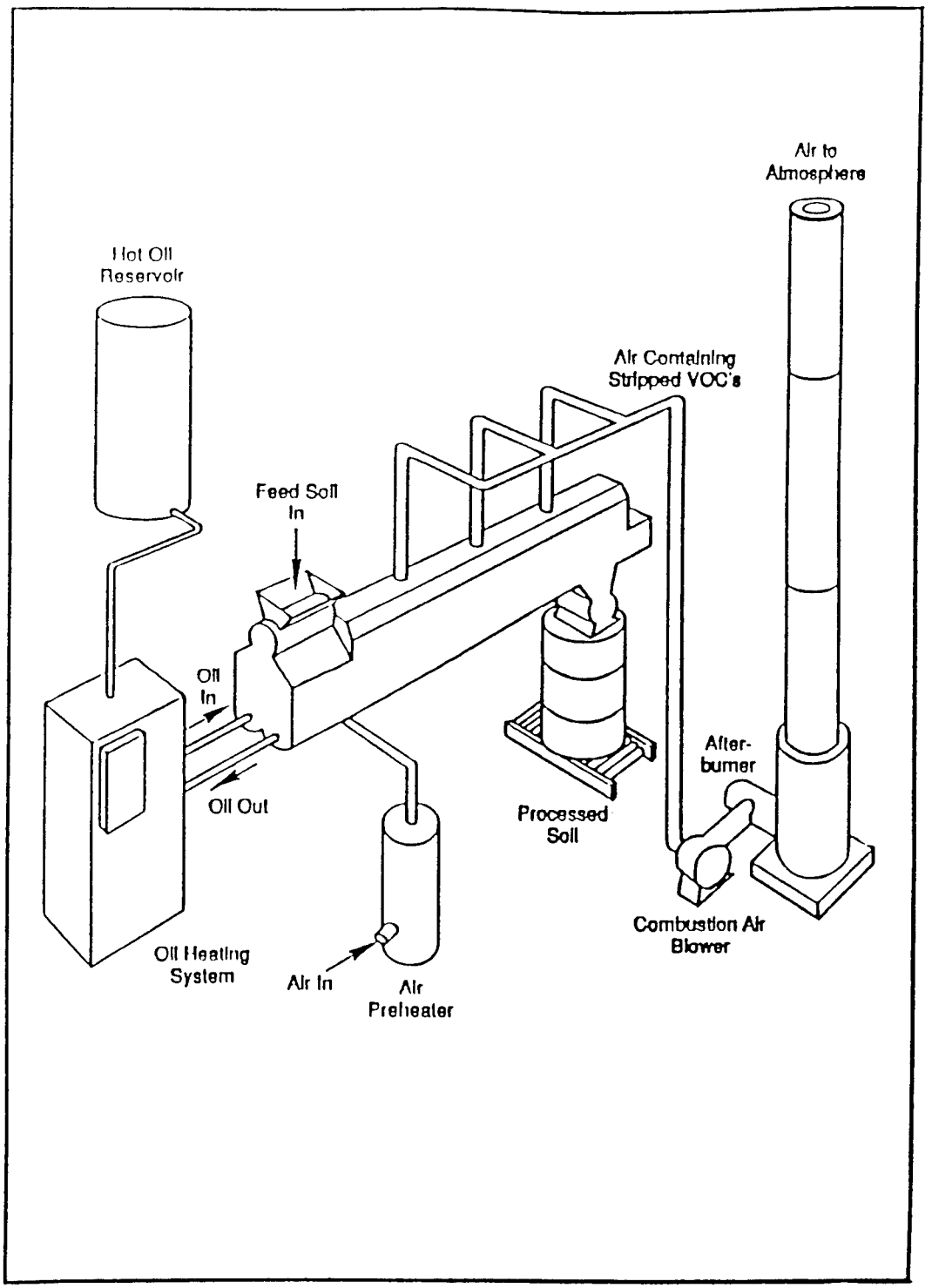

FIGURE 5

SCHEMATIC DIAGRAM OF THE PILOT SCALE LT^{3}® SYSTEM

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TABLE 4

COMPARISONS OF BENCH STUDIES AND PILOT PLANT STUDIES OF LOW TEMPERATURE THERMAL REMEDIATION OF SOILS AT LETTERKENNY ARMY DEPOT, PENNSYLVANIA (Johnson, 1987)

RESIDENCE TIME (MIN.)		DISCHARGE TEMP °C(°F)		FEED CONC. (PPM)		REMOVAL EFFICIENCIES (%)	
Bench Test	Pilot Study	Bench Test	Pilot Study	Bench Test	Pilot Study	Bench Test	Pilot Study
LOW TEMPERATURE RUNS							
17		49(121)		10.3		92.4	
22		51(124)		1.71		17.5	
	30(1)		57(134)		38.19		98.77
	30		53(128)		2996		51.73
34		58(137)		0.78		92.8	
43		69(157)		1.41		55.3	
	45(1)		53(128)		36.9		97.34
50		72(162)		0.742		95.1	
	60		121(250)		2996		99.7
64		87(189)		0.764		72.5	
HIGH TEMPERATURE RUNS							
16		141(286)		13.1		97.9	
18		167(333)		26.5		98.3	
	30(2)		143(290)		4353		99.09
32		183(362)		0.279		99.3	
36		185(365)		0.441		99.6	
	45		176(348)		2603		99.93
48		186(367)		0.09		99.6	
55		201(393)		0.113		99.7	
	60		176(348)		757		99.72

1. Two runs of identical data and results
2. Four runs of identical data and results

-Bench and pilot studies do not give reproducible results at low temperatures (soil exit temperatures between 49°C and 88°C [120°F and 190°F]), but reproducibility is greatly enhanced at higher temperatures (141°C to 201°C [286°F to 393°F]). If feed soil composition/conditions are similar and temperatures are kept to the high range, data from bench and pilot studies are comparable. Full scale plant temperatures will be the lowest needed to obtain acceptable VOC levels as determined in the permit process.

-The bulk of VOC removal occurred in the early phases of treatment when moisture was being removed. Semi-volatile contaminants continue to be removed efficiently even after detectable moisture has been removed from the soils.

-Moisture in the feed soil and residence time are statistically significant variables in all correlations (i.e. low, medium, high soil discharge temperatures). Excess moisture decreases efficiencies and increases costs.

-Fugitive discharges of VOC during excavation and handling must be taken into account (and it may be necessary to protect against) in order to protect air quality standards.

-VOC residuals can be removed effectively from soils by LTVS processes.

-Concurrent bench scale studies on soils from Sharp Army Depot [(SHAD)-silty fine to medium sand; VOCs and trichlorethylene], Aberdeen Proving Ground [(APG)-Clayey coarse to medium sand; Number 2 fuel oil], and Fort Campbell [(FC)-Silty clay; JP-4 fuel] demonstrated that VOCs can be removed from other soils. However, variations in soils and/or contaminants require that site specific bench and/or pilot pre-testing always be undertaken.

-As contaminant concentrations in feed soils increase, removal efficiencies also increase.

-Soil characteristics and handling parameters can be reliably evaluated with bench and pilot studies.

-Bench scale tests appear to be representative of a scaled down pilot unit if run at higher temperatures.

-The LTVS process can be designed to achieve specific VOC clean-up objectives. The level of residually VOC in the processed soil is a direct and predictable function of:

(a) VOC concentration in the feed soil,
(b) Processed soil temperatures,
(c) Soil residence time within the thermal processor
(d) Heat input rate to the thermal processor, and
(e) Moisture content of the feed soil and processed soil.

-Reprocessing treated soils that still contained a contaminant residue reduce the VOC concentration significantly; however, a residual still exists.

-Stack emissions can be controlled to meet air quality standards.

3.3 REMEDIATION OF THE IWTP LAGOONS

3.3.1 Description of Site, Its Contamination and Its Remediation:

Some of the more volatile components of the industrial wastes received by the IWTP concrete lagoon, including water, were discharged to the air thorough evaporation. The remainder either was carried over in the effluent or accumulated as sludges. When the concrete failed, underlying and neighboring soils were contaminated by leachates. In 1984 the lagoon sludge samples were analyzed (pertinent results are given in **Table 5**).

No analyses were done on the underlying and surrounding soils because of the assumption that the worst case scenario would be that for the sludge. It was believed that remediation processes sufficient to reclaim the sludges would be sufficient to reclaim affected soils, concrete and rocks. As a result of these analyses and decisions, remediation efforts, described elsewhere in this report, were initiated. All sludge material was removed; all concrete was taken out and broken to manageable sizes; some possibly contaminated underlying rocks were removed and reduced to manageable sizes; and all underlying soils to bedrock were removed. These materials were subjected to LTVS remediation processes. Product material from the LTVS was run in lots and each lot was analyzed during the operation phases. Generally it was reported that the samples contained either <50 ug/kg VOC or was "not present".

TABLE 5

ANALYSES OF IWTP LAGOON INFLUENT, EFFLUENT AND SLUDGES AT LETTERKENNY ARMY DEPOT IN 1984 AND REMEDIATED SLUDGES AND SOILS IN 1992

Volatile Organic	1984 Influent (ug/L)	1984 Sludge Analyses		1984 Efluent (ug/L)	1992 Analyses of Remediated Soils (ug/kg)
		Average (ug/kg)	Range (ug/kg)		
Chloroform	75	135	20 - 300	15**	<0.3
1,1-Dichloro-ethane	80	1,875	900 - 5,000		<0.3
1,1-Dichloro-ethene		720*	<10 - 1,700		<0.3
Ethyl Benzene		335*	<10 - 1,500		N/A
Methylene Chloride	7,000	270	100 - 430	1,500**	N/A
1,1,1-Trichloroethane	6,000	1,905	70 - 9,000	150**	<0.3
Toluene	5	289*	<10 - 1,1000		N/A
TOX (ug/L)		1,817	391 - 9,285		N/A

** Highest reported value of three separate analyses.

* Averages were calculated only on detectable quantities.

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Trichloroethate was detected in five lots after remediation: the sole reported value was >100 ug/kg (3/18/92). 1,2-Dichloroethane was reported in the remediated materials once (3/16/92); Chloroform once (3/17/92); and vinyl chloride once (4/9/92). On only one occasion was more than one VOC reported to be present (3/17/92) when a lot was found to contain Chloroform and Trichloroethane. Each lot that had detectable VOC was recycled through the LTVS. Thus adequate treatment was ultimately obtained for all materials.

3.3.2 Overview of Operations:

The prime contractor was Associated Chemical and Environmental Services (ACES) and the Low Temperature Thermal Treatment (LTTT) subcontractor was Williams Environmental Services. The LTTT unit was a rotary kiln.

Five trailer trucks were needed to transport the LTTT equipment to the site and it took one month each to set up and tear down. It took an additional month of "shake-down" operations to get the unit ready for full time operations. A diagram of the unit is given in **Figure 6.**

The LTTT unit operated at 585.75 kilowatts (kw) (2 million Btu/hr) and the unit operated for 1,640 hours. Using a conversion factor of 93,680,284 Joules/m^3 (2,516 Btu/ft^3) at 15.5° Celsius (60° Fahrenheit), approximately 590,650 m^3 (20,858,500 ft^3) of propane were used for all operations (Keehan, 1992). There is no information for consumption of fuels for utility vehicles, trucks, and earth movers including a rubber tired loader and a uniloader which were used at the LTTT site. A total of 23,586 Mg (26,000 tons) of soil and 4,717 Mg (5,200 tons) of concrete and rocks were remediated to an MCL of 50 ppb total organics. Remedial costs were $88/Mg ($80/ton) and the soil residual time in the kiln was 30 minutes.

During operations, baghouse blowdown was constantly fed directly to the discharge auger on the drier to intermixed freely with the treated soils. No attempt was made to monitor the quantity of this discharge or assess its residual chemical content.

Stack emissions were constantly monitored for carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), and total hydrocarbons (HC). There was no report that stack emission ever approached or exceeded applicable permissible limits. The only parameter available was Hydrocarbon Emissions Limit (HEL) of 1.8 kg/hr (4 lbs/hr).

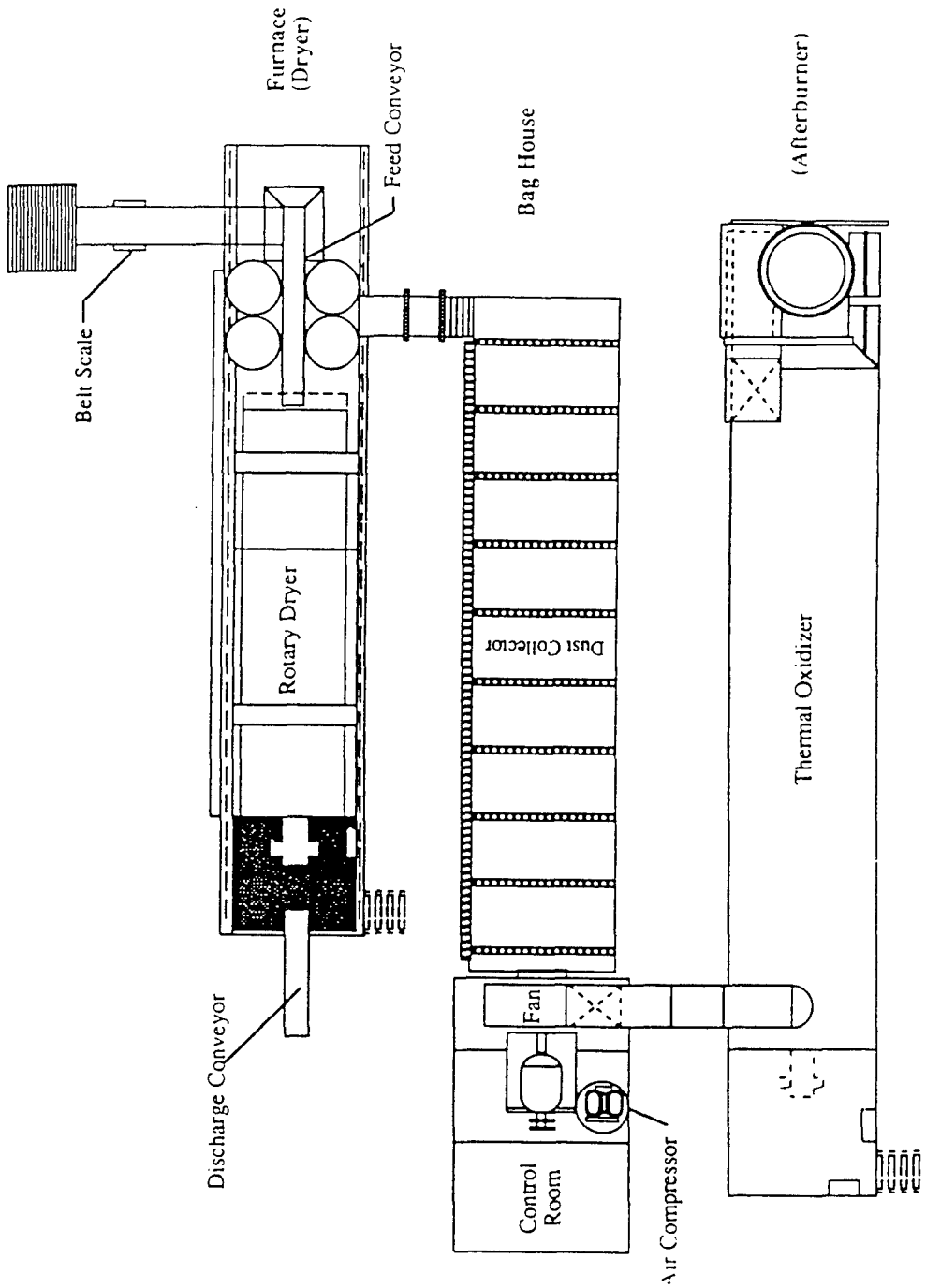

FIGURE 6

MOBILE MULTI-TEMPERATURE PROCESSING UNIT (M.M.T.P.U) LAYOUT FOR LOW TEMPERATURE, FOUR LOAD SYSTEM

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During start up operations (after the unit had been down for a period of time), the first soils passing through the unit were sampled every hour over a 24 hour period. These soils were carefully monitored to ensure adequate preheating and were stored separately from other soils in three eight-hour composite piles until analysis confirmed that they had been adequately remediated. In this manner, if further remediation was necessary, only the volume of an eight-hour pile would have had to be retreated.

After the start up period, remediated soils were processed in 2,268 Mg (2,500 short tons) lots and one composite sample was taken for each lot. A total of 24,312.6 Mg (26,800 short tons) of soil were excavated, treated, and backfilled into the former IWTP Lagoons site.

In addition to the remediated soils, some limestone bedrock was excavated, screened, crushed, and backfilled during these operations. This activity added an estimated $75,000 to the cost of the project.

These activities were conducted by a team of six person per shift: one project manager, two systems operators, two equipment operators, and one laborer.

3.3.3 Description of Operations:

At LEAD soil was excavated from the site to the bedrock as shown in **Photo 1**. The average depth was about 15 feet. The soil and accompanying rocks were trucked to a remote pad constructed of asphalt and separated as shown in **Photo 2**. The piles were covered to reduce blowing from the dust as the soil dried. The material was picked up in a bucket loader and dumped onto a shaker grater as shown in **Photo 3**. The soil was vibrated to break up the clumps into smaller particles that could be treated and these were fed by conveyer to the furnace as shown in **Photo 4**. The material was heated and the volatiles were drawn off to a baghouse while the soil was conveyed to the treated pile as shown in **Photo 5**. The baghouse removed fine particulates from the volatile gases and was stationed alongside the furnace as shown in **Photo 6**. From the baghouse the volatile gases were transported to an afterburner where they were incinerated and passed out a rectangular stack as shown in **Photo 7**. Once the materials were treated they were returned to the same hole and packed in place. The treated material is shown on the slope in **Photo 8**.

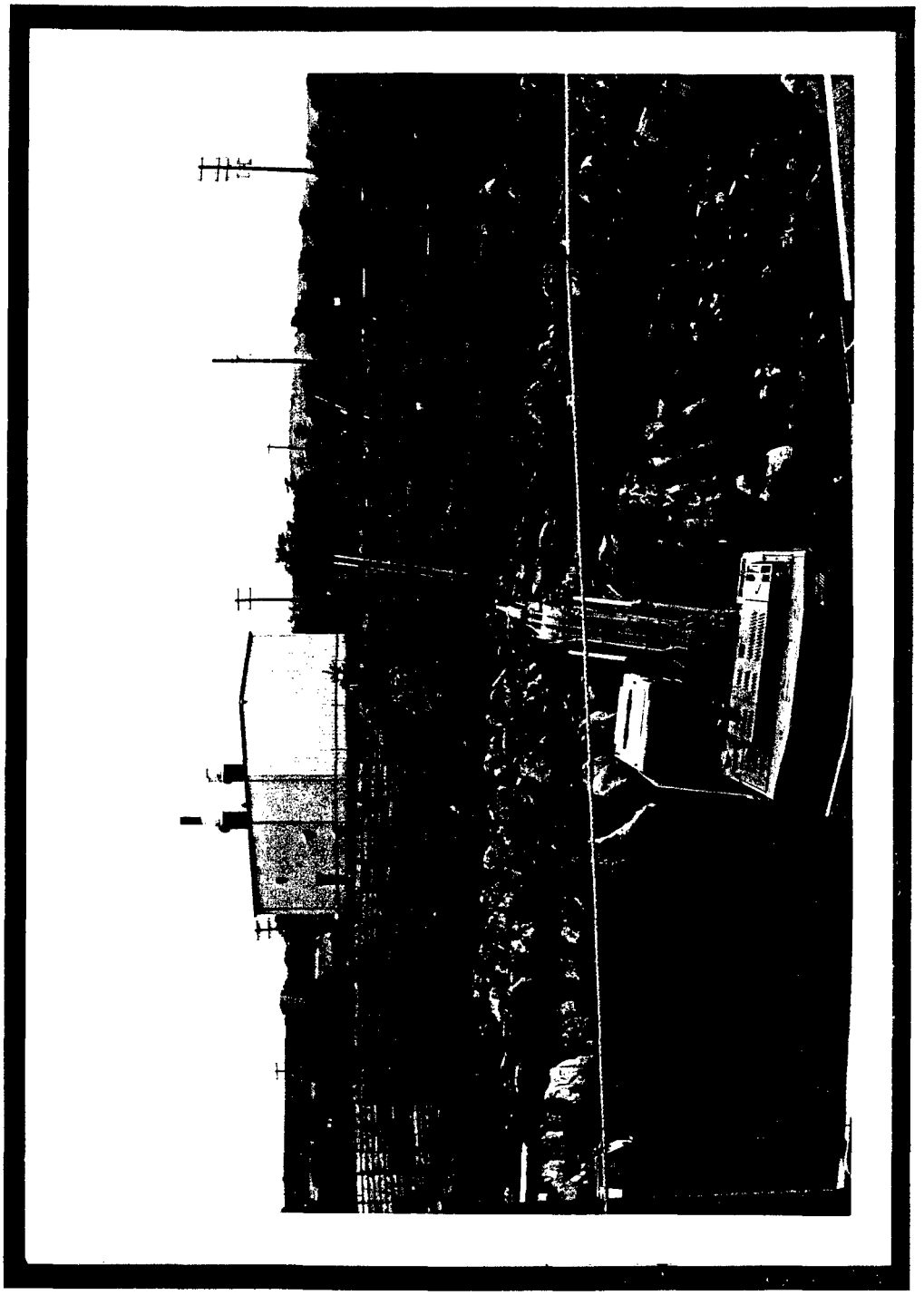

PHOTO 1
EXCAVATED HOLE

PHOTO 2
REMOTE PAD

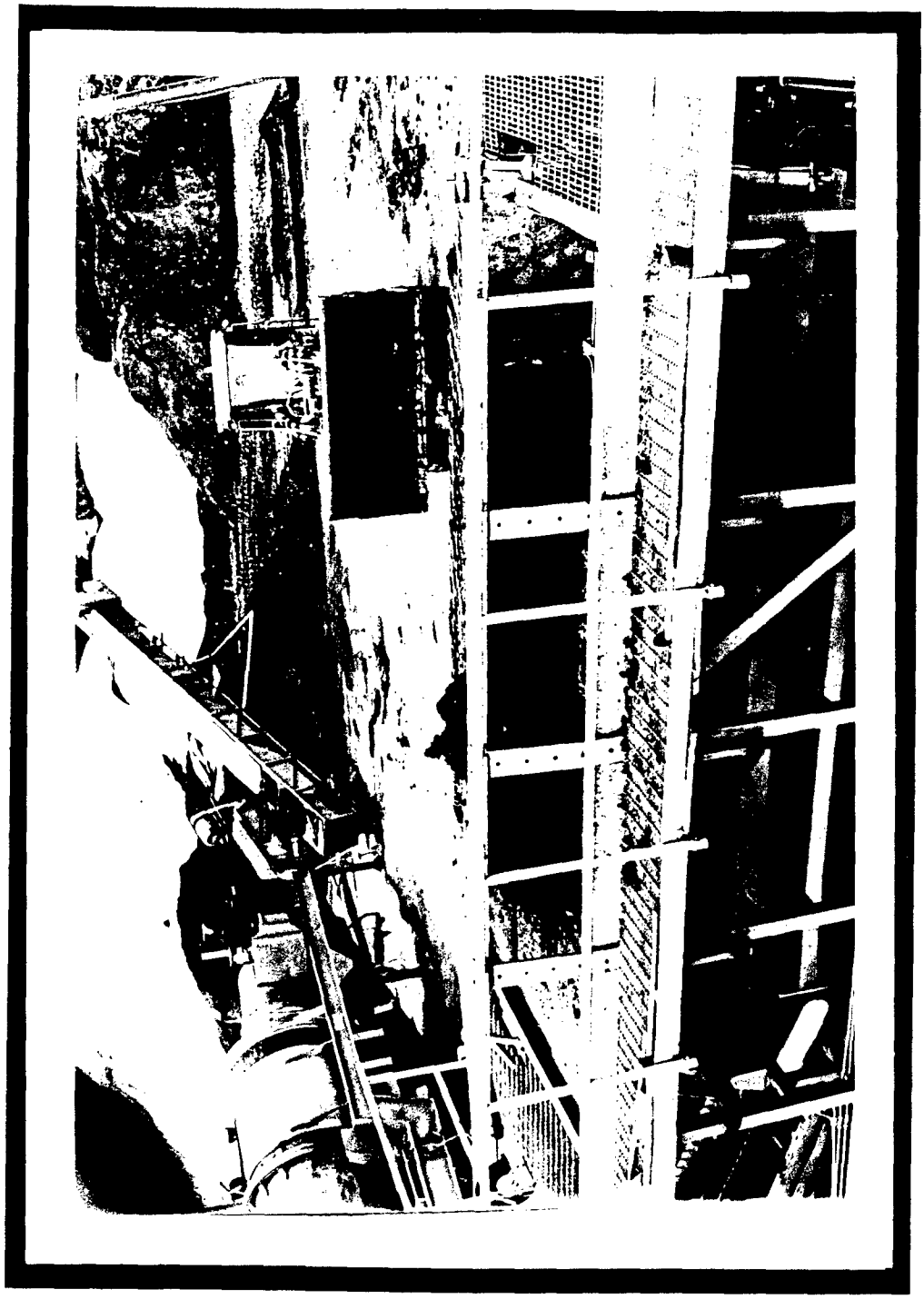

PHOTO 3
LOADING OPERATION

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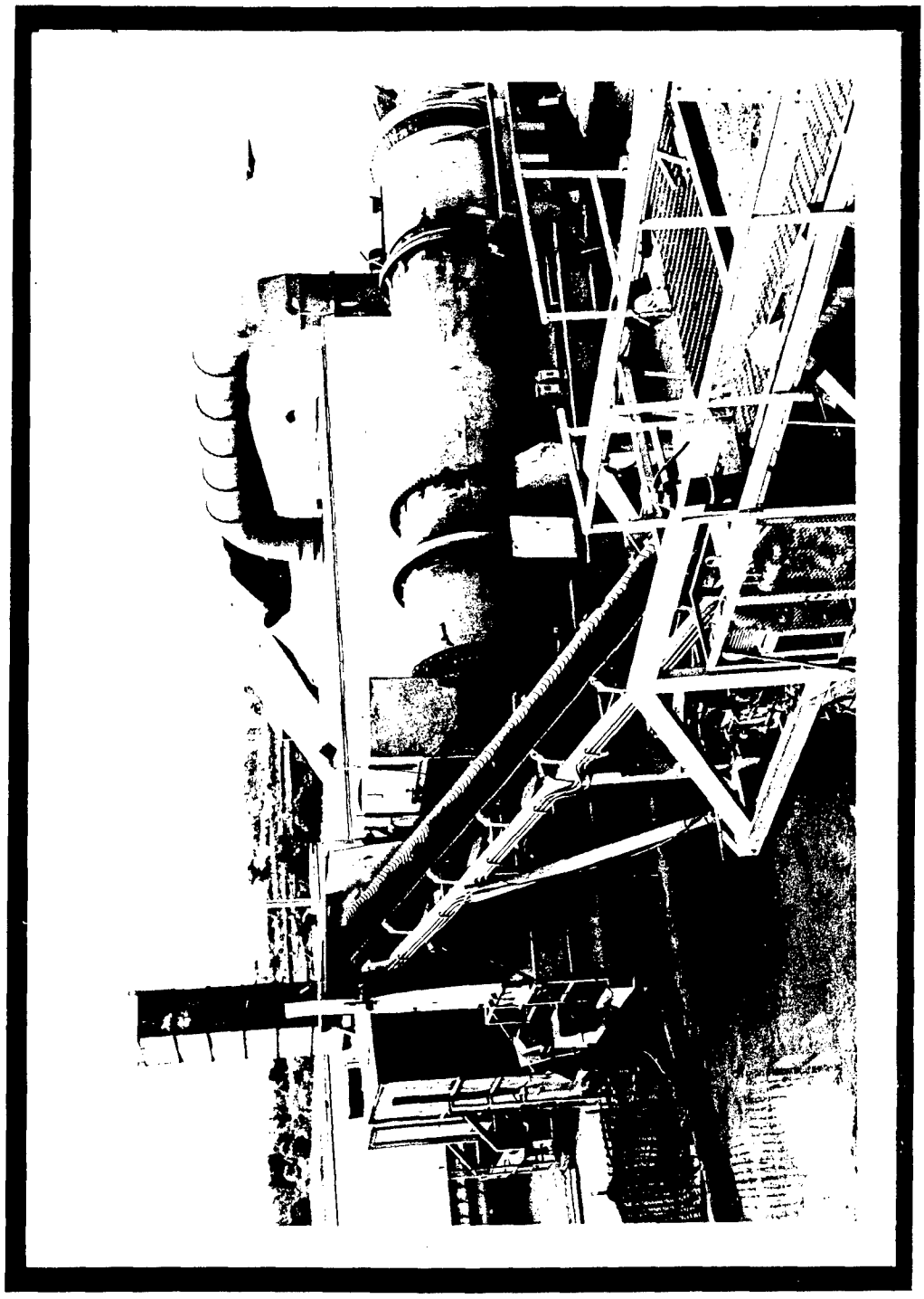

PHOTO 4
CONVEYER SYSTEM

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PHOTO 5
TREATED PILE

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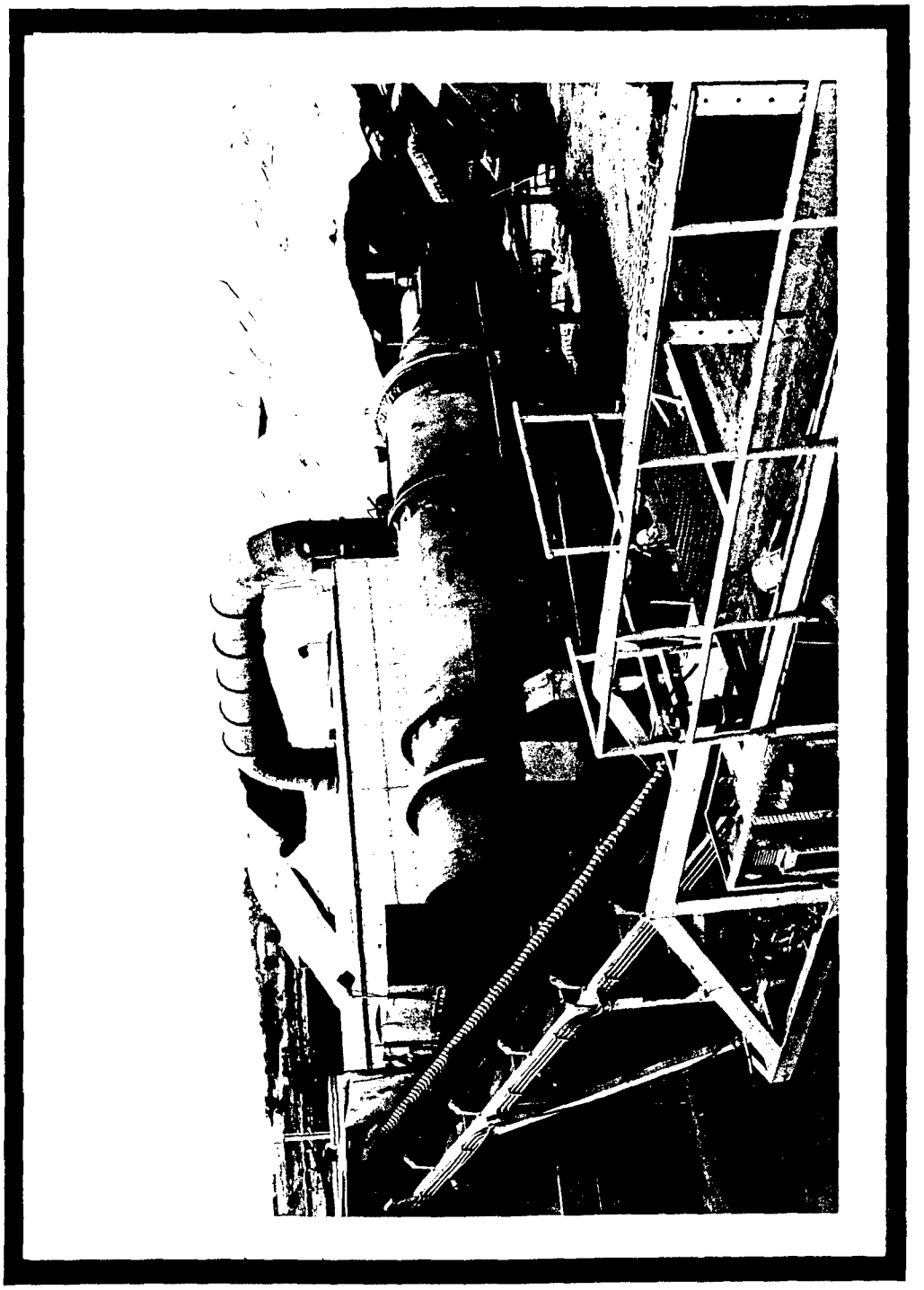

PHOTO 6
FURNACE AND BAGHOUSE

PHOTO 7
AFTERBURNER EXHAUST

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PHOTO 8
REPLACING SOIL

3.3.4 Problems Encountered:

A number of problems occurred that affected operations, but none were necessarily site specific:

Injuries: A safety officer was present during every shift and safety meetings were held every shift. No incidents of hazardous materials exposure or spillage of such materials occurred. There were 12 minor accidents during operations and one serious accident: a man broke his ankle during the installation of the truck scale.

Inclement weather: Excavation ceased during short periods of heavy rains and some delays were encountered when soils froze to the LTTT unit. Rain water entering the excavation site was pumped out and fed into LEAD's IWTP. Rainwater around the LTTT unit was collected in sumps and transported to the IWTP.

Soils management: When excavated soils were excessively wet, they were treated with lime to soak up the moisture. Excavated soils never were so dry as to require wetting before treatment.

Treated soils had water added at the discharge auger to control dust. Treated soils were covered with plastic to further control losses from wind and rain erosion. It was felt that as a result of these precautions negligible losses occurred from these operations.

Initially the treated start up soils were integrated with the subsequent complete soil lot. When it was found that the start up soils had been inadequately treated, it was necessary to rerun the entire 2,268 Mg (2,500 short ton) lot. This occurred twice before the protocol for soils management mentioned in paragraph 3.3.1 was inaugurated.

Mechanical difficulties: Most of the mechanical difficulties were routine. Soils froze to belts, belts broke, soils had to be screened to about 0.6 cm (0.25 in) for VOC removal efficiencies and sometimes limed for moisture control. Auger discharge failure did occur and vibration problems in the rotary drier arose due to the air flow rate which interfered with the flame.

Ground water: LEAD had been experiencing below average precipitation for the last two years so the water table was depressed when operations commenced. Ground water never

was encountered so it was not necessary to install nearby wells to draw down the water. The Ground Water Treatment Plant operated continuously during the excavation period nonetheless.

On one occasion a puddle of a black liquid was found to have flowed into the excavation site and mixed with rainwater. This water was assumed to be significantly contaminated. Much of it was soaked up with pads and the rest was pumped out and taken to the IWTP. The pads were discarded in the appropriate manner.

3.3.5 Lessons Learned:

A number of ideas for improved operations came from this effort. These are:

1. Excavated contaminated soils should be taken through a pug mill for size reduction before thermal treatment.
2. The baghouse should be sealed to control dust.
3. Belt wear/failure is to be expected and maintenance protocols should be established for routine inspection, repair, and replacement.
4. Augers tended to be unable to handle the quantity of material for which they were nominally designed. Oversized augers should be employed.
5. Daily equipment cleaning and cleaning before any shutdown will prevent soil freezing and belt sticking on the treatment unit.
6. If possible, it would be advantageous to process and backfill concurrently.
7. All work specifications must be planned and approved ahead of time. For example, there should be a specific protocol to handle unexpected contingencies (e.g. treated piles not passing laboratory testing). Management protocols should be adequate to minimize the amount of soil that needs a second remediation treatment.

4.0 CONCLUSIONS

Low Temperature Thermal Treatment technology has proven to be an effective and economical way to remediate soils contaminated with low molecular weight VOC. These procedures do not involve new or poorly tested technologies and they do permit on-site treatment of soils. In certain cases, as with the LEAD site, reclaimed soils may be backfilled and used for other purposes. When this occurs, significant expenses associated with spoiling to landfills are avoided.

Low Temperature Thermal Treatment operations are not particularly labor intensive, are safe by industrial standards, are not likely to lead to off-site contamination during clean-up procedures, and are unaffected by all but the more extreme weather conditions. Nevertheless, because this technology is not necessarily suited for all sites, bench and pilot studies should be undertaken before a full scale commitment is made to this remediation protocol.

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APPENDIX A
MAPS PERTAINING TO LETTERKENNY ARMY DEPOT, PENNSYLVANIA

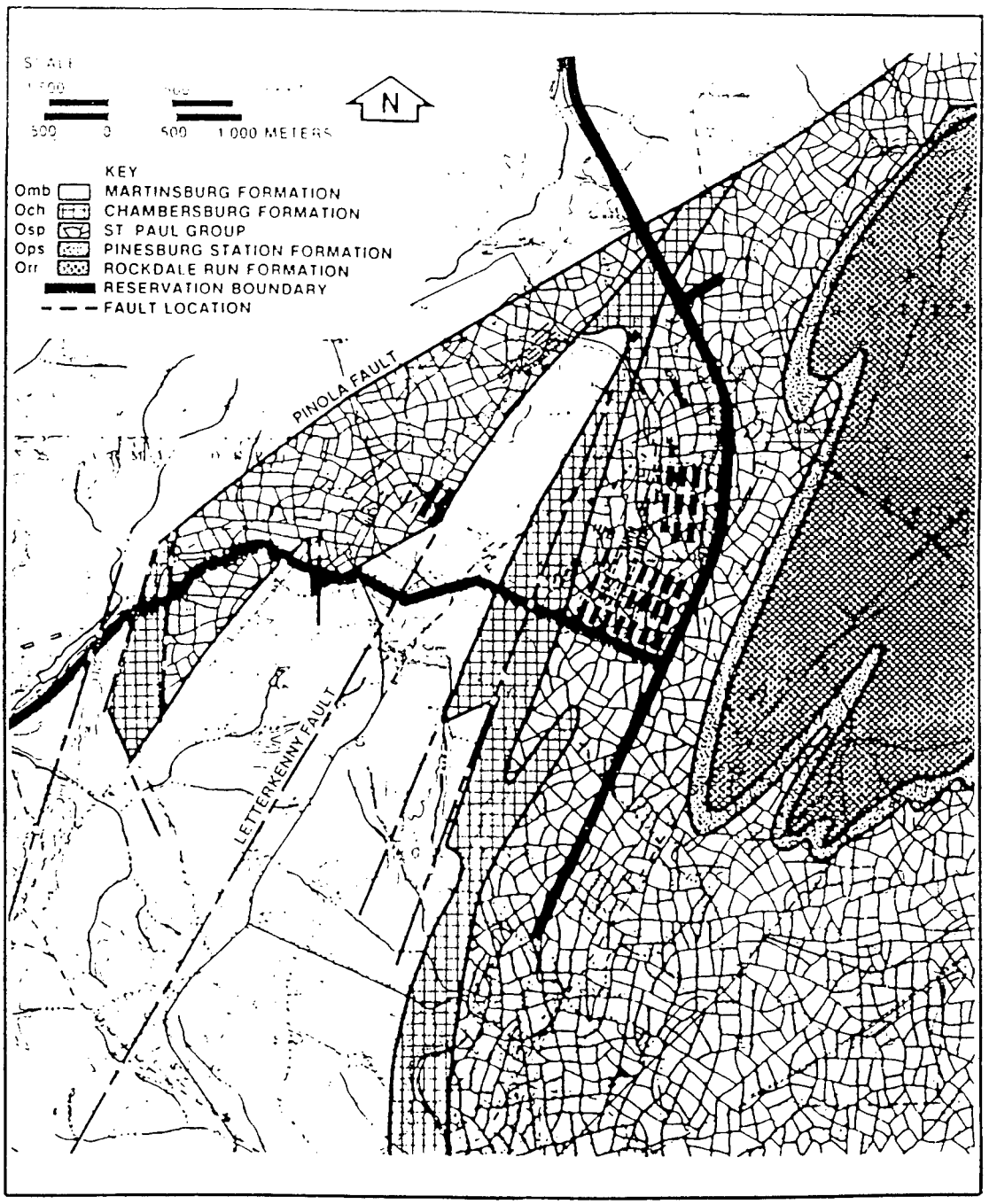

FIGURE A-1

GEOLOGIC MAP OF THE SE AREA, LETTERKENNY ARMY DEPOT, FRANKLIN COUNTY, PENNSYLVANIA

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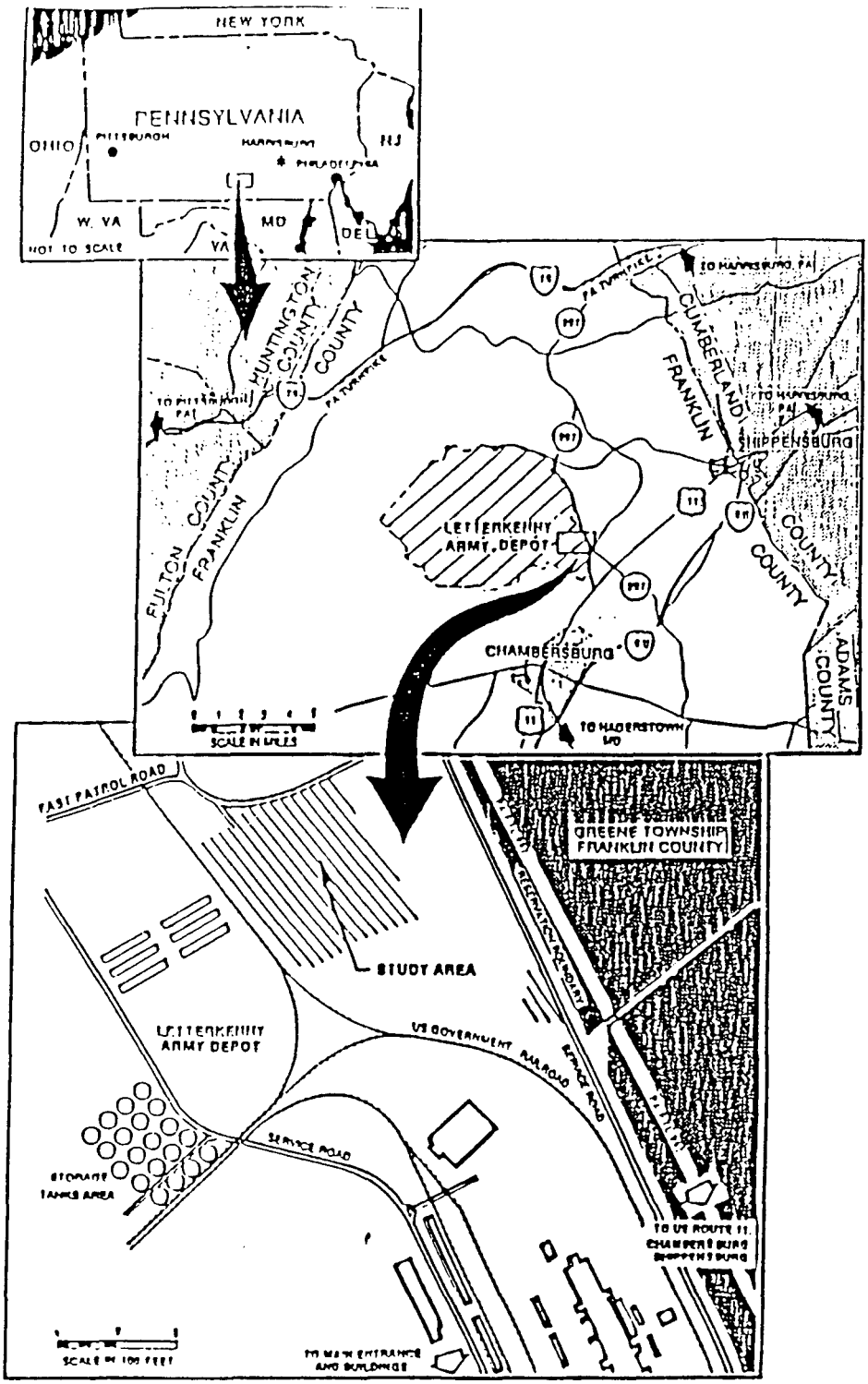

FIGURE A-2

GENERAL LOCATION MAP OF THE STUDY AREA ON THE LETTERKENNY ARMY DEPOT, FRANKLIN COUNTY, PENNSYLVANIA

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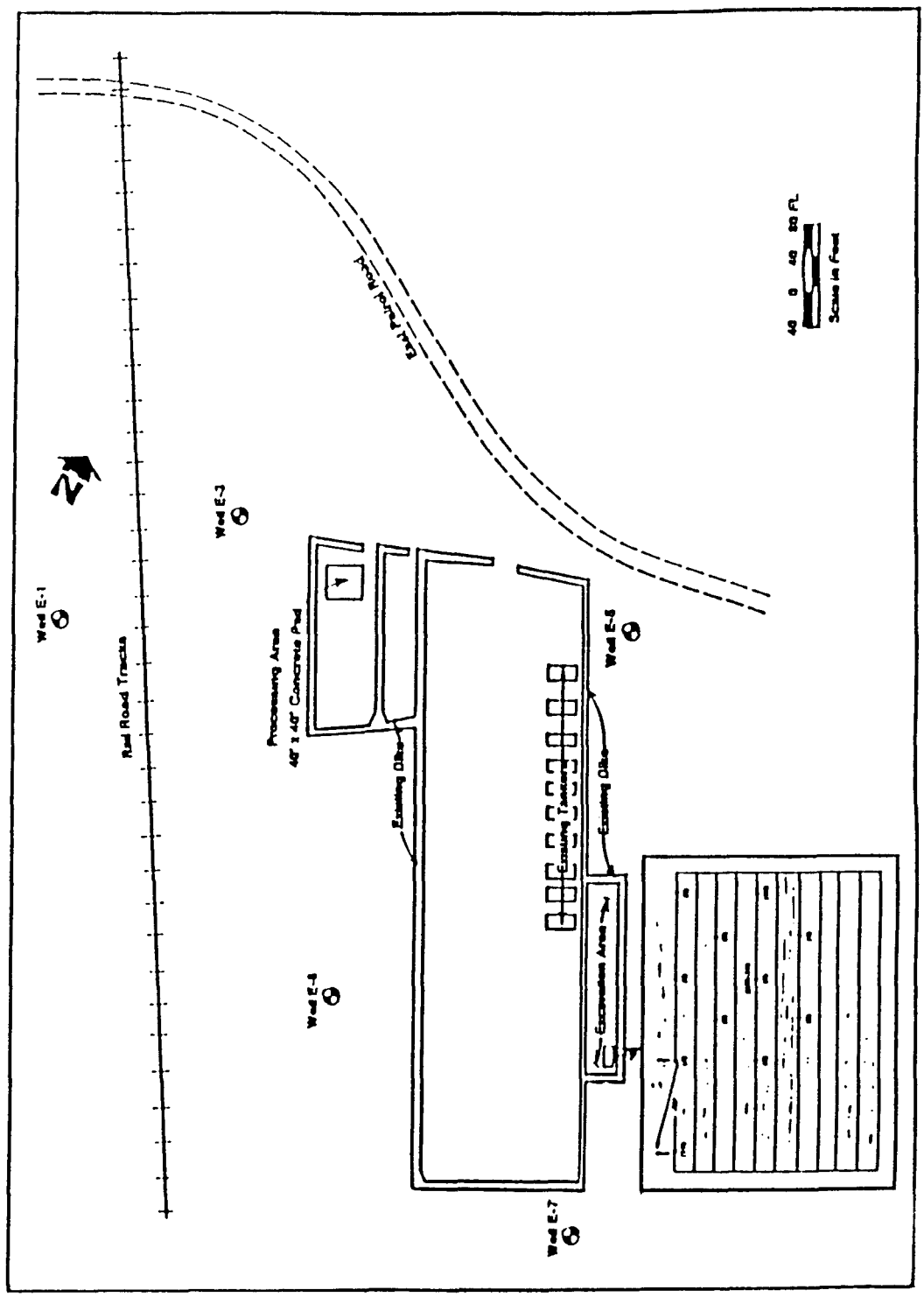

FIGURE A-3

LOCATION OF SOIL BOINGS DRILLED IN THE AREA K-1 DURING THE WASTE CHARACTERIZATION PHASE OF THE PILOT STUDY

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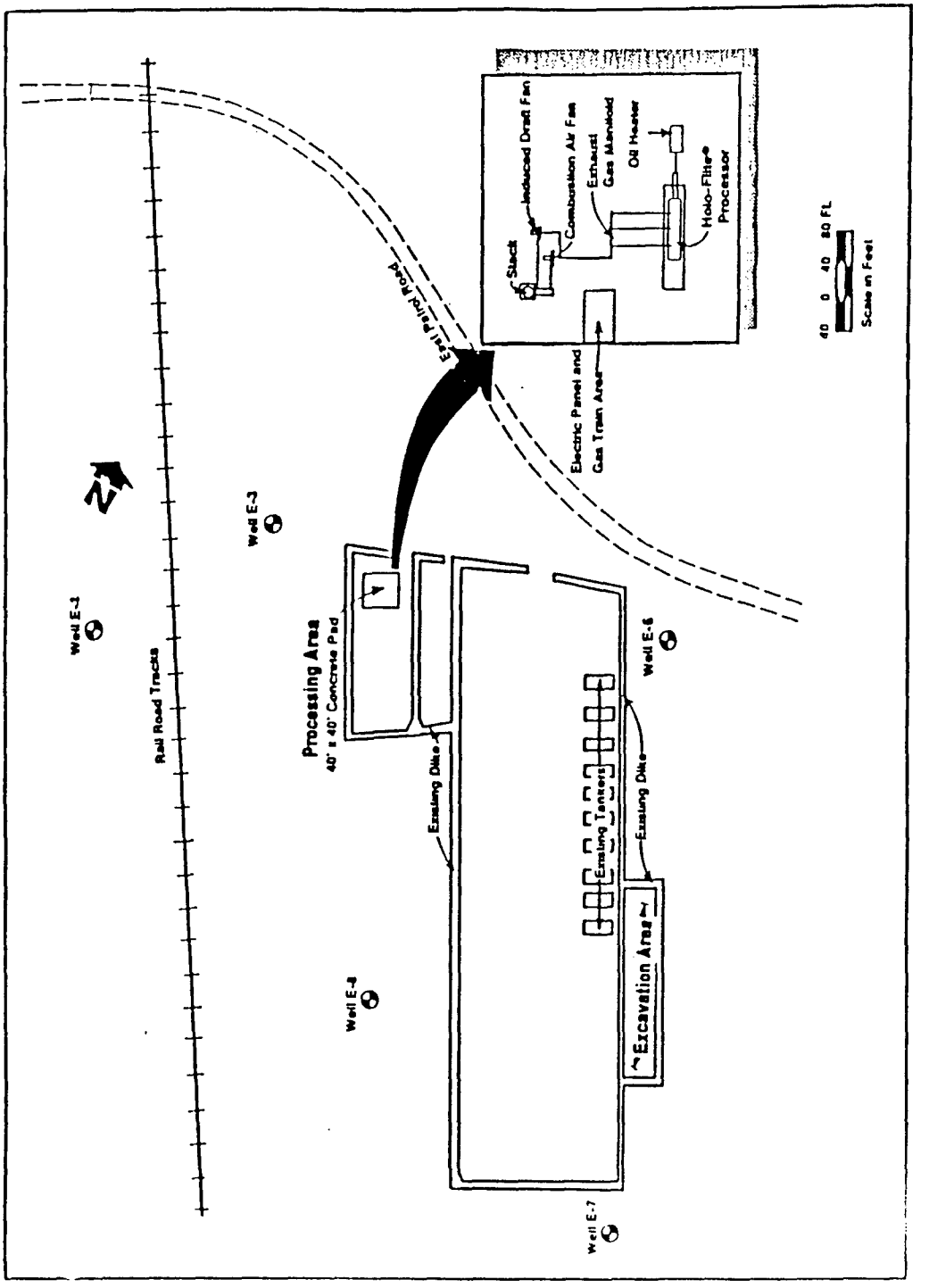

FIGURE A-4

LOCATION MAP OF THE PROCESSING AND EXCAVATION AREAS ON THE LETTERKENNY ARMY DEPOT

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