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	Engineering and Design THERMAL DESORPTION	
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U.S. Army Corps of Engineers
CEMP-RT Washington, D.C. 20314-1000

Technical Letter
No. 1110-1-173 31 May 1996

Engineering and Design
THERMAL DESORPTION

1. Purpose. This engineering technical letter (ETL) provides guidance to designers for the determination of applicability of thermal desorption systems and guidance for the preparation of a design to satisfy project requirements.

2. Applicability. This letter applies to HQUSACE elements, major subordinate commands (MSC), districts, laboratories, and field operating activities (FOA) with responsibility for Hazardous, Toxic and Radioactive Wastes (HTRW) projects.

3. References. This ETL should be used in conjunction with design guidance listed below:

a. ER 1110-345-100 Design Policy for Military Construction.
b. ER 1110-345-700 Design Analysis.
c. ER 1110-345-710 Drawings.
d. ER 1110-345-720 Construction Specifications.

4. General. The attached appendices present information for use in engineering and design of Thermal Desorption Systems.

a. Appendix A - References presents references cited in the text.

b. Appendix B - Design Considerations provides an introduction to the comprehensive overview of design and engineering considerations for thermal desorption.

c. Appendix C - Principles of Operation presents the principles of thermal desorption operation.

d. Appendix D - Predesign identifies thermal desorption predesign activities.

e. Appendix E - Design and Performance Criteria describes design and performance criteria for a thermal desorption system.

f. Appendix F - Treatment System Operations provides a discussion of treatment system operations.

g. Appendix G - Design and Construction Package describes design analysis, plans and specifications for thermal desorption.

h. Appendix H - Closure presents site closure activities.

i. Appendix I - Design Example presents typical calculations required in the design of a remedial design thermal desorption treatment application.

j. Appendix J - Treatability Scope of Work presents the work requirements for treatability studies for thermal desorption application.

5. Action. Each U.S. Army Corps of Engineers design element is responsible for implementation of applicable guidance in the preparation of HTRW designs. This ETL will be considered as the design guidance for thermal desorption of contaminated materials.

FOR THE DIRECTOR OF MILITARY PROGRAMS:

10 Appendices
(see Table of Contents)

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Chief, Environmental
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APPENDIX A
REFERENCES

1. **Code of Federal Regulations (CFR).**

40 CFR Part 261 Identification and listing of hazardous waste

40 CFR Part 268 Land disposal restrictions

2. **Military Handbook.**

MIL HDBK 1008 Military Handbook for Fire Protection for Facilities

3. **U.S. Army Corps of Engineers (USACE).**

3.1 **Guide Specifications for Military Construction (CEGS).**

CEGS	01110	Safety, Health and Emergency Response (HTRW/UST)
CEGS	01440	Contractor Quality Control
CEGS	01450	Chemical Data Quality Control
CEGS	02110	Clearing and Grubbing
CEGS	02210	Grading
CEGS	02221	Excavation, Filling, and Backfilling for Buildings
CEGS	02222	Excavation, Trenching, and Backfilling for Utilities Systems
CEGS	02271	Waste Containment Geomembrane
CEGS	02273	Geonet
CEGS	02288	Remediation of Contaminated Soils and Sludges by Incineration
CEGS	02445	Solidification/Stabilization of Contaminated Material
CEGS	02557	Bituminous Paving for Roads, Streets and Open Storage Areas
CEGS	02935	Turf
CEGS	02950	Trees, Shrubs, Ground Covers and Vines
CEGS	02955	Crown Vetch
CEGS	11225	Liquid Phase Activated Carbon Adsorption Systems
CEGS	11360	Plate and Frame Filter Press System

3.2 **Engineer Manual (EM).**

EM	200-1-2	Project Planning
EM	200-1-3	Requirements for Preparation of Sampling and Analysis Plan

EM	200-1-4	Human Health Evaluation
EM	200-1-6	Risk Assessment Handbook Volume 2 Environmental Evaluation
EM	385-1-1	Safety and Health Requirements Manual
EM	1110-1-501	Design Manual Wastewater Treatment
EM	1110-1-1807	Standards Manual for US Army Corps of Engineers Computer Aided Design and Drafting Systems (CADD), Parts 1 & 2
EM	1110-2-502	Guidelines for Preliminary Selection of Remedial Action for Hazardous Waste Sites
EM	1110-3-176	Removal of Underground Storage Tanks
EM	335-345-1	Report of Costs and Analysis, Military Construction

3.3 **Engineer Regulation (ER).**

ER	385-1-92	Safety and Occupational Health Document Requirements for Hazardous, Toxic and Radioactive Waste (HTRW)
ER	1110-1-12	Quality Management
ER	1110-1-263	Chemical Data Quality Management for Hazardous Waste Remedial Activities
ER	1110-345-100	Design Policy for Military Construction
ER	1110-345-700	Design Analyses
ER	1110-345-710	Drawings
ER	1110-345-720	Construction Specifications

3.4 **Technical Manual (TM).**

TM	5-800-2	Cost Estimates for Military Construction
TM	5-802-1	Economic Studies for Military Construction Design-Applications
TM	5-803-1	Installations Master Planning
TM	5-803-13	Landscape Design and Planting
TM	5-805-4	Noise and Vibration Control
TM	5-810-5	Plumbing
TM	5-811-1	Electrical Power Supply and Distribution
TM	5-811-2	Electrical Design Interior Electrical System
TM	5-811-3	Electrical Design Lightning and Static Electricity Protection
TM	5-814-1	Sanitary and Industrial Wastewater Collection - Gravity Sewers and Appurtenances
TM	5-814-3	Domestic Wastewater Treatment

TM	5-814-8	Evaluation Criteria Guide for Water Pollution Prevention, Control, and Abatement Programs
TM	5-815-1	Air Pollution Control Systems for Boilers and Incinerators
TM	5-818-1	Soils and Geology Procedures for Foundation Design of Buildings and Other Structures (Except Hydraulic Structures)
TM	5-818-4	Backfill for Subsurface Structures

4. **Army Environmental Center (AEC) (formerly U.S. Army Toxic and Hazardous Materials Agency (USATHAMA))**.

CR 200 1-5 The Low Temperature Thermal Stripping Process, August 1990.

5. **U.S. Environmental Protection Agency (USEPA)**.

EPA 68-03-3248 1988. A Handbook on Treatment of Hazardous Waste Leachate, (Revised December 1986).

EPA 450/4-80-023 1985. Guidelines for Determination of Good Engineering Practice Stack Height (Revised).

EPA 540/2-90/007 1990. Treatability Manual CERCLA Site Discharges to POTWs.

EPA 540-5-94/501 1994. Engineering Bulletin Thermal Desorption Treatment.

EPA 540-594/501 1994. Thermal Desorption Treatment.

EPA 540-689-009 1989. Guidance for Conducting Remedial Investigations and Feasibility Studies Engineering and Design Guidelines for Preliminary Selection of Remedial Action for Hazardous Waste Sites.

EPA 540-G-89 004 1988. Guidance for Conducting Remedial investigations and Feasibility Studies Under CERCLA.

EPA 540/R-92/071a 1992. Guidance for Conducting Treatability Studies under CERCLA

EPA 600/4-79-020 1979. Methods for Chemical Analysis for Water and Wastes.

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EPA 833-R-92-002 1992b. Summary Guidance Storm Water Management for Industrial Activities Developing Pollution Prevention Plans and Best Management Practices. Office of Water.

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6. **Other**.

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APPENDIX B
DESIGN CONSIDERATIONS

1. Scope. Elements discussed in this technical letter include principles of operation, predesign studies and reports, design and performance requirements, construction planning and preparation, regulatory requirements, construction activities and management, operation and monitoring of the unit, and closure of the site. This document will focus on onsite thermal desorption technology. However, the principles of operation and critical operating parameters may also be applied to offsite thermal desorption technologies.

2. Background. Thermal desorption has been used to treat contaminated material containing organic compounds and other organic contaminants since the early 1980s. A thermal desorber is designed to separate organic compounds from soils, sludges, sediments and debris (typically after dewatering) by the application of heat. Thermal desorption is a treatment technology which is typically appropriate for remediation of petroleum and some PCB contaminated materials. Materials principally contaminated with toxic metals are not amenable to thermal desorption due to the partitioning and/or volatilization of metals with the process components of the thermal desorption system. The contaminated material is heated (directly or indirectly) to a sufficient temperature to evaporate the volatile compounds from the solid matrix into an off gas stream.

Incineration, on the other hand, is a combustion process that utilizes rapid oxidation, excess air and high temperature to produce a condition whereby waste constituents are thermally broken down and destroyed.

In the mid 1980s, thermal desorption increased in popularity because it was a thermal technology that provided similar technical benefits to incineration without the regulatory and public relations problems associated with the use of incinerators at waste sites.

Thermal desorber technologies have been developed by a variety of companies and there is not a single, uniform thermal desorber design. Different designs will effect project economics, regulatory requirements and performance efficiencies.

Thermal desorption treatment temperature ranges from 150° to 550°C (300° to 1000°F). Treatment operating temperatures are dependant upon the volatility of the target contaminant(s) present in the soil. A low temperature thermal desorption unit <350°C (<650°F) is effective in treating soil contaminated with a lighter volatile organic compound with a relatively low boiling point, (e.g. benzene boiling point 80°C (176°F)), a high temperature thermal desorption unit >340°C (>650°F) is suitable for treatment of soil organic compounds with low volatility classified as semi-volatile with a heavier contaminant such as chrysene (boiling point = 448°C (838°F)).

Currently there are numerous commercially available thermal desorption units. Each system contains unique components. Based on system design, thermal desorbers can also be classified into the following general categories:

- Direct Fired Thermal Desorbers (e.g. Direct Rotary Dryers, Conveyor Furnace Dryers);
- Indirect Heated Thermal Desorbers (e.g. Thermal Services, Indirect Rotary Dryer);
- Off-gas handling systems which condense the desorbed constituents or off-gas handling systems which burn the desorbed constituents in an afterburner; and
- Off-gas handling systems which use carbon adsorption or ion exchange technology.

The design team is not required to design or build a thermal desorption unit, however important design analysis and considerations are necessary.

During the remediation of any HTRW site the design engineer must keep in mind that all project activities must be protective of human health (including onsite workers) and the environment. With this in mind, planning an effective program for the remediation of contaminated material using a thermal desorber requires that specific attention be given to the following issues:

- Coordination with the appropriate regulatory agencies;
- Health and Safety (ER 385-1-92);
- Chemistry (ER 1110-1-263);
- Achieving performance criteria or remediation requirements;
- Air emissions controls;
- Site Closure
- Providing complete bid package for contractors;
- Construction Activities required to bring a thermal desorber to a site;

In order to coordinate all the activities listed above, the design engineer will need to refer to a number of existing Corps documents.

The sites which the design engineer will encounter will typically fall into two categories:

- Hazardous waste site; and
- Non hazardous waste sites (typically fuel oil or gasoline releases).

Remedial activities shall be coordinated with the appropriate state and federal regulators, regardless of the site classification.

Based on location and use, desorber units fall into the following two categories:

- Onsite Units - these units include both skid mounted and transportable thermal desorbers;
- Offsite Units.

The following subsections discuss these types of units in greater detail.

2.1 Onsite Thermal Desorption Units. Under CERCLA, an onsite thermal desorption unit would be defined as a unit which only accepts waste from the site where it is located. Under Section 121(e) of CERCLA, the desorption unit would not be required to have a RCRA permit, and once remediation is completed would be dismantled and transported to a different site.

2.2 Offsite Thermal Desorption Units. An offsite thermal desorber would be a unit which receives wastes from multiple sites and is permitted under RCRA. A facility might construct a thermal desorber for a particular hazardous waste site and then use the desorber to treat waste from other sites. The desorber under those conditions would be considered an offsite unit.

3. Theory. Thermal desorption is a process in which contaminated material are heated and the moisture and organic contaminants evaporated. This can be accomplished by heating the contaminated material to a temperature at which the constituents will not burn but will volatilize. Thermal desorption can also be accomplished by heating the contaminated material at higher temperatures in an oxygen deprived atmosphere that prevents combustion (Troxler, Cudahy, et al, 1993).

Figure B-1 is a general schematic of the thermal desorption process. In most cases, the contaminated material is agitated inside the desorber. The most common desorber units are rotary kilns (rotary dryers) and augers (thermal screw).

Systems can be directly fired, in which the contaminated material is desorbed in the same zone as the heating flame or indirectly fired, in which the heat is applied to the outside the shell of the desorber, with heat transferred to the contaminated material by conduction (Troxler, et. al., 1993).

Oil heated thermal screw systems consist of the following components: a solids pretreatment and feed system; an indirect heated screw(or auger); a heat transfer fluid heating system; a cooling conveyor for treated solids; an off-gas treatment system; and a water treatment system. The thermal screw systems are heated by circulating a hot heat transfer fluid (oil or steam) through the covered trough in which the screw rotates. The oil or steam is also circulated through the hollow auger flights and subsequently returned to the hollow auger shaft to heat the transfer fluid system (Troxler, et. al., 1993).

Energy equal to the heat capacity of the contaminated material multiplied by the change in temperature is used to heat a specific organic contaminant to its boiling point. Additional energy equal to the heat of vaporization of the specific organic contaminant is used to boil off or volatilize this contaminant. Prior to the volatilization of the specific contaminant, initial energy is required at the onset of treatment to vaporize water present in the contaminated material. The moisture content of the soil will impact the energy required to heat the soil due to the initial energy required to vaporize water; the heat of vaporization of the water may be significant. Additional energy is also required during the process to make up system heat losses. This process is continued until the organic contaminants are distilled from the contaminated material. The off-gas is maintained below the combustion threshold which is a function of: temperature, pressure, and oxygen concentration (US EPA, 1994).

After volatilization, organic constituents are either condensed, adsorbed or destroyed in a secondary device such as an afterburner or catalytic oxidation unit. Systems that condense and collect the volatilized organics produce a liquid waste stream that is generally treated or destroyed off-site. Adsorption media may be regenerated or incinerated, on or off-site. Systems that destroy the volatilized organics in a secondary device, such as an afterburner or a catalytic afterburner, must be tested to ensure destruction of the volatilized constituents is performed in accordance with applicable state and federal regulations. The off-gas can also be treated by adsorption on activated carbon or ion exchange media (EPA, 1988).

The critical design parameters for thermal desorption include required temperatures and retention times for adequate treatment and design of gas phase control/recovery systems. The required bed temperature and residence times depend to a large extent on the types of contaminants and soil or solid matrix being desorbed.

3.1 Direct Fired Units. Direct fired desorber units can supply heat to a waste using the following methods:

- Heat is supplied to a waste by contact with a hot gas which is heated by a flame; or
- Heat can be radiated (Infrared Thermal Desorber) onto the contaminated material.

Some infrared units use silicon carbide elements to generate thermal radiation beyond the red end of the visible spectrum. Materials to be treated pass through the unit on belts and are exposed to the radiation. Off-gases pass into a secondary chamber for further infrared irradiation and increased retention time to volatilize any contaminated particular matter present in the off gas.

3.2 Indirect Fired Units. Indirect fired desorber units can supply heat to a waste using the following methods:

- A desorption chamber can be heated indirectly at its surface by hot combustion gases that do not contact the contaminated material; or
- A desorption chamber can be heated indirectly by contact with a thermal screw that is heated with hot oil or another heat transfer fluid such as molten salt.

In either case, the vaporized constituents are removed by a carrier gas such as nitrogen. In most indirectly fired thermal desorption systems, the carrier gas is recirculated (US EPA, 1994).

Soils are transported through indirect fired units (thermal screws) by movement along the flights of the spinning auger or paddles and the auger trough. Use of this material transport

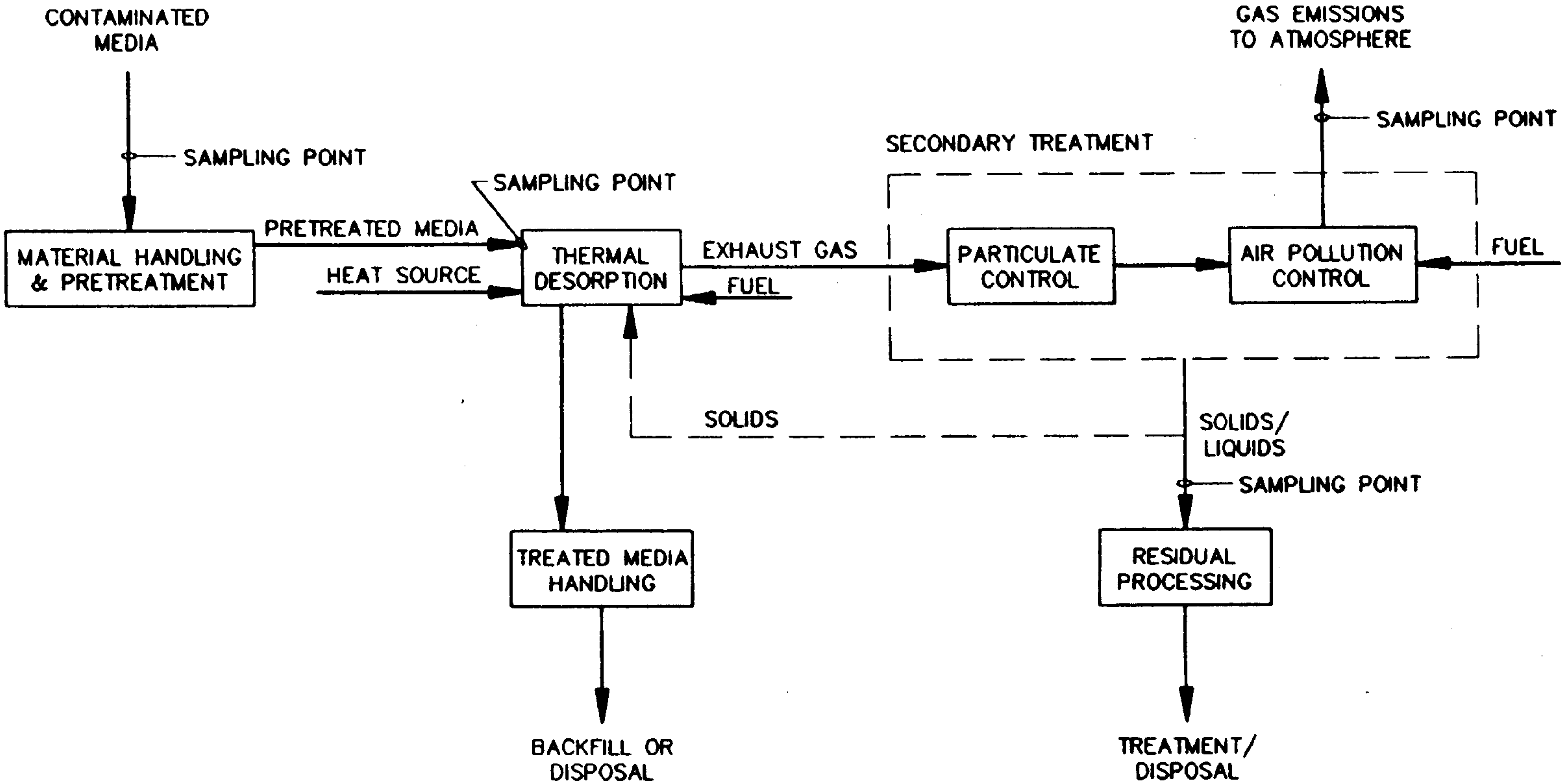


FIGURE B-1

THERMAL DESORPTION SYSTEM SCHEMATIC

system allows for the mixing, movement and heating of the contaminated material (Troxler, et. al., 1993). Some indirect fired units radiate the heat into a thin layer.

3.3 Transportable Units. When considering a transportable thermal desorption unit it should be understood that while the unit has been designed, constructed, and in many cases demonstrated to be effective at other waste sites, it is subject to site or contaminant specific permitting requirements. The transportable unit which has demonstrated its effectiveness to treat soil with a particular contaminant at one site may face different regulatory requirements hence design or operational modifications may be required at a second site with the same constituent. Furthermore, varying contaminated material constituents from site to site may impact treatment effectiveness and desorption unit performance. As a result design changes to the unit may be required to meet changing performance requirements. It is not uncommon to modify the air emissions control system from site-to site.

4. Definitions. Contaminated Material - Soil, sludge or sediment contaminated with hazardous and non- hazardous chemicals. Chemicals which have been successfully treated using thermal desorption are presented on Tables B-1 and B-2. The tables are based upon current available information related to demonstrated effectiveness at some scale of treatability testing or potential effectiveness of desorption to effectively remove the contaminant from the media.

Remediation Goals - Final concentrations of the constituents remaining in the media. Remediation goals should be established prior to starting design.

5. Objectives. The objective of this document is provide the design engineer or construction manager with information which is unique to the execution of a thermal desorption remediation project. The letter is based on an extensive review of Department of Defense agency documents, EPA, literature, and contractor information.

TABLE B-1
Effectiveness of Thermal Desorption on General Contaminant Groups for Soil, Sludge, Sediments, and Filter Cakes (for Low Temperature Units)

Contaminant Groups		Effectiveness			
		Soil	Sludge	Sediments	Filter Cakes
Organic	Halogenated Volatiles	■	▲	▲	■
	Nonhalogenated volatiles	■	▲	▲	■
	Organic cyanides	▲	▲	▲	▲
Inorganic	Volatile cyanides	■	▲	▲	▲

■ Demonstrated Effectiveness: Successful treatability test at some scale completed

▲ Potential Effectiveness: Expert opinion that technology will work

X No Expected Effectiveness: Expert opinion that technology has no expected effectiveness for treatment of the following contaminant groups: Organic corrosives, nonvolatile metals, asbestos, radioactive materials, inorganic corrosives, inorganic cyanides, oxidizers and reducers; contaminant groups PCBs, pesticides and furans are more appropriately heated in a high temperature unit.

Source: EPA Engineering Bulletin. Thermal Desorption Treatment. EPA/540/5-94/501.

TABLE B-2

Effectiveness of Thermal Desorption on General Contaminant Groups for Soil, Sludge, Sediments, and Filter Cakes (for High Temperature Units)

Contaminant Groups		Effectiveness			
		Soil	Sludge	Sediments	Filter Cakes
Organic	Halogenated semivolatiles	□	□	▲	□
	Nonhalogenated semivolatiles	□	▲	▲	□
	PCBs	□	▲	□	▲
	Pesticides	X	▲	▲	▲
	Dioxins/Furans	X	▲	▲	▲

□ Demonstrated Effectiveness: Successful treatability test at some scale completed

▲ Potential Effectiveness: Expert opinion that technology will work

X No Expected Effectiveness: Expert opinion that technology will not work

Source: EPA Engineering Bulletin. Thermal Desorption Treatment. EPA/540/5-94/501.

APPENDIX C
PRINCIPLES OF OPERATION

1. Overview. This section reviews the principles of thermal desorption system operation. The discussion emphasizes components of desorption systems which are similar regardless of the manufacturer. Specifics of individual components and operation will vary.

2. Materials Handling and Pretreatment. Pretreatment is dependant on both the type of contaminated material and treatment system utilized. Pretreatment for the contaminated material feed consists of two categories:

- particle size adjustment;
- dewatering.

Particle size adjustment is included in material handling activities. Materials handling includes the management of soil excavation and materials preparation prior to thermal treatment, and backfilling and dust control after thermal treatment.

The success of thermal desorption is dependant on proper materials preparation and handling prior to treatment. The contaminated material must be conditioned to a size and consistency required by the selected desorption process. Several desorption technologies have size and consistency limitations and are designed to accommodate a homogeneous feed stock.

The materials handling operation of a thermal desorption process may include one or more of the following components:

- Contaminated material excavation and transport to and from the thermal desorption system;

- Particle size reduction/sorting for removal of oversized and non homogeneous materials (via screening, shredding, crushing, blending);

- Removal of excessive moisture content by use of a pretreatment dewatering operation (evaporation, filtering, drying, centrifuge, thickening, chemical addition) to produce a suitable filter cake;

- Material stockpiles are used to synchronize the desorption process, to provide continuous feed, and to provide a sampling location;

- Control of fugitive emissions with the use of dust suppressants, negative air pressure systems, foams or covered shelters.

Materials handling must be carried out properly to comply with handling, storage and disposal regulations and contaminant specific health and safety requirements. Excavation should be conducted in a manner to prevent cross contamination. The area and volume to be excavated and treated must be established by the design team including the survey and investigative data. Materials involved in handling operations include contaminated treated materials and treated materials. Material handling is a very important component of a successful thermal desorption remedial action. The design engineer and construction manager must pay particular attention to this design and operation component of a thermal desorption technology. Control of runoff is critical to maintenance of the excavation site. Measurement and payment is generally based on in-situ measurement of volume.

2.1 Material Excavation and Transport. Standard heavy construction excavation equipment used for the removal of large volumes of contaminated material from a remediation site. Equipment typically used includes the following:

- Dragline - Crane operated excavator bucket used to dredge soils below surface depth and far reaches and sludge from lagoons, ponds or pits;

- Backhoes - Used for surface or subsurface excavation of soils and sludges;

- Mudcat - articulated, tracked vehicle/equipment used for moving wet sludge like material in a swamp or lagoon type area; and

- Heavy Earthmoving Equipment - Include excavators, bulldozers and dump trucks used for excavation and transport. Common types of earth moving equipment are summarized in Table C-1.

Positive displacement pumps (e.g., air driven diaphragm, progressing cavity) may be used to transfer high density, abrasive or high viscosity sludges. Sludges can then be dewatered in a dewatering technology such as a filter press prior to thermal treatment.

TABLE C-1
Earth Moving Equipment

Type	Description	Application
Prime Movers Crawler Tractors	Track type prime mover 40-500 HP	Used with mounted bulldozers, rippers, winches, cranes and side booms
Wheel Tractors	Range from small rubber tired units to large diesel powered types	Small units used with scoops, loaders and backhoes. Large units used for propelling wagons, scrapers and bulldozers
Crawler Type Devices Bulldozers-Crawler Type	Crawler tractor with a front mounted blade. Straight, angling and tilting type blades are available.	Pioneering access roads, boulder and tree removal, and short haul earth moving in rough terrain. Also push-loads self propelled scrapers and used with rear mounted rippers to loosen firm material.
Loader-Crawler Type	Track type prime mover with front mounted movable bucket. Capacities from 0.5 to 4 cubic meters (0.7 to 5.0 cubic yards).	Digging ditches, loading trucks and hoppers, and placing, spreading and compacting earth.
Wheel Type Devices Bulldozers-Wheel Type	Four wheel drive, rubber tired tractor with hydraulically operated front mounted blade.	Push loading self propelled scrapers, grading cuts, spreading and compacting fill and drifting loose material on firm ground for distances up to 150 m (500 feet).

TABLE C-1 (cont)
Earth Moving Equipment

Type	Description	Application
Loader-Wheel Type	Four wheeled rubber tired prime mover with front mounted hydraulically operated shovel. Often called a Pay loader. Capacities from 0.4 to 15 cubic meters (0.5 to 20.0 cubic yards).	Handling and loading materials of all kinds on firm surfaces.
Scrapers-Tractor Drawn	Four wheeled rubber tired trailers used with crawler tractors. Capacities from 5 to 20 cubic meters (7 to 27 cubic yards).	Loading, hauling, dumping and spreading earth. One way moving up to 300 m (1,000 feet) or on terrain unsuitable for self propelled scrapers.
Scrapers-Self Propelled	Scraper with integral self propelled two or four wheel tractor. All wheel drive self loading types also available.	High speed earth moving.
Bottom Dump Wagons	Available in capacities to 135,000 Kg (150 short tons).	Used in place of scrapers on large wheel tractors or trucks for hauling earth, sand or gravel over long distances.
End Dump Trunks	Heavy duty, diesel powered truck with rear dump body. Capacities of 11,000 to 320,000 kg (12 to 350 tons).	Used for hauling and dumping hard and abrasive shovel loaded materials.

Source: Marks' Standard Handbook for Mechanical Engineers, 8th Edition

2.2 Waste Size Classification. Particle size distribution of contaminated material is a physical characteristic that influences the applicability of desorption. Soils are generally classified according to the Unified Soil Classification System (USCS). The four major divisions of the USCS are: (1) coarse grained; (2) fine-grained; (3) organic soils; and (4) peat. Coarse grained soils can be classified according to grain size distribution, whereas, fine grained soils are generally related to their plasticity.

The standard for classifying soils involves the use of a 74µm sieve. Coarse grained soils have more than 50% of their material captured by a 74µm sieve. Fine grained soils have more than 50% of their material pass through a 74µm sieve (Troxler, et al., 1993).

Finely grained soils, such as silts, may become entrained in the off-gas stream of a thermal desorption system and not achieve proper residence time at the required temperature. Between 5 to 30% of fine grained soils fed into a direct fired thermal desorber may become entrained in the gas stream, and between 1 to 5% of the fine grained soils fed into an indirect fired thermal desorber may become entrained in the gas stream. The extent of particulate entrainment is a function of the average particle size of the soil, the off gas velocity through the unit and the type of material transport mechanism. Gas velocities within a direct fired unit are typically between 1.5 to 3 meters (5 to 10 feet) per second and between 0.3 to 1 meter (1 to 3 feet) per second within an indirect fired unit. Estimates of entrainment are dependent on system design, however, entrainment is proportional to the percentage of finely grained soils and higher off gas velocities through the system. In these cases, the entrained material may be recycled back to the thermal desorber (typically through a cyclone) with a corresponding loss in treatment capacity (U.S. EPA, 1994).

2.2.1 Screening. Contaminated materials excavated from a remediation site may vary widely in aggregate size. Initially, large size debris is separated from the other contaminated materials. The smaller debris and materials can then be directed to a screening mechanism to further separate debris greater than the maximum treatment size from the materials. The screening process is repeated until the required particle size is achieved.

Thermal desorption systems typically require that material feed stocks be screened to a particle size of 2.5 to 5 cm (1 to 2 inches.)

A variety of screening devices are commercially available; the selection of an appropriate screening device is dependent upon the degree of screening required. A combination of one or more screening devices may be used to achieve a successive reduction in particle size. Typical screening devices include vibrating type screens, static screens and grizzlies.

Depending on the contaminated material for treatment, oversize materials may or may not have to be tested to determine if thermal treatment is required. This is a function of the nature and viscosity of the contaminants and the permeability of the oversized material. For example if a site contained 80,000 cubic meters (100,000 cubic yards) of soil contaminated with PCBs that required treatment and 95% of the particle size of this soil was smaller than 5 cm (2 inches), then 4,000 cubic meters (5,000 cubic yards) of oversize material may need to be crushed to a size less than 5 cm (2 inches) prior to treatment. The issue is whether or not this oversized material requires treatment. If the contaminated material to be treated consists of soil and rocks and does not contain landfill debris or organic materials such as wood, paper or other materials that readily absorb contaminants, then the oversize material may not require treatment. The design team should consult the regulators and determine whether or not such material requires thermal treatment or whether a less expensive solution would meet the cleanup standards.

Fuel contaminated sites with large quantities of soil 2.27 x 10^7 kg (25,000 ton) have been treated for $65/1000 kg ($59/ton) while smaller sites less than 4.53 x 10^6 kg (5000 ton) have been awarded at $440/1000 kg ($400/ton). Presented below are examples of the screening and crushing or pulverizing devices typically used on excavated materials prior to thermal treatment.

2.2.2 Shredding. Large sized debris and aggregate material can be pretreated with shredding equipment. Shredders typically employ two or more pairs of cutting wheel assemblies or auger blades. The wheels or blades of each pair rotate in opposite directions and the debris or aggregate material is fed in between each pair and is broken up with shearing action. Shredders are available to handle a wide variety of materials including some clays (and abrasive clay clumps and/or cohesive clay balls), metal wood, rubber and concrete.

Debris such as metal drums and rubber tires may be processed through these devices (note: if the drums contain a hazardous waste then they would need to be disposed off-site).

2.2.3 Crushing. Large aggregate material can be pretreated with the use of crushing devices that reduce the size of the material by direct impact. Hammer mills are devices used to reduce the particle size of soft materials. Impact crushers use rotating hammers or bars to break up materials containing impurities and cracks. Tumbling mills employ a rotating drum filled with balls, rods, tubes or pebbles to reduce the size of rocks and other materials. Pulverizers reduce the size of large aggregate such as concrete, stone or glass prior to further crushing. Pulverizers also separate reinforcing bar from reinforced concrete.

2.2.4 Blending. Mechanical blending is a pretreatment option used to handle contaminated materials with the following elevated parameters: moisture content, plasticity, and/or high concentrations of volatile organics.

The lowest moisture content at which soil will deform without shearing is known as the plastic limit. Thermal desorption of fine grained soils with moisture contents exceeding the plastic limit is extremely difficult due to plastic soils compacting into larger particles when subjected to pressure. The larger particles are difficult to heat because of their low surface area to volume ratio. Other problems associated with the treatment of plastic soils include the following.

- Difficulty in removal of debris and aggregate;
- Adherence to material handling equipment;
- Clogging the system; and
- Reducing the heat transfer efficiencies.

The moisture content of plastic soils may be decreased below the plastic limit by mixing the contaminated material with drier soil or other inert materials.

For contaminated materials with elevated levels of volatile organic concentrations, mechanical mixing may be used to equalize volatile organic loading and optimize the feed rate to the thermal desorber by blending inert materials or materials of lower volatile organic concentrations (Troxler, et al., 1993).

Mechanical mixing of contaminated material is done with standard construction equipment such as backhoes, excavators, and clamshells. Blending equipment such as bladed rotating blending heads for attachment to standard construction equipment is commercially available.

2.3 Dewatering. Dewatering is a significant pretreatment for thermal desorption of contaminated material with an elevated moisture content. Moisture content of contaminated material will impact the treatment cost of thermal desorption. Moisture content is the percent by weight of water in soil, and is calculated either using a dry weight basis or a wet weight basis.

For example:

If 1 kg, (2.2 lb) of moist soil loses 0.2 kg (0.44 lb) of water when dried in a furnace, the 0.8 kg (1.76 lb)or the 1.0 kg (2.2 lb) can be used to calculate the percent weight.

0.2 kg (0.44 lb) water/0.8 kg (1.76 lb) soil = .25 or 25% water (dry basis)

or

0.2 kg (0.44 lb) water/1.0 kg (2.2 lb) soil = .2 or 20% water (wet basis)

Dewatering is a physical process used to reduce the moisture content of contaminated materials. Dewatering can fall into three categories:

- Natural dewatering which utilizes natural evaporation;
- Mechanically assisted dewatering which uses a mechanical device to physically reduce the moisture content of the contaminated material. The selection of a suitable dewatering device is dependent on materials to be dewatered. A sludge not amenable to mechanical dewatering could be dewatered on a sand drying bed. Typical types of dewatering processes include belt filter presses, recessed plate filter presses, drying beds, and lagoons; and
- Dewatering by heat addition.

The belt filter press is the most effective mechanical device used and most common technology for dewatering almost all types of solids. Since the belt filter press dewaters solids relatively quickly, it is an effective pretreatment device for solids prior to treatment in a thermal desorption unit. A typical belt filter press consists of feed pumps, polymer feed equipment, a belt filter press, a sludge cake conveyor, and miscellaneous support systems. Depending on the type of belt press used, a feed containing 1 to 10% solids can be dewatered to 10 to 50% solids (Metcalf and Eddy, 1991).

In a plate and frame filter press, the solid is dewatered by driving the water from the sludge under high pressure.

This type of dewatering apparatus can produce a filter cake with solids concentrations ranging from 30 - 50%. A typical filter press consists of a series of rectangular plates, recessed on both sides, that are supported face to face in a vertical position with a frame. The frame has a fixed and a moveable head. Each plate is generally covered with a filter cloth. The slurry is pumped into the spaces between the plates, and pressure is applied and maintained for one or more hours. The liquid is squeezed out of the slurry and collected beneath the press (Metcalf and Eddy, 1991). Design of filter press applications is discussed in separate guidance. CEGS 11360 Plate and Frame Filter Press System is used to specify a filter press for dewatering.

Drying beds are used to dewater sludge. Drying beds fall into four categories:

- Conventional sand;
- Paved;
- Artificial media; and
- Vacuum assisted.

After drying the sludge in a drying bed, the dewatered sludge can be removed and treated in the thermal desorber. Drying beds are generally capable of providing solids ranging from 10 to 35% final concentrations. The performance of drying beds is impacted by bad weather, precipitation and low temperatures (Corbitt, 1990).

Drying lagoons can be used as a substitute for drying beds for dewatering sludges. Lagoons are not recommended for dewatering untreated sludges, or sludges with a high-strength supernatant due to their odor and nuisance potential. Lagoons are most effective in areas with high evaporation rates. Like drying beds, lagoon performance is affected by weather (Corbitt, 1990).

Relative cost effectiveness of the unit processes for dewatering and thermal desorption should be evaluated prior to design of a system for dewatering and thermal desorption. Mechanical dewatering can reduce moisture in contaminated material to 50% moisture by weight. The cost of dewatering ranged between $22/1000 kg and $44/1000 kg ($20 and $40/ton) at 1994 prices. Thermal desorption costs may double from $165 to $386/1000 kg ($150 to $350/ton) for a contaminated material containing 15-20% moisture to $330 to $660/1000 kg ($300 and $600/ton) for thermally treating a contaminated material containing 50% moisture.

2.4 Feed Hopper Systems. Feed hoppers collect pretreated contaminated materials for feed into the thermal desorber. Contaminated materials are generally loaded from the stockpile into the feed hopper by front end loader or other similar type construction equipment (Troxler, et al., 1993).

Some hoppers are equipped with a non vibratory screen at the inlet to act as a final screening device for the contaminated material. A feed screw or rotary air lock is installed below the feed hopper to meter the material into the thermal desorber. Weigh hoppers consisting of a feed hopper with weigh scale or weight sensor can be used to meter material to the desorption device. Feed hopper systems can use magnets to remove metal if the contaminated material was excavated from an industrial area.

2.5 Conveyance Systems. Conveyors are used to transport contaminated material into and treated material out of the thermal desorber. Screw type conveyors are generally used to transport the contaminated material from the outlet of the feed hopper to the inlet of the desorption device. Belt or screw conveyors are used to carry the treated material from the desorber outlet to a truck or temporary storage area. Weigh scales may be installed as part of the conveyance system to weigh the treated material prior to disposal or on-site backfilling.

The capacity of the conveyance systems selected is dependent upon the throughput capacity of the thermal desorber. Variable speed conveyors may be selected to accommodate changes in processing feed rate.

3. Desorption of Contaminants. This section discusses types of desorption units for removal of organics from solids and desorption theory.

3.1 Dryer Systems. Commercially available, dryer systems to treat organic contaminated soil include: thermal screws, rotary dryers, and conveyor furnace dryers. The mechanical design features and process operating conditions vary considerably among the various types of systems. A brief description of each of these technologies dryer systems is provided below.

3.1.1 Thermal Screws. Thermal screws are available with treatment capacities ranging from 2,700 to 13,610 kg (3 to 15 tons) of contaminated material per hour. Thermal screw systems are generally trailer-mounted. The number of trailers required depends on the size and capacity of the system - with two to four trailers being typical. Thermal screws are typically classified as low temperature thermal desorbers.

Figure C-1 is a diagram of an indirectly fired thermal screw. A typical thermal screw process contains the following major components:

- Indirectly heated screw or paddle augers;
- Heat transfer fluid heating system; and
- Treated solids cooling conveyor.

A thermal screw processor may consist of from one to four screw or paddle augers. Augers can be arranged in series to increase solids residence times, or in parallel to increase contaminated material input capacity. The auger system conveys, mixes, and heats contaminated material to volatilize the organic compounds which are then carried away via an exhaust system. Most thermal screw systems are heated by hot oil, molten salt or with process steam; some systems utilize molten salt. The heat transfer fluid heating system is fired with either propane, natural gas, or No. 2 fuel oil. The heat transfer fluid is circulated through the jacket trough in which each auger rotates. The heat transfer fluid is also circulated through the hollow auger flights and returned through the auger shaft (Troxler, et. al., 1993).

Combustion gas does not contact the waste material and normally can be discharged directly to the atmosphere without emissions control. A fraction of the flue gas from the hot oil heating system is recycled to the screw conveyor. Recycled flue gas maintains the thermal screw off gas exit temperature above 150°C (300°F) so that volatilized organics and moisture do not condense. The recycled flue gas has a low oxygen content (less than 2% by volume) and provides an essentially inert atmosphere to minimize oxidation of organics (Troxler, et. al., 1993).

The maximum temperature to be attained in the thermal screw system is limited by the temperature of the heat transfer fluid and materials of construction of the system. Hot oil heated systems can achieve feed material temperatures of up to 260°C (500°F); steam heat systems can heat soil up to 177°C (350°F) (Troxler, et. al., 1993); molten salt systems up to 370°C (700°F); electrically heated screws may be hotter.

After the treated material exits the thermal screw, water is sprayed on the treated material for cooling and dust control. The water may be mixed with the hot treated material in a screw conveyor or pugmill (Troxler, et. al., 1993).

Vaporized organics, water, and inert off-gas are drawn from the screw conveyor under an induced draft and pulled through the off-gas treatment system. A particulate control device,

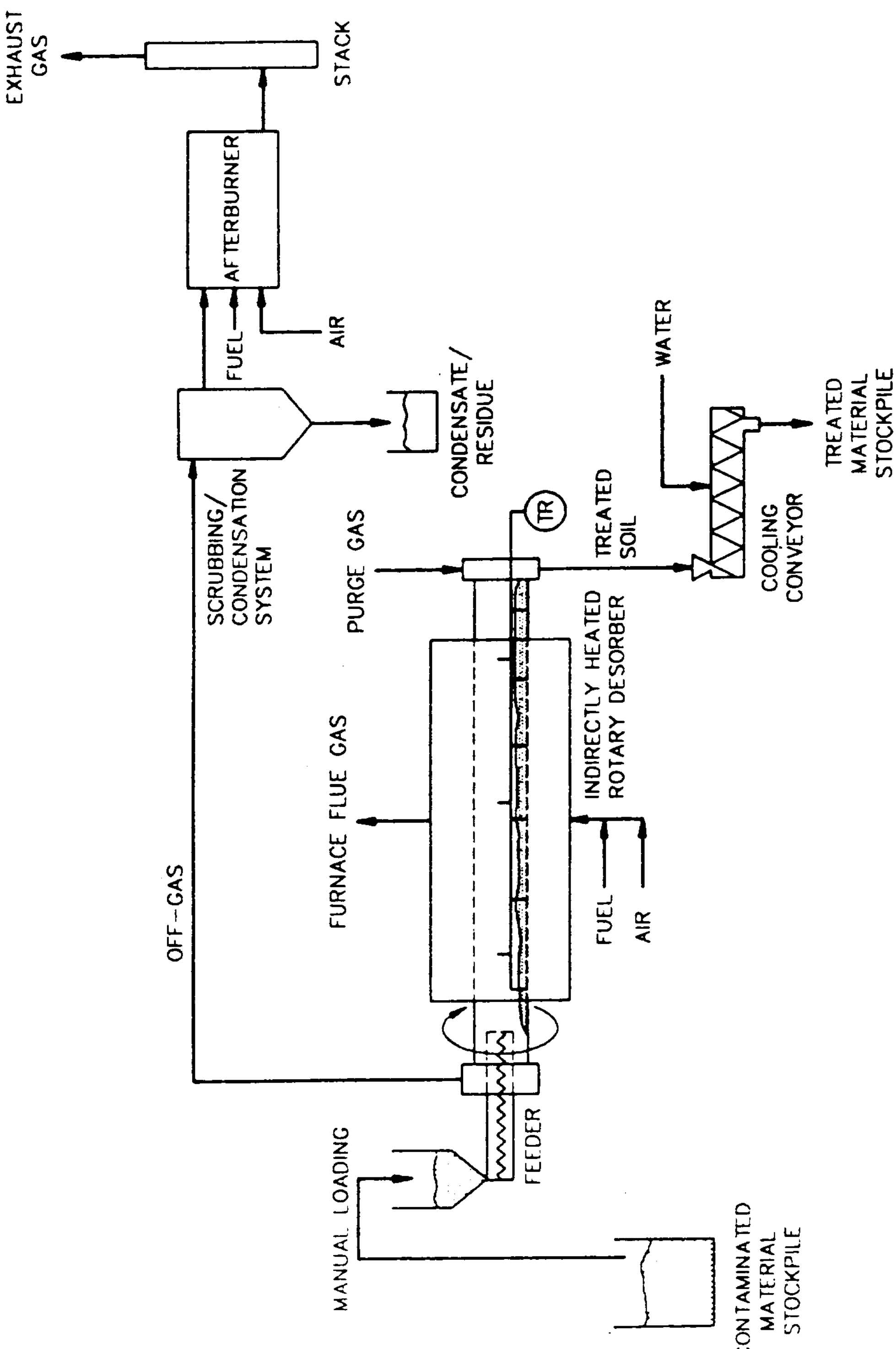


FIGURE C-1
TYPICAL THERMAL SCREW PROCESS DIAGRAM

REFERENCE:
Hilsel, 1989 and Troxler et al., 1993

such as a venturi scrubber, cyclone or bag filter, is commonly used directly down stream of the thermal screw. Other devices used to control emissions from thermal desorption units include cyclones, afterburners, baghouse filters, venturi scrubbers, scrubbers and activated carbon (Troxler, et. al., 1993). Most screw use a single- or multi stage condensation system combined with other unit operations.

Off-gas volume from the primary thermal treatment unit operation of an indirectly heated, thermal screw may be a factor of 2 to 10 times less than the volume from a directly heated system with an equivalent feed material processing capacity. The corresponding exhaust treatment systems for indirectly heated thermal screws are relatively small unit operations that are well suited for mobile applications. Indirect heating systems allow processing materials with high organic content by use of inert gas blanketing which prevents oxidation of desorbed organic compounds. Thermal screws are typically used on the following compounds, solvents such as TCE, gasoline, naptha and jet fuels within a distillation temperature range of 93°C to 88°C (200 to 550°F), (Troxler, et. al., 1993).

3.1.2 Thermal Screw Pilot System. Contaminated material is fed into the soil feed hopper. The soil falls into the thermal processor. The thermal processor consists of two units, each containing four hollow screws. As the screws turn, they churn the feed material, breaking it up and pushing it from the feed end of the processor to the discharge end. In the meantime, a hot liquid (oil typically) is pumped through the inside of the screws. The constant churning of the soil and movement of hot liquid up and down the length of the screws heat the feed material and volatilizes the volatile organics. Additional heat is provided by the walls of the processor which also contains flowing hot liquid (USATHAMA Cir 200-1-5). The thermal processor heats up to a maximum of about 340°C (650 degrees Fahrenheit).

Once the volatile organics are vaporized, they flow through piping into a burner or other means of treatment, such as a scrubber or carbon adsorption system. The off gas then passes through a discharge stack monitored for volatile organics.

In the meantime, the treated material which is now virtually volatile organic-free, falls into the discharge end of the processor, where it can be put back into the excavation area. Figure C-2 provides a schematic diagram of a thermal screw pilot system.

3.1.3 Rotary Dryers. Rotary dryers are available as both mobile and stationary systems. Treatment capacities range from 4,500 to 1.8 x 10^6 kg (5 to over 100 tons) of contaminated material per hour (Troxler, et. al., 1993). Rotary dryers can operate at low or high temperature. A typical rotary dryer system contains the following major process components:

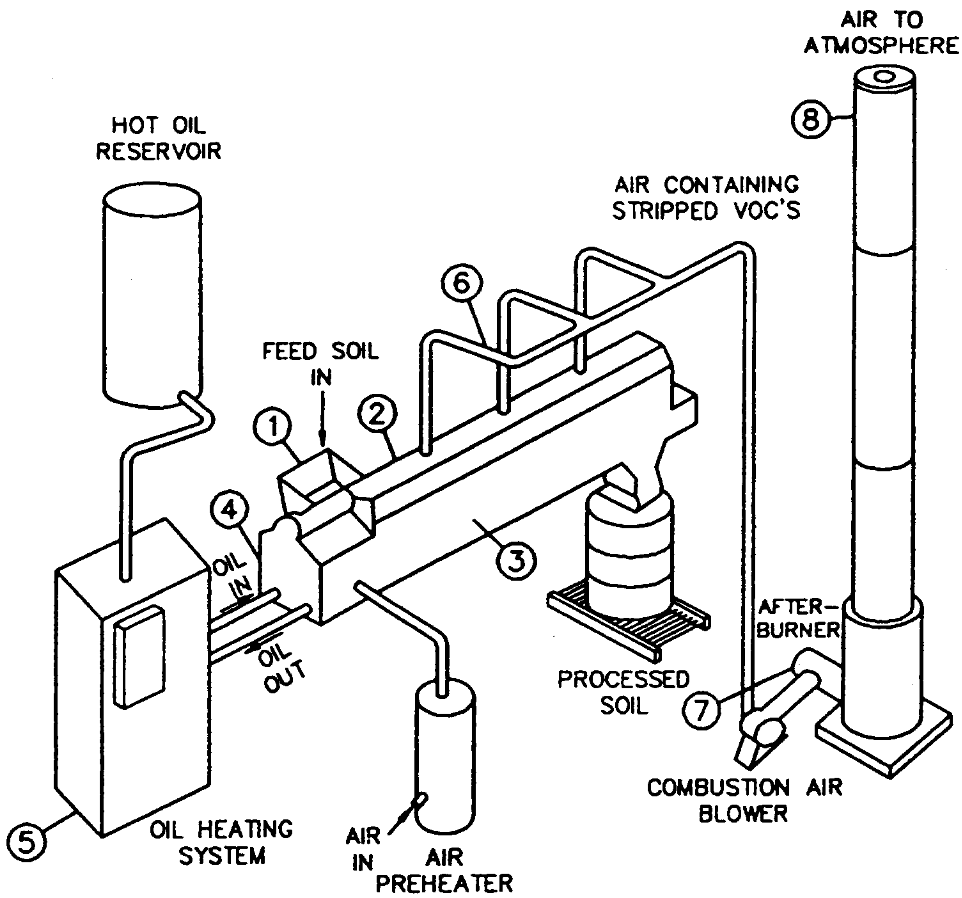
- Rotary dryer (co-current or counter current);
- Treated soil cooling system; and
- Air pollution control(cyclones, baghouse filters).

Co-current firing in a rotary dryer involves the flow of solids (contaminated material) through the dryer in the same direction as the off-gas, whereas counter-current firing is the flow of solids (contaminated material) through the dryer in the opposite direction of the off-gas. The following describes advantages and disadvantages of co-current and counter-current rotary dryer systems.

A rotary dryer system uses a cylindrical metal reactor (drum) that is inclined slightly relative to the horizontal position. A natural gas, propane or fuel oil fired burner located at one end of the dryer provides heat to raise the temperature of the feed material sufficiently to desorb the organic contaminants. Organic contaminants are removed by the off-gas. The flow of solids may either be co-current or counter current to the direction of the off-gas flow. A series of lifters inside the drum pick up the feed material, carries it to the top of the drum and drops it through hot combustion gases from the burner. The intense mixing which occurs in a rotary dryer enhances the heat transfer by direct contact with the hot gases and allows feed materials to be heated rapidly. As the drum rotates, the feed material is conveyed through the drum.

The residence time of solids in the drum is controlled by the rotational speed of the drum and the angle of inclination, and the arrangement of internal lifters. (Troxler, et. al., 1993).

The maximum soil temperature in a rotary dryer is dependant on the construction material for the dryer shell. Normally these shells are constructed of carbon steel and operate at soil discharge temperatures of 149 to 316°C (300 to 600°F). Rotary dryers are constructed of alloys which can heat contaminated materials up to a temperature of 650°C (1200°F) (Troxler, et al., 1993). After the treated material exits the rotary dryer, it is sprayed with water for cooling and dust control.



Schematic diagram of the low temperature thermal stripping pilot system:
(1) soil feed hopper
(2) thermal processor
(3) hollow screw conveyor with hot fluid flowing inside
(4) trough jacket
(5) oil heating system
(6) off-gas emission monitoring
(7) afterburner
(8) stack testing for VOC, particulates and HCl

AEC (formerly USATHAMA Cir 1-5), 1990

FIGURE C-2
LOW TEMPERATURE THERMAL STRIPPING DIAGRAM

Counter current rotary dryers are typically followed by wet scrubbers, a cyclone, a baghouse, an ID fan, an afterburner, and a stack. The off gas temperature from a counter-current rotary dryer is limited by the material of construction of the bags in the baghouse. This temperature limitation is normally in the range of 260 to 350°C (500-660°F). A key advantage of the counter current system is that the off gas can go directly to the baghouse without adding water or air for cooling. However, because of the relatively low baghouse operating temperature, there is some potential for high molecular weight organics to condense in the baghouse and contaminate the baghouse fines or to blind the bags (Troxler, et. al., 1993). Temperature is limited to material of construction of the bags in the baghouse (if a baghouse is used). Temperatures can be higher if a wet scrubber or water quench is used.

A common equipment arrangement of co-current rotary dryer is a cyclone, an afterburner, an evaporative cooler, a baghouse, an ID fan, and a stack. Rotary dryers that operate in co-current mode discharge off gas at a temperature of 10 to 40°C (50 to 100°F) hotter than the soil discharge temperature. This results in exhaust temperatures that may range from 200 to 540°C (400 to 1,000°F). (Troxler, et. al., 1993).

3.1.4 <u>Bed Desorption Systems</u>. A bed desorption system is essentially a desorption system which utilizes a conveyor and a bed. The system is typically a transportable mobile unit which is transported on flatbed trailers. The capacity of this system is 4,500 to 9,000 kg (5 to 10 tons) of soil per hour. The conveyor furnace uses a flexible metal belt to convey contaminated material through a primary heating chamber. A 2.54 cm (one inch) deep layer of contaminated material is spread evenly over the belt. A series of burners fire into a chamber above the belt to heat the feed. This system can heat materials to temperatures ranging from 150 to430°C (300 to 800°F). After the treated material exits the conveyor furnace, it is sprayed with water for cooling and dust control.

The off-gas exits the conveyor furnace and is treated in an off-gas treatment system which consists of an afterburner, quench chamber, and a venturi type scrubber. Water discharged from the scrubber is used to cool the treated material (Troxler, et. al., 1993).

3.1.5 <u>Batch Processes</u>. Batch thermal treatment process systems can remediate soil contaminated with volatile and semi-volatile organics to below detectable limits. The process does not alter the chemical structure of contaminants, which allows the contaminants such as petroleum to be recovered and recycled. In many cases, the process is considered to be an enhanced vacuum extraction system, and can operate without air monitoring controls. On HTRW sites activated carbon or quench, cyclone, and wet scrubbers have been added as necessary. Depending on the type of contaminant and the moisture content of the soil, batch treatments can remediate as much as 51 x 10^3 kg (56 tons) of soil per hour, per unit. The process is especially suitable for use in clay media. Petroleum hydrocarbons, chlorinated solvents, pesticides, PCBs and mercury have been treated successfully. Arsenic in a chloride or organically bound form also can be handled. The process recently has been tested as a method for extracting volatiles from mixed waste (Pollution Engineering, 1994).

3.1.6 <u>Low Temperature Volatilization System</u>. The Low Temperature Volatilization System is a batch type system used to thermally treat contaminated soil at exit temperatures. The primary thermal treatment component of this system is a natural gas or propane fired, countercurrent rotary dryer with internal flights. Contaminated material is fed into the dryer where the internal flights lift and spill the soil through the hot gas stream. Treated material from the dryer exits into a discharge auger where it is water-cooled. The cooled soil drops onto a stacking conveyor and is conveyed to a temporary stockpile. The air pollution control system consists of a baghouse, an afterburner quench, and packed bed scrubber. Entrained particles in the thermal desorber off gas are removed by the baghouse. Volatilized organic compounds from the thermal desorber off gas are destroyed in the afterburner. Following the afterburner, a wet air pollution control system is used to remove HCl and Cl2 present in the off-gases. A block flow diagram of the Low Temperature Volatilization System is shown in Figure C-3. The block flow diagram begins where soil feed and auxiliary fuel are introduced into the thermal desorber and then traces the off-gases through the air pollution control system.

3.2 <u>Waste Contact with Heat Transfer Surface</u>. The volatilization of the organics contaminants and water from the soil is primarily dependent upon the physical and chemical characteristics of both the soil and the organic contaminants.

3.2.1 <u>Volatilization of Organics</u>. Volatilization processes within this document are focused primarily on contaminants. Toxic metals present in contaminated material may also be volatilized and are subsequently partitioned between the treated material and the off gas. (In general, materials with toxic metals as the principal contaminants are <u>not</u> amenable to thermal desorption).

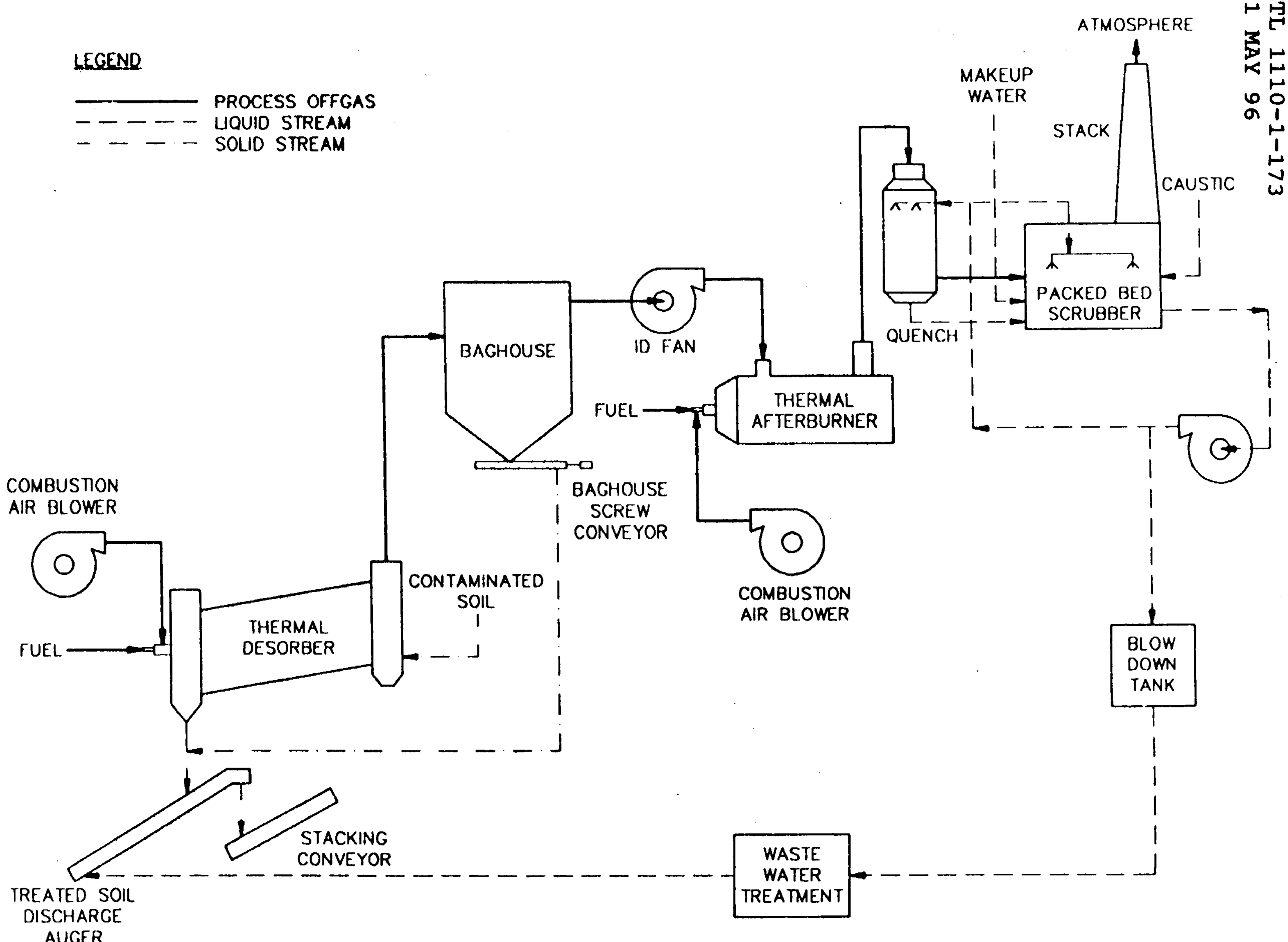


FIGURE C-3
LTVS BLOCK FLOW DIAGRAM

Volatilization of organics is dependant on the following physical and chemical characteristics:

- Soil temperature: the soil temperature is a function of the moisture content of the soil, heat capacity, particle size of the soil, and the heat transfer and mixing characteristics of the thermal desorption device.
- Exposed contact surface between soil and air or other carrier gas.
- Contaminant Characteristics: the contaminant characteristics of most importance include the vapor pressure of the organic, and the concentration of the organic in the soil.

Soil Temperature

Soil characteristics such as size, moisture and plasticity affect the desorption of contaminants from soil.

A major factor affecting the temperature of the soil is its specific heat or its thermal capacity. The moisture content tends to buffer the soil from rapid changes in temperature.

The particle size of the soil indirectly impacts the volatilization of organics. Fine-grained soil particles such as silts and clay may become entrained in the process gas and pass through a thermal desorption device without adequate residence time to allow desorption. The organics adhere to fine particles and as a result become entrained in the gas stream. This phenomenon impacts both the performance of the desorber and the air emissions. Typically, the entrained particles are recycled back through the desorber. (Brady, 1984))

Contaminant Characteristics

Table C-2 provides a list of physical and chemical characteristics and their relevance to thermal desorption. The vapor pressure of the organic constituent is a key parameter which influences the rate and temperature at which a contaminant is thermally desorbed.
The operating temperature must be below the point where combustion can occur. The combustion of organics is a function of temperature and oxygen concentration; these parameters are controlled to prevent combustion.

Vapor pressure versus temperature curves can be used to determine the operating temperature range to desorb organics. When the vapor pressure of an organic compound is equal to atmospheric pressure, the organic compound begins to boil.

Vapor pressures of organic compounds may be found in references, such as Yaws (Yaws, 1994) or calculated. The following modification of the Clausius-Clapeyron equation (Petrucci, 1982) is useful in the calculation of vapor pressure:

$$\log (P_2/P_1) = -)H_{vap}/(2.303R)*((T_2 - T_1)/(T_1T_2))$$

where: T = is expressed in Kelvin
$)h_{vap}$ = heat of vaporization expressed in Kj/mol
P = is expressed in mm Hg
R = 8.314 $Jmol^{-1}K^{-1}$

Use of this equation requires the calculation of the temperature for small changes in pressure (pressure difference 10 mm Hg or less) in order to remain accurate. The pressure and temperature at the boiling point of is known for most organics (pressure = 760 mm Hg). Therefore, the equation can be solved iteratively for T_2 for a very small difference in pressure. In the first iteration, P_2 should be equal to 750 mm Hg. The calculations are easily executed using a computer program or a spread sheet.

Another equation which can be used to generate vapor pressure vs. temperature information is Antoine's equation:

$$Ln(VP) = A - (B/(T+C))$$

where: Ln(VP) = the natural log of vapor pressure in mm Hg;
A = Antoine curve fit constant
B = Curve fit constant (in Kelvin)
C = Curve fit constant (in Kelvin)
T = temperature in kelvin.

Antoine's coefficients and other chemical/physical properties can be obtained from a standard source containing properties of gases and liquids.

Autoignition Temperature

The autoignition temperature of a substance is the temperature at which vapors ignite spontaneously from the heat of the environment. (Bodurtha, 1980) The autoignition temperature, which may be found in references such as Lange’s Handbook of Chemistry, is generally significantly higher than the boiling point. For example, peat moss and highly volatile organic materials possess low autoignition temperatures and could burn in the primary chamber of a thermal desorber.

TABLE C-2
Contaminant Characteristics

Characteristic	Reason for Potential Impact
Physical Characteristics	
Vapor pressure	Contaminant vapor pressure and contaminant removal rate increase as soil treatment temperature increases.
Boiling point	Relative indicator of degree of difficulty for volatilizing a specific compound.
Molecular weight	Boiling point temperature generally increases as molecular weight increases, therefore, molecular weight is a good indicator of the degree of difficulty of volatilizing a specific compound.
Octanol/water partition coefficient, K_{ow}	Measure of relative distribution of a chemical substance between organic and aqueous phases (< 1 mg/kg).
Soil/water partition coefficient, K	Measure of relative distribution of a chemical substance between solid and aqueous phases. A higher value of K represents a greater affinity for the soil.
Aqueous solubility	Potential for leaching soluble components into groundwater.
Autoignition temperature	Combustion of compounds if concentration in thermal desorber off gas is above lower explosive limit and sufficient oxygen is available to support combustion.

TABLE C-2 (cont)
Contaminant Characteristics

Characteristic	Reason for Potential Impact
Chemical Characteristics	
Concentration of metals or organics in TCLP extract	Untreated waste may be a RCRA hazardous material.
	Treated material may be classified as a RCRA hazardous waste and require stabilization. Most likely contaminant is lead from leaded gasoline.
Concentration of metals	Stack emissions of metals are regulated on a state by state basis. Most likely metals contaminants are lead, nickel, and vanadium. Waste lubricating oil may contain a variety of metals. Some states also have criteria for maximum allowable concentrations of metals in treated soil.
BTEX	Soil cleanup criteria established by state standards.
Sulfur	Potential air emissions of sulfur dioxide are generally insignificant. Regulated on a state-by-state basis.
Nitrogen	Concentration of nitrogen oxides in thermal desorption system stack gas are generally below 100 ppmv. Stack emissions are regulated on a state-by-state basis. NOx generation could be a concern due to nitrogen content present in contaminated material (soil) and or fuels especially in direct fire units.
Organic content of soil	Highly organic soils (e.g. loam) contribute BTUs to thermal desorption system providing stronger bonds for organic contaminants requiring higher treatment temperatures
Organic gasoline additives	Residual MTBE concentration is a cleanup parameter in some states.

TABLE C-2 (cont)
Contaminant Characteristics

Characteristic	Reason for Potential Impact
Contaminant Concentration	
Lower Explosive Limit	Maximum concentration of organics in feed material to direct fired thermal desorbers must be limited to prevent the concentration of organics in the off gas from exceeding the lower explosive limit. Maximum petroleum hydrocarbon feed concentrations for direct fired thermal desorption systems are in the range of 1 to 4 percent.
Soil treatment time and temperature.	Selection of required soil treatment temperature and residence time to meet soil cleanup criteria established by state standards.
Afterburner auxiliary fuel usage	Increasing concentration of organics in feed soil reduces afterburner auxiliary fuel requirements if an afterburner system is used. High concentrations of organics in feed soil (greater than 2 to 4 percent) may cause concentration of organics in thermal desorber exhaust gas to exceed afterburner thermal capacity.
Liquid waste disposal costs	Increasing concentration of organics in feed material increases organic liquid waste disposal costs if a condensing type off gas treatment system is used.
Source: Troxler, et al. 1993.	

Table C-3 provides boiling point, autoignition temperature and other characteristics of compounds contained in petroleum products.

Thermal desorption operating temperature is maintained below the auto ignition temperature of the organics.

This parameter could play a key role in the selection of a thermal desorption system. For example, assume that soil has been contaminated with the organics presented on Table C-3. The temperature range need to desorb the organics ranges from 0-450°C (32-838°F). The auto ignition temperature ranges from 261-562°C (502-1,044°F). Ignoring the auto ignition temperature, the operating temperature range for the desorber would be calculated using the procedure identified in the discussion on vapor pressure. At 261°C (502°F), n-hexane will burn in an oxidizing atmosphere. In order to deal with this complex waste stream, the engineer could either have multiple chambers with operating temperatures increasing or use a desorber which utilizes an inert sweep gas such as nitrogen.

Thermal desorption of a semi volatile organic compound is assisted by gas flow and can be accomplished at temperatures below boiling. Provided the partial pressure of a substance above the substrate is lower than the vapor pressure, the substance will evaporate. Rate of evaporation is slowed by operation at below boiling temperatures.

3.2.2 Application of Physical Characteristics. An initial input parameter for the thermal desorption process involves the determination of soil characteristics such as moisture content, particle size distribution and heat capacity.

The design team should develop a table containing both the boiling point and the average soil concentration data for all the organic compounds targeted for treatment. The energy required to vaporize the organics with the highest concentrations should be calculated. The first step involves determining the energy needed to heat the soil to the desired temperature.

BASIS: 1.0 kg (2.21 lb) dry soil mixed with 0.2 kg (0.44 lb) of water both initially at 20°C (68°F) is passed through a desorber. The goal is to raise the temperature of the soil to 700°C (1292°F). Specific heat of soil is 200 cal/kg°C (0.2 BTU/lb°F) and specific heat of water is 1000 cal/kg°C (1 BTU/lb°F).

TABLE C-3
Characteristics of Compounds in Petroleum Products

Compound	Formula	Molecular Weight	Boiling Point °C (°F)	Lower Explosive Limit (% Volume)	Autoignition Temperature °C (°F)
n-Butane	C_4H_{10}	58	0 (32)	1.9	405 (761)
1-Pentene	C_5H_{10}	70	30 (86)	1.5	273 (523)
Pentane	C_5H_{12}	72	36 (97)	1.4	309 (588)
Benzene	C_6H_6	78	80 (176)	1.4	562 (1,044)
n-Hexane	C_6H_{14}	86	67 (156)	1.1	261 (502)
Toluene	C_7H_8	92	111 (232)	1.4	536 (997)
o-Xylene	C_8H_{10}	106	144 (291)	1.0	464 (867)
Ethylbenzene	C_8H_{10}	106	136 (277)	1.0	432 (810)
1,2,4-Trimethylbenzene	C_9H_{12}	120	169 (336)	NA	521 (970)
Naphthalene	$C_{10}H_8$	128	218 (424)	0.9	526 (979)
1-Methylnaphthalene	$C_{11}H_{10}$	142	240 (464)	NA	528 (982)

TABLE C-3 (cont)
Characteristics of Compounds in Petroleum Products

Compound	Formula	Molecular Weight	Boiling Point °C (°F)	Lower Explosive Limit (% Volume)	Autoignition Temperature °C (°F)
1,4-Dimethylnaphthalene	$C_{12}H_{12}$	156	268 (514)	NA	NA
Phenanthrene	$C_{14}H_{10}$	178	340 (644)	NA	NA
Pyrene	$C_{16}H_{10}$	202	404 (759)	NA	NA
Triphenylene	$C_{18}H_{12}$	228	425 (797)	NA	NA
Chrysene	$C_{18}H_{12}$	228	448 (838)	NA	NA
Perylene	$C_{20}H_{12}$	252	400 (752)	NA	NA

NA - Not Available
Source (U.S. EPA, 1994)

- The energy required to raise the temperature of the soil from 20 to 100°C (68 to 212°F) is 1.0 kg (2.2 lb) dry soil x 80°C (144°F) x 200 cal/kg°C (0.2 BTU/lb°F) = 16,000 cal (63.5 BTU).

- The energy required to concurrently raise the water associated with the soil from 20 to 100°C (68 to 212°F) is 0.2 kg (0.44 lb) water x 80°C (144°F) x 1000 cal/kg°C (1 BTU/lb °F) = 16,000 cal (63.5 BTU).

- The energy required to evaporate water is 0.2 kg (0.44 lb) water x 5.4 x 10^5 cal/kg water (972 BTU/lb) = 108,000 cal (428 BTU).

- The energy required to raise the dry soil from 100 to 700°C (212 to 1292°F) is 1.0 kg (2.2 lb) x 600°C (1080°F) x 200 cal/kg°C = 120,000 cal (476 BTU).

- Thermal energy required to raise the temperature of the soil at 20% moisture from 20 to 700°C (68 to 1292°F) is 16,000 cal (63.5 BTU)+ 16,000 cal (63.5 BTU) + 108,000 cal (428 BTU) + 120,000 cal (476 BTU) = 260,000 cal (1,032 BTU).

For the relatively dry soil, nearly half of the energy is used to raise the water temperature and evaporate it. The additional energy required to evaporate the organics is inversely related to the vapor pressure and directly related to the affinity of the organic material for the soil.

This information helps determine the power requirements for the system and if the unit itself can provide the energy required to raise the soil temperature.

The maximum concentration of petroleum hydrocarbons that can be treated by a thermal desorption device is dependent on gas flow through the device, the oxygen content of the off gas, the type of hydrocarbon present, and the heat input.

3.2.3 Sweep Gas. As discussed in previous sections, the off-gases may be inert or oxidative. An example of an inert gas is nitrogen, and an example of an oxidative gas is low oxygen content combustion gas. For direct fired units, low oxygen content combustion gas is utilized. For indirect fired units, inert gases are utilized. The maximum allowable organic content of feed material is 1 to 2% organic contents (for gasoline contamination) and up to 3 to 4% for No. 6 fuel oil contamination for an oxidative thermal desorption system (US EPA, 1994). Thermal screws and other indirect fired units may operate under an inert or very low oxygen content atmosphere.

Therefore, these types of units can accept waste with up to 50% organic compounds.

3.3 Treatment Temperature. As discussed in the previous section the thermal desorption treatment temperature is a function of several parameters:

- Moisture content;
- Heat capacity of the soil;
- Particle size of the soil;
- The temperature range which the organics will desorb; and
- The heat transfer and mixing characteristics.

As the solids progress through the reactor, they are processed in the following zones:

- Warming Zone - moist soil is heated to the boiling point of water 100°C (212°F);
- Drying Zone - soil is maintained at 100°C (212°F) until the moisture has evaporated;
- Heat Up Zone - dry soil is heated from 100°C (212°F) to the target treatment temperature; and
- Holding/Treatment Zone - dry soil is processed at or above the target temperature to desorb the organic.

The energy requirement for heating soil will significantly exceed the energy requirement for solely heating the water (without evaporating it).

4. Secondary Treatment. Thermal desorption of contaminated material generates process residuals that require secondary treatment. During the heating of contaminated material, contaminants are transferred to the sweep gas, creating an off-gas which contains particulate, vaporized organic contaminants and water vapor. Particulates are removed from the off-gas prior to off-gas treatment. In addition to the particulate matter generated, a wastewater stream is generated by the water vapor present in the off-gas which condenses in the heat exchanger.

4.1 Off-Gas Particulate Removal. Particulate matter is typically the largest emission factor (by weight or volume) generated from the thermal desorption unit. The particulate matter primarily consists of fines and dust which when entrained into the sweep gas exit the desorption chamber. The particulate matter often has organic compounds adhered to its surface which require the removal of particulate matter from the organics and sweep gas. Common control devices utilized for this process include settling chambers, inertial separators (cyclones), impingement separators, wet scrubbers, fabric filters (bag houses), and electrostatic precipitators. Wet scrubbers, cyclones and baghouses, in combination or alone, are commonly used to remove particulate from the off-gas of thermal desorbers.

TM 5-815-1 Air Pollution Control Systems for Boilers and Incinerators provides guidance and procedures for selection of control equipment.

4.1.1 Inertial Separators. An inertial separator uses centrifugal force to separate large particles (greater than 15 μm) from the off gas. The smaller particles are typically removed in scrubbers and filters such as baghouses. A cyclone is the most common type of separator used for thermal desorption systems. It is a low cost inertial separator which separates particles without the use of moving parts. The performance of a cyclone separator is primarily dependant upon the particle size of the particulate. The vortex required for particle separation is created by injecting gas into the cylinder section. The particle is then propelled into the cyclone along its walls and at the point the vortex changes direction (Corbitt, 1990). The pressure drop across the cyclone is the motive force for the removal of particles from the sweep gas. Cyclone efficiency will increase with the following parameters:

- Decrease in gas viscosity (inversely proportional);
- Increase in cylinder diameter (directly proportional);
- Increase in inlet duct width or area (directly proportional); and
- Increase in density difference between gas and particulate (directly proportional).

Table C-4 provides efficiency ranges for conventional and high efficiency cyclones.

TABLE C-4
Efficiency Range for Cyclones

Particle Size Range, µm	Efficiency Range, wt % Collected	
	Conventional	"High Efficiency"
Less than 5	Less than 50	50-80
5-20	50-80	80-95
15-40	80-95	95-99
Greater than 40	95-99	95-99

Source: Stern, 1977. Air Pollution, Vol. IV Engineering Control of Air Pollution, Academic Press, NY. Ed by Arthur Stern

4.1.2 Wet Scrubbers. Wet scrubbers are collection/removal devices that wet particulate matter present in the off gas stream. The major categories of wet scrubbers include the following:

- Preformed spray scrubbers;
- Packed-bed scrubbers;
- Plate scrubbers;
- Venturi scrubbers;
- Orifice scrubbers; and
- Mechanical scrubbers.

Wet scrubbers use water sprays to wash the off gas free of particulate. The wash water (blowdown) would be incorporated into the wastewater stream (Corbitt, 1990). Scrubbers can also be used to remove acid gases from the off gas.

4.1.3 Fabric Filters. The most efficient device for removing particles is the fabric filter. Fabric filters have the capability of removing particles 0.3 µm and greater. The basic design feature of fabric filter unit consists of woven or felted fabric, usually in the form of tubes (bags) that are suspended in a housing structure or baghouse. Unlike cyclones and scrubbers, this system operates with a low pressure drop. Depending upon the contaminant levels of the particulate, the collected particulate could either be added to the treated material or reprocessed through the treatment unit. Fabric filters may be coated with lime to react with acid gases.

4.1.4 Electrostatic Precipitators. Electrostatic precipitators are particle removal devices where an electric charge is imparted to a particle by exposing it to an electrostatic field of sufficient strength (3000-6000 v/cm (5080 to 7620 v/m), overall potential 20,000 to 100,000 v). The charged particle then migrates toward the oppositely charged ground collection electrode, where the charge is neutralized. Once "collected" on the electrode, the particle falls to a collection hopper under the force of gravity. Generally particles are removed from the collection or ground electrodes using mechanical "rappers", however they can also be removed by water washing.

4.2 Off-Gas Organics Treatment. After particulate removal, off-gas can be treated by condensing the contaminants into concentrated forms, burning the organic contaminants, or use of carbon or ion exchange media bed to adsorb the contaminants. Following treatment, the off-gas can be vented to the atmosphere.

4.2.1 Vapor Ion Exchange. Regenerable ion exchange systems maybe used to concentrate the off-gas prior to thermal oxidation, condensation or recovery of valuable materials.

4.2.2 Combustion. Organic contaminants can be treated by passing the off-gas through an afterburner or thermal oxidizer.

An efficient afterburner design must provide adequate dwell or residence time for complete combustion, sufficiently high temperatures for volatile organics destruction and adequate velocities to ensure proper mixing. Catalytic afterburners operate similarly except that a catalyst is used to lower the activation energy needed for combustion so that the catalytic afterburner can operate at a lower temperature.

In afterburners, the volatile organics-laden off-gas is delivered to the refractory-lined burner area by a blower. The combustible matter is thoroughly mixed with the burner flame in the upstream portion of the chamber and then passed through the remaining portion where combustion is completed. Residence times of 0.3 to 1.0 second at temperatures ranging from 538 to 871°C (1,000 to 1,600°F) are generally required. Natural gas may be used to ignite the mixture and maintain combustion temperatures. Heat recovery efficiencies vary from 35% to 70%; destruction efficiencies from 95 to 99+%.

The catalyst in catalytic afterburners are made up of platinum and its alloys, copper chromite, copper oxide, chromium, manganese and nickel. These catalysts are deposited in layers on an inert substrate, usually honey-comb shaped ceramic. For the catalyst to be effective the active sites upon which the organic gas molecules react must be accessible. The percent LEL of the gas stream must be kept below 20% to keep the temperature below 538 to 649°C (1,000 to 1,200°F).

USACE Documents that provide additional information regarding desorption include Incinerators, General Purpose (CEGS 11181) and Remediation of Contaminated Soils and Sludges by Incineration (CEGS 02288).

4.2.3 Vapor Phase Carbon Adsorption. Contaminants in the off-gas can be collected in a vapor phase carbon adsorption system. These systems are commercially available and widely used by industry. The off-gas must be cooled, filtered and have moisture removed to below 50% relative humidity for best results prior to carbon adsorption. Data from vapor phase isotherms for the contaminants of concern is used to design and size the system. The vapor phase isotherm is the relationship between the partial pressure of the organic contaminant and the weight adsorbed by the carbon. The isotherm assumes very low moisture in the vapor phase. Vapor phase carbon systems are available in regenerable and non-regenerable units. Non regenerable units are changed in the field and the spent unit is returned to the supplier for regeneration. Regenerable units may be selected if the degree of contamination is high, and frequent changing of the carbon units is required. The type of system selected is dependant on project economics.

Note that off-gases have a relative humidity of 100% which greatly reduces efficiency and effectiveness of using carbon. Carbon capture efficiency is between 80-95%, where as combustion systems remove 95-99%.

4.3 Off-Gas Condensation. Few thermal desorption systems incorporate off-gas condensation and disposal.

Typically, in those thermal desorption systems that do condense off-gas, an inert carrier gas transports the volatilized water and organics to the off-gas handling system. The off-gases are condensed. Temperature heat exchangers are used to accomplish the condensation. The water is then separated from the organic phase. The water is sent to a wastewater treatment plant and the organics are collected and disposed offsite.

4.4 Wastewater. The wastewater generated from a thermal desorption system can be treated with conventional wastewater treatment technologies such as chemical precipitation and ion exchange for metal and inorganics removal, or carbon adsorption for organic removal and general polishing. If necessary, wastewater may require additional treatment using oil/water separation techniques such as coalescence and dissolved air flotation technologies. Since metals and organics are generally not volatile, they are not expected to be in wastewater fraction at large concentrations. Metals precipitation may be ineffective if metal concentration is low. The type of treatment is dependant upon the contaminants in the wastewater and the discharge limits either established by a regulatory agency or treatment authority (local wastewater treatment plant).

TM 5-814-3 Domestic Wastewater Treatment and TM 5-814-1 Sanitary and Industrial Wastewater Collection - Gravity Sewers and Appurtenances provide design guidance for wastewater treatment systems.

4.4.1 Liquid Phase Carbon Adsorption. Wastewater generated by the off-gas condensation process is typically treated by using a carbon adsorption process. Adsorption of organics from wastewater is a treatment technology which is now widely accepted. The acceptance in part is based on its long history of effectively removing organic contaminants from groundwater and wastewater systems.

The first consideration in the design of an activation carbon system is carbon selection. The waste water stream must be characterized, the contaminants identified, quantified, and treatment goals established. A number of activated carbons are commercially available, and selection is usually determined by laboratory or pilot testing of the particular carbon. The two most important variables in carbon system design are contact time breakthrough characteristics, and flow requirements. Breakthrough is defined as the point at which the contaminant concentration exiting the adsorber exceeds the treatment goal. Contact times may be varied by changing bed depth at constant flow, which alters the time to breakthrough and may be determined experimentally with column tests.

Downflow fixed bed absorbers are the simplest and most widely used design for water treatment application. The water enters the top of the absorber, is distributed across the packed bed, and is collected at the bottom of the vessel. The fixed bed can either be gravity or pressure driven. A fixed bed pressure absorber is usually an ASME coded steel pressure vessel with corrosion resistant lining.

Further information on carbon adsorption can be obtain from the following document(s):

EM 1110 1-501, Design Manual for Wastewater Treatment
Evaluation Criteria Guide for Water
TM 5-814-8, Evaluation Criteria Guide for Water Pollution Prevention, Control and Abatement Programs
CEGS 11215, Liquid Phase Activated Carbon Adsorption Systems

4.4.2 Precipitation. When the wastewater contains metal contaminants, precipitation or ion exchange can be employed to remove the metals from the wastewater.

Table C-5 lists the metals and the precipitation technology used to remove the metal. As indicated on Table C-5, metals can be removed from water as one of several salts. The various forms of precipitation are described briefly below. Figure C-4 shows the solubilities of selected metal ions as hydroxide or sulfide metal salts.

Hydroxide precipitation generally uses quicklime (CaO) or hydrated lime ($Ca(OH)_2$) as a source of a hydroxide ion which raises the pH of the water to the optimum pH for precipitation. This optimum pH varies with the target metal. Caustic soda (NaOH) can be used instead of lime; the reagent costs are higher, although less sludge may be generated. A general form of the hydroxide precipitation reaction is:

$$M^{n+} + n(OH^-) = M(OH)_n$$

Note that the solubility depends on the presence of chelate in the water, as well as the pH.

Carbonate precipitation generally uses sodium carbonate or calcium carbonate to convert metals into an insoluble metal carbonates. The general form of the carbonate precipitation reaction is:

$$M^{n+} + (n/2)(CO_3^=) = M(CO_3)_{n/2}$$

The treatment efficiency depends on the pH of the water. Carbonates are much less soluble than the corresponding hydroxides and as a result, lower concentrations of the target metals can be achieved in the treatment plant effluent. For certain metals (i.e., lead and cadmium), carbonate sludge has more desirable settling and dewatering characteristics than the hydroxide sludge (Patterson, 1985).

Sulfide precipitation results when a sulfide ion reacts with a metal ion to form an insoluble metal salt. A simple form of sulfide precipitation is written below:

$$M^{n+} + (n/2)(S^{=}) = Ms_{n/2}$$

Sulfides are less soluble than the corresponding hydroxides and carbonates, and lower concentrations of the target metals can be achieved in the treated water. Two processes used in sulfide precipitation are:

- Insoluble sulfide precipitation - sulfide is added as a slightly soluble iron sulfide slurry;

- Soluble sulfide precipitation - sodium sulfide or sodium hydrosulfide is added. With this process overdosing of sulfide compounds can produce toxic hydrogen sulfide gas; therefore, the reaction tanks should be covered and off gasses should be treated prior to discharge to the atmosphere.

4.4.3 Liquid Ion Exchange. Liquid ion exchange is a process of exchanging selected dissolved ionic compounds with a set of substitute ions. The exchange occurs on a synthetic or natural resin. The target compounds are removed from the wastewater through direct contact with the resin. Once the resin is saturated with the targeted ions, backwashing/ regeneration of the resin is necessary to remove these ions from the resin. Regeneration solutions generally consist of acids and bases. Hence, the waste regenerant solution will typically contain a concentrate of dissolved metals and have an undesirable pH.

Liquid ion exchange requires suspended solids kept below 50 mg/l, and total dissolved solids kept below 5000 mg/l. Iron, manganese, calcium, and high organic concentrations may permanently foul the resins. Large organic molecules may clog pore species between in the resin.

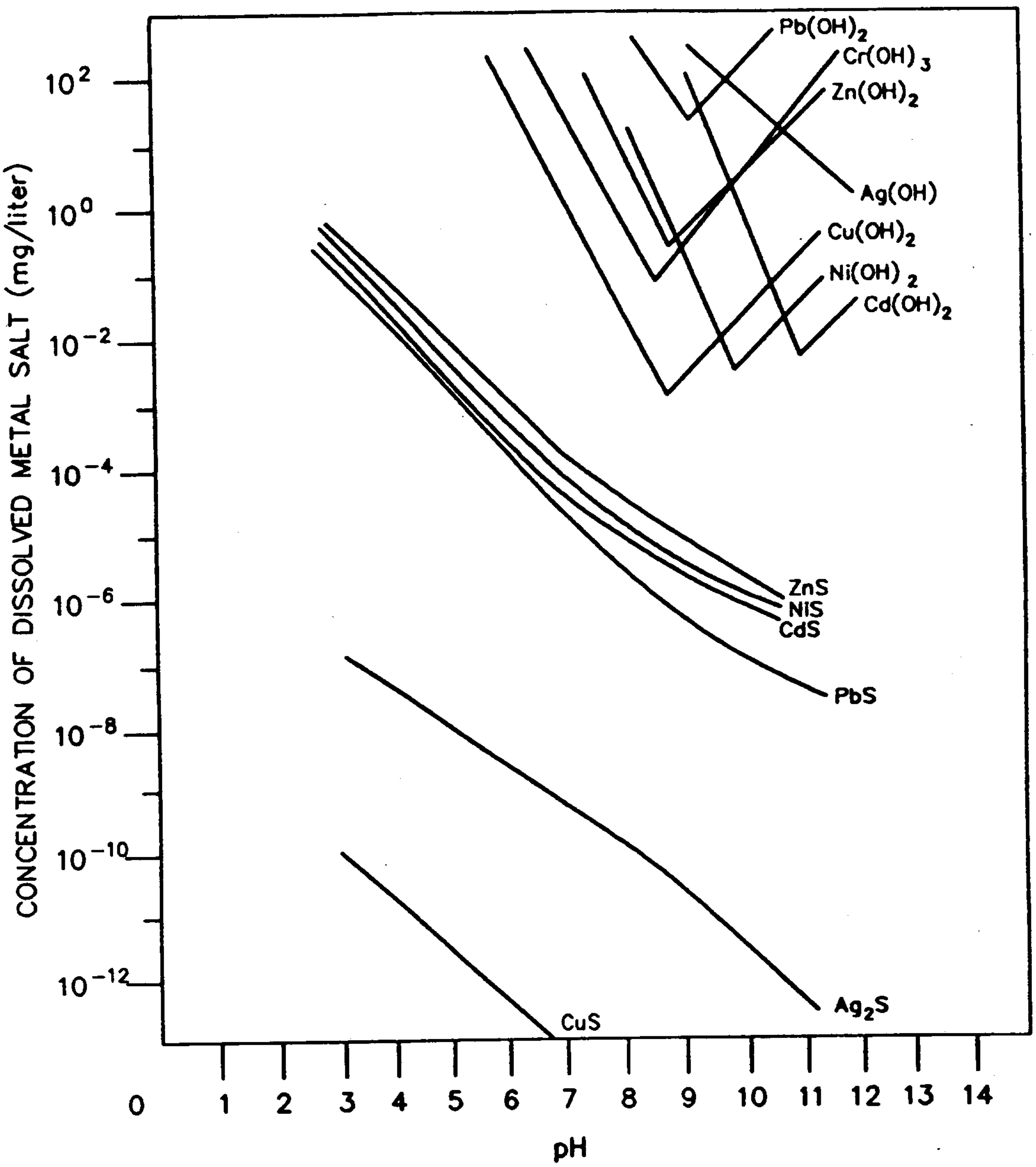
Ion exchange is an expensive water treatment technology which includes a waste stream requiring additional treatment and/or disposal. It is generally not recommended. However, if stringent discharge limits are imposed by a regulatory agency, ion exchange may be necessary to meet inorganic discharges.

TABLE C-5
Effective Types of Precipitation for Selected Metal Ions

Metal Ions	Hydroxide Precipitation	Sulfide Precipitation	Carbonate Precipitation
Antimony			
Arsenic	x	x	
Beryllium		x	T
Cadmium	x		x
Chromium	x	x	
Copper	x	x	
Lead	x	x	x
Mercury		x	
Nickel	x	x	x
Selenium			
Silver	x	T	
Thallium		T	
Zinc	x	x	T
Iron	x	x	
Manganese	x	T	

The effluent concentrations reported assumes the oxidation states of the metal ion is amenable to precipitation.
x - indicates the process is applicable for the metal ion removal.
T - indicates the process may be applicable for the metal ion removal. Bench scale or pilot studies are not available for confirmation.

Source: United States Environmental Protection Agency, CERCLA Site Discharges to POTWS Treatability Manual, USEPA 540/2-90-007, August 1990.



SOURCE:
A Handbook on Treatment of Hazardous Waste Leachate (U.S. EPA, 1988)

FIGURE C-4

SOLUBILITY DIAGRAM

5. Residual Handling.

5.1 Treated Material Handling. Treated material will be transported from the treatment unit to a treated material discharge area by a conveyor belt system. The treated material will be considered contaminated until laboratory analysis confirms that the material has been treated to within specified cleanup standards. The treated material discharge area should be designed to prevent cross-contamination. Possible cross-contamination scenarios include: storm water causing the leaching of contaminants the underlying soil, storm water runoff carrying contaminated material to the surrounding areas, and contaminated material being blown to surrounding areas by the wind. Common designs used to prevent cross-contamination implement some combination of the following; HDPE lining, concrete slabs, sumps connected to the water treatment plant, impermeable covers, berms, silt fencing and hay bales.

If laboratory analysis indicate that the treated material does not meet treatment requirement for organics, the material will be handled as contaminated and fed through the treatment unit again. The treated material discharge area would then need to be decontaminated before sending more treated material to it. The evaluation of treated material should include a review of all inorganic analyses of the waste.

Various guide specifications addressing layers and features of landfill construction. For example CEGS 02445: Solidification/Stabilization of Contaminated Material addresses further treatment that may be necessary prior to placement.

If laboratory analysis indicates that the treated materials meet cleanup standards, the treated material will be brought to the backfill area or treated material stockpile area. To allow the treatment unit to operate continuously, more than one treated material discharge area is required. While waiting for analytical results on treated material in one discharge area, the treatment unit could be discharging into another area. If the treated material fails TCLP requirements then, it may need to be treated (stabilization and/or solidification) prior to backfilling.

5.2 Particulate Dust Control System. The particulate matter both from the cyclone and the baghouse is managed based on the concentration of organics and inorganic compounds. If the particulate matter contains organics, it is then generally recycled through the unit for reprocessing. If the particulate matter removed by air pollution control equipment does not contain organic constituents, it can either be backfilled on site, treated to immobilize inorganic constituents, or disposed offsite (dependent on inorganic concentrations of particulate matter). Particulate management varies from site to site. Therefore, the evaluation of particulate management should also include a review all inorganic analyses of the waste.

5.3 Clean Off-Gas. After treatment in the thermal desorption unit, the clean off-gas is discharged to the environment.

5.4 Spent Carbon. On some projects, spent carbon units in excess of 4530 kg (10,000 lb) can be sent back to the vendor for regeneration. In the event the vendor is not capable of accepting the carbon then the carbon must be disposed at an approved facility. Typically, projects and units using less than 4530 kg (10,000 lb) canisters are not regenerated.

5.5 Ion Exchange Residuals and Backwash Water. After saturation of the ion exchange resins, backwashing/ regeneration of the resin is necessary to remove the undesirable ions from the resin. Regeneration solution generally consist of acids or bases. The regenerant is classified as a liquid hazardous waste and must be disposed of in an appropriate manner. Depending on the duration of the project, the resin may need to be changed out when regeneration is no longer effective.

5.6 Oversized Material Management. If the oversized material is hazardous a pug mill or crusher can process large stones and aggregate prior to thermal treatment. Boards, plastic, and miscellaneous debris can be decontaminated and sent to a solid waste landfill for disposal. The liquid generated and residue can be treated in the wastewater treatment plant.

If the oversize material is nonhazardous, all oversized material can be sent off-site for disposal in a solid waste landfill.

5.7 Condensate. If condensers are used to treat off gas, both concentrated contaminants and wastewater are generated. The vaporized organic contaminants are condensed. A gravity decanter or a centrifugal device facilitates separation of the condensate into water and organic phases yielding a concentrated liquid. The concentrated organic liquids are then sent to a recycler for reclamation or disposed of by incineration, typically off-site. Recycling or additional treatment is generally required prior to disposal of the water phase in a wastewater treatment plant.

APPENDIX D
THERMAL DESORPTION PREDESIGN

1. Predesign. The site investigations and decision making process to render a decision regarding the choice for treatment should be completed prior to predesign. Further evaluations may be necessary to validate the decisions and to quantify the treatment criteria for the remediation contract. Other guidance documents address the RI/FS process.

2. Technology Evaluation. Information regarding site characterization, development of remediation goals, and choosing an alternative can be found in EM 1110-2-502, CEGS 02288, CEGS 02445, EM 1110-3-176, Cooper and Alley, Cross/Tessitore and Associates, and John Pinnion. The site investigation and feasibility study are essential in determining the appropriate technology to remediate the site. The first step in the process of investigating the site is to review all records of operating procedure and disposal practices. A summary of existing site-specific and local environmental information should be prepared. The local information will be used to evaluate surface, subsurface, and atmospheric pathways for contaminant migration and risk to receptors. The regional information would also help establish background conditions which could be helpful in deriving remediation goals for the site.

Once the data has been collected and compiled, the second step in the site investigation process is to develop a plan to identify the potential constituents of concern and site investigation activities. Depending upon the level of understanding of the site, the following is a list of activities which are typically included in a site investigation.

- Safety and Health Plan;
- Sampling and Analysis Plan;
- Non intrusive geophysical investigations;
- Sampling and environmental analyses;
- Soil and water (groundwater and surface water) sampling and environmental analyses onsite, up gradient of the site, and down gradient of the site;
- Air monitoring and sampling and environmental analyses;
- Water table measurements and aquifer characteristics;
- Unsaturated subsurface soil characterization;
- Ecological reconnaissance and impact studies; and

- Baseline risk assessment and contaminant fate and transport modeling.

The ultimate goal of the site investigation is to characterize the nature and extent of site contamination.

The next step in the site investigation process is to determine through a feasibility study the most appropriate remediation option for the site. The remediation can be as simple as installing institutional controls or as complex as excavation, treatment, and disposal of contaminated media. The technology used to remediate the site is dependent upon remediation goals developed for the site. Remediation goals are typically derived from the information presented in the baseline risk assessment and/or based on established cleanup standards and guidelines.

There are generally three phases involved in developing waste management option (remediation) during the feasibility study process:

- Identification of innovative/alternative technologies;
- Identification of all technologies which can treat/dispose of the waste stream;
- Development of alternatives for site remediation (it should be noted that an alternative will include all measures and phases required to remediate the site);
- Detailed evaluation of the alternatives with respect to effectiveness, implementability, and cost.

When completing an evaluation under Superfund regulations the effectiveness evaluation is expanded to include the consideration of the following RI/FS criteria:

- Over all protection to human health and the environment;
- Compliance with all applicable or relevant and appropriate regulations;
- Long-term effectiveness of the remediation;
- Reduction of toxicity, mobility, and volume of waste through treatment; and
- Short term effectiveness.

The remaining RI/FS criteria are not germane to an "effectiveness" consideration. The design team needs to focus on the five criteria during the effectiveness evaluation. The ultimate goal of this evaluation is to select an alternative which will cost effectively remediate the site while being protective of human health and the environment.

3. Evaluation of Site Characterization Data. Once the site investigation and feasibility study has been completed, the engineer must review the data presented in the study to identify any the data gaps. This is a critical step in the process since typically 4-5 years may pass between the completion of the remedial investigation and the start of the design process. It is the responsibility of the design team to fill the data gaps in the predesign phase.

3.1 Review. The design team should endeavor to conduct an objective review of the data. In the event the evaluator determines that a thermal desorber would be unable to achieve the remediation goals, additional data would need to be gathered in order to determine an appropriate management option. Table D-1 is a summary of the minimum physical and chemical data needed for the screening of thermal desorption.

3.1.1 Site Geology. Important geological characteristics to review are the soil classification, moisture content, and contaminant concentration in the soil. As discussed in Appendix C, waste up to 5 cm (2 inches) in diameter can be processed in a thermal desorber. Soil characteristics which may adversely impact the performance of a thermal desorption system include the following:

- High percent of clay or silts: results in high levels of fugitive dust emissions during handling. This includes soils which have a high percentage of fines which pass through the No. 200 sieve (75 micron size);

- Tightly aggregated soil: resulting in incomplete volatilization of contaminants from the soil;

- Rock soil or Glacial till: Rocks fragments interfere with processing;

TABLE D-1
Physical and Chemical Data Required
to Screen Thermal Desorption System

Parameter	Method
BTU/lb (Heat Content)	ASTM D240-85
Ash	ASTM D2974
Halides (Cl, Br, F)	300.0
Sulfur	300.0
Moisture Content	ASTM D2216-80
Nitrogen, Nitrates & Nitrite-N	353.2
Phosphorus	365.3
pH	SW 846 90451 150.1/ASTM D4972
Grain Size (soil classification)	ASTM D422M
Sieve (particle classification)	ASTM D2488-84
Total Organic Carbon	SW-846 Method 9060/415.1
TCLP	SW-846 Methods 1311, (3015, 3051, 6010, 7470, 7471, for Metals) 8260, for volatiles 3550, 3510A, 8270 for semivolatiles
Ignitability	101D (flashpoint, Pensley-Martens) or 1020 (Setaflash, Closed Cup)
Reactivity, Cyanide & Sulfide	9010 and 9030
Corrosivity	9040/9045 or 1110 (Coupon Method)
Atterberg Limits/(Plasticity)	ASTM D 4318-84

Source: ASTM, 1994. Annual Book of ASTM Standards, 1994, ASTM, Philadelphia, PA.
Columbia Analytical Services, Inc., 1993. Columbia Analytical Services, Inc. (CAS).
Price List effective March 5, 1993. Anchorage, AK.

- High moisture content: As discussed in Appendix C, there is a high energy input required to volatilize water. Dewatering may be required; and

- High plasticity: Materials can stick to the screening and conveying equipment. Clays, for example, are difficult to screen crush and will stick to thermal desorption equipment. Clays can also remold into large particles. Materials with a liquid index greater than one can not be processed in a thermal desorber without pretreatment (EPA, 1994).

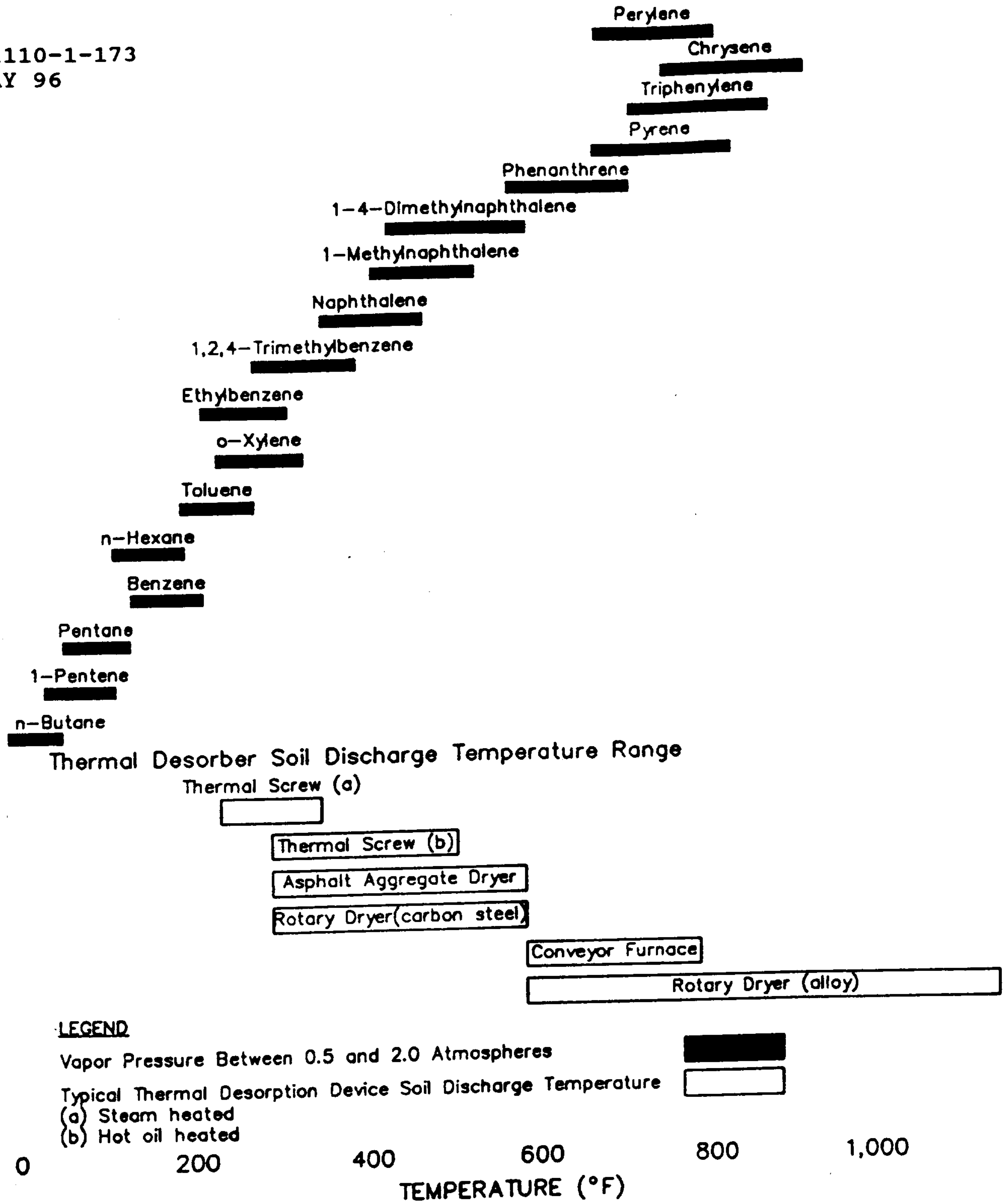
USACE Technical Manual Soils and Geology Procedures for Foundation Design of Buildings and Other Structures TM 5-818-1 provides additional information about soils and geology concerns.

3.1.2 Site Hydrogeology. The hydrogeologic conditions which can adversely impact a thermal desorption remediation process include the following:

- High water table or seasonal fluctuations of the water table;
- Subsurface clay lenses which can perch water or non-aqueous phase liquids;
- Karst terrain solution channels that can hold pockets of non-aqueous phase liquid.

These factors adversely impact the excavation and material handling of the soil. With any of the above conditions, the moisture content will generally be greater than normal (normal is considered to be 20% moisture). Pockets of non-aqueous phase liquids also can significantly increase the concentration of contaminant in the soil.

3.1.3 Contamination. Contaminants that have been desorbed and the theoretical vaporization temperature range of each are presented in Figure D-1. Table C-3 presented physical and chemical characteristics for chemicals listed in Figure D-1. Contaminated soils which are amenable to thermal desorption treatment include fine grained soils such as silts and clays,peat and most coarse grained sands. Coarse soils consisting of gravels are not amenable to treatment without prior crushing.



SOURCE:
U.S. EPA, 1994

FIGURE D-1
SOIL TREATMENT TEMPERATURES FOR SELECTED PETROLEUM HYDROCARBONS

3.1.4 Buried Materials. Excavation of buried materials (such as liners and covers from old landfills) is largely a materials handling issue. Prior to screening of soils, large debris such as rubber tires, car parts, foundations pieces would have to be separated from smaller debris in a separate staging area. 40 CFR 268.3, defines debris as solid material exceeding a 60 mm particle size that has been manufactured, or plant, or animal matter, or a natural geologic material. The large debris would be washed and, if necessary, hauled off site for disposal. Waste water would be collected and treated at the site wastewater treatment plant. Debris is considered to be hazardous waste if it exhibits toxicity characteristic for one or more of the constituents subject to U.S. EPA RCRA TCLP standards, or if it has been mixed with listed hazardous waste, or if listed hazardous waste is contained in the debris.

3.2 Supplemental Site Investigation. In situations where additional information is required to either better understand site characteristics or further delineate site contamination, supplemental site investigations may be necessary. This is particularly true if there has been a long period of time between the remediation investigation and the start of the design and/or if additional physical or chemical parameters need to be collected to confirm the thermal treatment option. Analytical data on metals is sometimes inaccurate for sites where the primary emphasis has been on organic contamination. Supplemental investigation activities generally fall into three categories:

- Identification and delineation of contaminated areas and depth of contamination;
- Additional characterization of contaminated material to establish performance criteria for thermal desorption; and
- Additional characterization of the site and contaminated material for characteristics which could interfere with, impede or reduce the effectiveness of thermal desorption remediation.

3.2.1 Identification of Supplemental Investigation Activities. The need for supplemental sampling and analysis will depend upon the data derived from the site investigation. If further delineation of the site wastes is required, sampling activities may include the following:

- Sampling to further delineate the aerial extent of contamination and establish the limits of the remediation area. Field screening can be used as a preliminary screen for contamination. A sampling grid or identification of hot spots is developed to determine where to collect environmental samples. The samples are generally collected at predetermined intervals until remediation goals are met.

- Sampling to determine the depth of contamination. Soil samples can be collected from soil borings or test pits to ascertain contamination depths in the remediation area. Samples are collected at regular and at various depths intervals until remediation goals are met or the water table is encountered (since contamination below the water table is generally considered a groundwater remediation issue).

If additional characterization of the contaminated material is needed, sampling activities will include collection of contaminated material samples to test for physical properties (moisture, grain size analyses, percent fines, etc.). Sufficient volume of representative soil samples, minimum twenty liters (five gallons), are generally collected using trowels and augers and are composited into a plastic lined 20 liter (5 gal.) pail.

3.2.2 Review of Analytical Data. Data are reviewed with regard to completeness of the package and compliance with the specified methodology. Care should be taken to note all method detection limits and to establish remediation requirements for the comparison. Some regulated sites have had remediation goals identified which were below the method detection limit. If this occurs, the EPA should be contacted to verify the method and detection limits and to discuss implementation of the remediation goals. Evaluations are performed according to project specific protocols contained in the Quality Assurance Project Plan (QAPP) incorporating the accepted analytical methods and produced in accordance with ER 1110-1-263 Chemical Data Quality Management for Hazardous Waste Remedial Activities.

3.2.3 Remediation Quantities Delineation and Estimates. Remediation quantities can be estimated by either using CADD or by hand calculations.

- Concentrations of the constituents of concern are plotted on a site plan. It is best to plot constituent concentrations for samples taken at the same depth.

- Concentrations on the site plan are compared with the remediation goals.
- Sample locations which exceeded the remediation goal are marked.
- Sample locations which are equal to and below the remediation goal are marked.
- The perimeter of the remediation site ,is established by establishing points halfway between locations above and those below the remediation goal.
- Lines that join the points to form boxes enclose areas that exceed the remediation goal. Samples that equal the remediation goal should fall near the lines.

Professional judgement will need to be exercised in areas of uncertainty. Once the areas have been enclosed, calculate the area requiring remediation. Multiply the area by the depth to obtain volumes for remediation. The volume is converted to tonnage by multiplying volume by the bulk density of the soil only when required for calculation. The material to be treated is defined by location.

Generally, classes of compounds are summarized by a single point. For example, when trying to determine the remediation area for polynuclear aromatic hydrocarbons, the toxic equivalent (developed in the risk assessment) of all the polyaromatic hydrocarbons is represented by a single number which is compared to the remediation goal. Once a supplemental investigation is completed and the site has been delineated, excavation quantities can be calculated by using CADD programs. USACE Standards Manual for U.S. Army Corps of Engineers Computer Aided Design and Drafting (USACE CADD) provides standards and procedures for use with CADD applications (EM 1110-1-1807).

In addition to using CADD applications and/or hand calculations, remediation quantities and excavation volume estimates can be determined using geostatistics coupled with three-dimensional data analysis. Geostatistics applications use measurements from one subsurface location to estimate the value at another sampled subsurface location. The correlation of two or more data location points is represented by a variogram (an equation of the graph of the expected square error of an estimate versus distance and direction). After definition of a variogram, a technique called kriging is used to estimate values at unsampled locations to produce a map of the sampled variable. The variables used in this type of geostatistical analysis include concentrations of constituents of concern and depth. Software packages are available which combine geostatistical analysis, variography and kriging for excavation estimates.

4. Identification of Data Gaps. Treatability studies are typically based upon a preliminary evaluation of soil/sediment technologies. The decision process used during the preliminary evaluation of technologies to determine the need for treatability studies consists of the following steps:

- Consider site characterization data gaps;
- Determine if the existing site data or literature is sufficient to evaluate the technology in detail;
- Determine if the site-specific data in conjunction with the available information on the technology is sufficient to determine the performance, operating parameters, and relative cost of the remedial technology; and
- Determine if a treatability study will reduce the uncertainty or risk of the use of a given technology to an acceptable level so that the best possible remedy can be selected.

Uncertainties associated with the applicability of thermal desorption include:

- The ability of the technology to reach the site-specific cleanup levels;
- Temperatures and solids retention times required to adequately treat the soils, and the energy requirements to hold and maintain these conditions;
- The impact of fine silts in the soils on the ability of the technology to adequately treat the soils;
- The moisture content of the waste;
- Removal of and potential emissions control requirements for metals;

- Impacts of high concentrations of PAH in the soils on the adequacy of treatment; and

- Because some thermal desorption technologies are non-destructive, the characteristics of the residuals, and subsequent management requirements, are uncertain.

Metals will not be adequately treated by thermal desorption. The thermal desorption process could alter the condition of the treated soils (e.g., concentrate metals) and possibly require the implementation of metals control technologies, such as stabilization of residuals.

5. Recommendations for Treatability Studies. Prior to the selection of thermal desorption as a remediation technology, treatability studies are required for the following reasons: to ensure that a selected treatment technology is applicable for waste characteristics; to ensure that cleanup goals can be obtained, and to provide data which supports the selection and implementation of the remedial alternative. Implementation of treatability studies for thermal desorption applications addresses the five RI/FS primary balancing criteria:

- Overall protection of human health and the environment;
- Compliance with applicable or relevant and appropriate requirements (ARARs);
- Implementability;
- Reduction of toxicity, mobility or volume;
- Short term effectiveness;
- Cost; and
- Effectiveness.

Appendix J includes a treatability study scope of work. Additional information required includes a description of a typical treatability unit, data to be collected from the unit, methods to analyze data, and procedures for extrapolation of this data for either the system design and or the operation of a full scale unit.

Three levels of treatability studies exist which are: remedial screening, remedial selection and remedial design. Remedial screening treatability studies establish the ability of the technology to treat a waste and typically, have a low cost ($30,000 in 1994 dollars). Remedial selection treatability studies identify technology performance for a specific site and require higher precision with increased QA/QC for sample handling and analysis. Remedial design treatability studies provide quantitative performance, cost and design information for a specific thermal desorption unit. Remedial screening treatability study tests provide the following information: temperature, treatment times, initial contaminant concentration, and treated contaminant concentration. Selection type treatability studies provide the following information: expected full scale through put, material handling system design requirements, air pollution control system design requirements, and requirements for air pollution control measures during excavation, preparation and handling (Cross/Tessitore and Associates, P.A., 1993).

Each of the three levels of treatability studies must be incorporated into both the project schedule and budget at the onset of a remediation project. Initiation and planning of treatability studies can begin as early as the site characterization phase of a project and continue through the technology screening and into the remedial design phase of a project. However, treatability studies are not required when data on similar applications of the technology is available (Cross/Tessitore and Associates, P.A., 1993).

The level of quality assurance (QA) and quality control (QC) increases accordingly throughout the treatability studies process. Since the remedial screening phase of a treatability study is concerned primarily with the ability of a technology to treat a waste, analytical requirements are focused on representative indicator parameters (such as most common contaminant or most hazardous). Remedial selection treatability study analytical requirements will require more stringent QA/QC requirements. QA/QC requirements during the remedial selection testing could require duplicate or triplicate analysis to confirm reproducibility and verification of meeting established cleanup goals (Cross/Tessitore and Associates, P.A., 1993). For more specific information regarding data quality and quality control, refer to ER 1110-1-263 Chemical Data Quality Management for Hazardous Waste Remedial Activities and CEGS 01450 Contractor Chemical Data Quality Control.

Thermal desorption treatability studies can be conducted in either a laboratory or field setting. Laboratory equipment available for laboratory treatability studies includes muffle furnace equipment and rotary quartz kiln applications. Muffle furnace equipment provide a rudimentary general determination of the ability of thermal desorption to adequately treat a specific waste stream, whereas rotary quartz kiln applications are more suitable for the remedial selection level of treatability studies. Other types of thermal desorption equipment which can be used for treatability studies include static tray tests, differential bed reactors (DBR), fixed bed reactor, rotary kiln simulators which depending on site specific concerns, could be used for on-site pilot scale demonstrations (Cross/Tessitore and Associates, P.A., 1993).

Typically, the treatability study objective determines the sampling and analysis requirements during a thermal desorption treatability study. Prior to any treatability study activity, a site specific sampling plan consisting of sample location, depth, collection technique and homogenization procedures should be in place. Treatability sampling of identified hot spots is typical if the treatability study is focused on testing the technology ability to handle worst case contaminant concentrations. Composite samples (average samples for an entire site) are collected when the test objective is determine the ability of the technology to treat a representative homogenous waste (Cross/Tessitore and Associates, P.A., 1993).

Treatability studies are primarily conducted to reduce the uncertainties discussed in the previous paragraph. Typically testing can be performed by using bench scale or pilot scale techniques. Bench scale testing is usually performed in a laboratory, in which comparatively small volumes of contaminated material are tested for individual parameters. Presented below is a description of different types of treatability studies.

5.1 Bench Scale Tests. Thermal desorption bench-scale data is generally used to establish the viability of the technology to treat various contaminated materials. The data will also provide some approximate cost information and operating conditions for the technology. Positive bench scale test results indicate that a technology is feasible, subject to scale-up and materials handling limitations. Negative results are generally inconclusive; Additional pilot scale testing is generally necessary to confirm a technology's effectiveness and/or provide design data if it is selected for implementation.

Typical goals of the bench scale treatability study would be to:

- Make an initial determination of the ability of the technology to reduce concentrations under site-specific conditions;

- Provide initial input into the determination of energy and utilities requirements for full scale operations; and

- Provide initial input into system design parameters, such as required solids retention times and temperatures, thereby making possible estimates of treatment rates and clean-up cost estimates.

The results of these tests should establish the effectiveness of thermal treatment to reduce concentrations of the contaminants in the soil under laboratory conditions and the likely operating conditions necessary to achieve this removal.

Bench scale test equipment used for thermal desorption include a muffle furnace, or rotary quartz kiln/tube. Conceptually, small quantities of the soil samples will be exposed to a contaminated material of temperature and residence times in a rotary quartz kiln tube or muffle furnace. These temperatures and residence times represent operational range typical of commercial thermal desorption systems. Treated soils will then be analyzed to determine the effectiveness of the treatment. Parameters to be determined in comparing treated versus untreated soils would be:

- Concentrations of individual contaminants; and
- Loss of total organics.

Rotary quartz tube kilns are also used as bench scale devices for thermal desorption applications. This system utilizes a rotary batch quartz kiln, a drive motor, and temperature controls. Soil samples are placed into a rotating quartz kiln while the temperature of the medium is uniformly maintained by a temperature control system. Process gases generated from thermal desorption unit processes are passed to a thermal oxidation unit, condensers or a carbon adsorption column. Data such as temperature, retention time, system pressure and process gas composition can be monitored and recorded during bench scale testing (Hazen Research Inc.,1994).

Advantages of using rotary quartz tube kiln devices for thermal desorption bench scale testing include the following: simulation of soil mixing and system turbulence (found in rotary dryer applications); measurable, controllable and recordable temperatures and retention times throughout testing; and process gas composition and emissions can be determined and analyzed (Quinn Process Equipment, 1994).

Muffle furnace devices used for bench scale testing offer significant initial cost advantages (the cost of muffle furnace equipment(~$2000-3000 in 1994 dollars) is significantly cheaper than a rotary quartz tube kiln system (~$17000 to 20000 in 1994 dollars), however data generated from a rotary quartz kiln test is typically more complete and representative of full scale treatment, allowing for better estimates of treatment costs, times and temperatures.

5.2 Pilot Scale Tests. Pilot scale tests are intended to simulate the physical and chemical parameters of a full scale process. The volume of soil required for a pilot scale unit is much greater than that for a bench scale tests. Pilot scale tests are intended to serve as a practical testing approach for full scale operation.

Pilot units operate in a manner as similar as possible to the operation of a full scale system. Most contractors of thermal desorption units have pilot scale systems which are used to determine the design and operation criteria for a successful system operation. Examples of information provided from pilot scale testing include:

- Effects of mixing on the system;
- Off-gas emissions expected from the system; and
- Actual power requirements for the system.

The Waterways Experiment Station (WES) has a pilot scale thermal screw that may be available.

6. Treatability Test Run. A treatability test run utilizing a rotating quartz kiln system can substantiate the selection of thermal desorption as the remediation process. Results of a treatability test run can include information regarding materials handling, feed systems, temperature, retention time, system pressure, and process gas composition. A rotary quartz kiln system allows for the soil sample temperature to remain uniform. Process gases exit the kiln to either a thermal oxidation unit, condensers or a carbon adsorption column for decomposition or collection of vaporized contaminants.

6.1 Treatment Temperature. As discussed in the previous paragraph, the thermal desorption treatment temperature is a function of several parameters:

- Particle size of the soil;
- Moisture content;
- Heat capacity of the soil;
- The temperature range which the organics will

desorb; and
- The heat transfer and mixing characteristics.

As the solids progress through the reactor, they are processed in the follow zones:

- Warming Zone - soil is heated to the boiling point of water 100°C (212°F);
- Drying Zone - soil is maintained at 100°C (212°F) until the moisture has evaporated;
- Heat Up Zone - soil is heated from 100°C (212°F) to the target treatment temperature; and
- Holding/Treatment Zone - soil is processed at or above the target temperature to desorb the organic.

It is important to remember that the energy required to heat the soil will be substantially greater than heating only the water (without evaporating it) contained in the soil.

6.2 Residence Time. Residence time for soils in a thermal desorber system is a function of the shape of the treatment unit, rotational speed of the soil conveyor (shell or auger) and the angle of the treatment unit (U.S. EPA, 1994, EPA/540-594/501). Typically, soil residence times range from 3 minutes to over an hour (U.S. EPA, 1994, Troxler, et. al., 1993). Based upon results generated from treatability studies, information such as time of treatment and corresponding temperature to meet clean up levels for particular contaminant(s) can be included in the contract specifications.

6.3 Organic Removal Efficiencies. Organic removal efficiencies of the thermal desorption test run are calculated using the following equation:

Organic Removal Efficiency (%) =

$$1- \frac{\text{(Organic Concentration after Treatment)}}{\text{(Initial Organic Concentration before treatment)}} \times 100\%$$

where organic concentrations are expressed as a dry weight basis.

Removal efficiencies are typically greater at high temperatures; at low temperatures, removal efficiency is dependent on the volatility of the organic compound.

Residence times required are also reduced at higher temperatures.

6.4 Corrosive Effects on Selected System. Corrosive effects on a selected thermal desorption system are dependent on the type of purge gas used (oxidative or inert), on the type of thermal desorption system utilized (direct fire or thermal screw), and on the contaminants present in the soil.

Typically, combustion gas from the burner of a direct fire unit serves as a purge gas. The allowable organic content of the soil in a direct fire system is limited due to the excess oxygen contained in the purge gas and the potential of supporting combustion within the unit. Thermal screw systems operating with an inert gas such as nitrogen can treat soils and sludges with higher organic concentrations due to limited presence of oxygen to support combustion.

Contaminated materials containing chlorinated and fluorinated hydrocarbon as contaminants can create hydrochloric and hydrofluoric acids during treatment. The acids will develop because of the volatilization of sulfides, chlorides and fluorides and evaporation of soil moisture in the unit causing corrosive damage to the carbon steel structures present within the treatment unit.

6.5 Energy Input Required. Energy input required for a thermal treatment desorption treatability test run is energy required to heat the thermal device used to simulate thermal desorption unit (oven, furnace, incinerator, asphalt mixing plant) and energy requirement for the off gas collection device (hood, vent, vacuum). Power requirements for hoods and vents comprising the off gas collection device are directly related to the product of the fluid pressure loss multiplied by the volumetric flow rate for the system in watts (ft-lb/min). The relationship is valid provided the volumetric flow rate and pressure loss are determined at the same conditions within the off gas collection device. Fans provide required energy to move gas and air through the hoods of the collection system. Fan performance is indicated on "fan curves" which identify the relationships between airflow, static pressure delivered, mechanical efficiency, and brake horsepower (Cooper and Alley, 1986).

Energy input required for a full scale thermal desorption treatment system is a function of operating temperature, retention time, type of system (direct fire, indirect fire, or thermal screw) and the extent of air pollution control/emissions equipment present on a full scale system.

6.6 Suitability of Treated Materials for Backfill or Disposal Purposes. The use of thermally treated materials for backfill purposes is primarily a function of the material characteristics, specifically, in the case of soils, the USCS Soil Classification and moisture content. The most suitable soil type for use as backfill would be those coarse grained soils (SW, SP, SM, SC) with low moisture content because of minimal pretreatment requirements and good heat transfer characteristics. Materials not suitable for backfill would be fine grained soils ML, OH, MH, CL, and Pt. These materials would reduce system capacity due to particulate carry over (U.S. EPA, 1994a).

Specifics regarding suitability of soils for desorption, backfill operations, USCS Soil Classification, and soils stabilization/solidification can be found in the following Army Corps of Engineers Documents:

CEGS 02228 Remediation of Contaminated Soils and Sludges by Incineration
CEGS 02445 Solidification/Stabilization of Contaminated Material
ETL 1110-1-158 Treatability Studies for Solidification/Stabilization of Contaminated Material
TM 5-818-1 Soils and Geology Procedures for Foundation Design of Buildings and Other Structures (except Hydraulic Structures)
TM 5-818-4 Backfill for Subsurface Structures

6.7 Presence of Volatile Metals. Volatile metals such as arsenic, mercury and lead may be removed from the soils during thermal desorption treatability test run. Recovered particulate and organics from a treatability test run can contain elevated concentrations of volatile metals such as mercury, arsenic and lead. The treated soils may contain concentrated levels of metals due in part to the volume loss as a result of volatilized organics. Soil treatment may increase the leachability of metals and the potential for failure of the toxic characteristic leachate procedure (TCLP) analysis.

APPENDIX E
DESIGN AND PERFORMANCE CRITERIA

1. Pretreatment. As discussed in Appendix C, pretreatment essentially includes two categories:

- Dewatering
- Particle size adjustment

1.1 Particle Size Adjustment. A variety of size-reduction equipment is available. In general, size reduction equipment can be classified into the way in which forces are applied, as follows:

- force applied between two surfaces as in crushing and shearing;
- force applied only on one surface (impact);
- non-mechanical size reduction (thermal shock, explosive shattering).

Table E-1 shows a practical classification of crushing and grinding equipment. Selection of the appropriate equipment is based on feed size and hardness and is summarized on Table E-2. Additional information on particle adjustment can be found in Perry's Chemical Engineers' Handbook (sixth edition, Perry, 1984).

1.2 Dewatering.

1.2.1 Belt Filter Presses. Belt filter presses are the most common devices used for dewatering sludges. A typical belt filter press dewatering system consists of sludge feed pumps, polymer feed equipment, a sludge conditioning tank, belt filter press, sludge cake conveyor, and support pumps. Several parameters affect the performance of belt filter presses, including:

- Sludge characteristics (includes viscosity, specific gravity, and % weight moisture);
- Unit differential pressure;
- Machine configuration;
- Belt porosity, speed and width.

Belt filter presses are available in sizes from 0.5 to 3.5 m (1.5 to 12 ft.) in belt width. Sludge-loadings rates vary from 90 to 680 kg per meter of belt with per hour (60 to 450 lb per foot of belt per hour) depending on the sludge type and feed concentration. Hydraulic throughput based on belt widths ranges from 1.6 to 6.3 L/m s (7.7 to 30 gal/ft min). Safety

TABLE E-1
Types of Size-Reduction Equipment

A.	Jaw crushers: 1. Blake 2. Overhead eccentric 3. Dodge
B.	Gyratory crushers: 1. Primary 2. Secondary 3. Cone
C.	Heavy-duty impact mills: 1. Rotor breakers 2. Hammer mills 3. Cage impactors
D.	Roll crushers: 1. Smooth rolls (double) 2. Toothed rolls (single and double)
E.	Dry pans and chaser mills
F.	Shredders: 1. Toothed shredders 2. Cage disintegrators 3. Disk mills
G.	Rotary cutters and dicers
H.	Media mills: 1. Ball, pebble, rod, and compartment mills: a. Batch b. Continuous 2. Autogenous tumbling mills 3. Stirred ball and sand mills 4. Vibratory mills
I.	Medium peripheral-speed mills: 1. Ring-roll and bowl mills 2. Roll mills, cereal type 3. Roll mills, paint and rubber types 4. Buhrstones
J.	High-peripheral-speed mills: 1. Fine-grinding hammer mills 2. Pin mills 3. Colloid mills 4. Wood-pulp beaters
K.	Fluid-energy superfine mills: 1. Centrifugal jet 2. Opposed jet 3. Jet with anvil

Source: Perry's Chemical Engineers Handbook, 6th ed.

TABLE E-2
Guide to Selection of Crushing and Grinding Equipment

Size Reduction Operation	Hardness of Material	Size: Range of Feeds cm (in.) Max.	Size: Range of Feeds cm (in.) Min.	Size: Range of Products cm (in) Max.	Size: Range of Products cm (in) Min.	Reduction Ratio	Types of Equipment
Crushing							
Primary	Hard	150 (60) 50 (20)	30 (12) 10 (4)	50 (20) 13 (5)	10 (4) 2.5 (1)	3 to 1	A to D
Secondary	Hard	13 (5) 4 (1.5)	2.5 (1) 0.6 (0.25)	2.5 (1) 0.5 (0.19)	0.5 (0.2) 0.1 (0.03)	5 to 1	A to F
	Soft	50 (20)	10 (4)	5 (2)	1 (0.4)	10 to 1	C to G
Grinding Pulverizing							
Coarse	Hard	0.5 (0.19)	0.1 (0.03)	0.006 (0.02)	0.008 (0.003)	10 to 1	D to I
Fine	Hard	0.12 (0.05)	0.015 (0.006)	0.008 (0.003)	0.01 (0.0004)	15 to 1	H to K
Disintegration							
Coarse	Soft	1.3 (0.5)	0.17 (0.07)	0.057 (0.02)	0.008 (0.003)	20 to 1	F, I
Fine	Soft	0.4 (0.16)	0.05 (0.02)	0.008 (0.003)	0.001 (0.0004)	50 to 1	I to K

* 85%by weight smaller than the size given.
Source : Perry's Cheical Engineers Handbook, 6th ed.
Values have been rounded and metric equivalents added.

considerations which should be addressed in the design include adequate ventilation and to prevent loose clothing from being caught between rollers (Metcalf and Eddy, 1991). Caution should be exercised in sizing the filter or any other equipment based on a municipal sludge application since this is an industrial waste application and may not produce a waste stream with characteristics similar to municipal sludge. Table E-3 shows the advantages and disadvantages of belt filter presses.

1.2.2 Plate and Frame Press. Plate and frame press advantages and disadvantages are listed on Table E-4 (Perry, 1984).

1.2.3 Sand Drying Beds. Sand drying beds are constructed of with fine to coarse-graded sand and gravel layers which cover an open-joint pipe drainage system. Figure E-1 is an example of a type of drying bed layer system. Table E-5 lists the design advantages and disadvantages of using drying beds. Table E-6 presents typical design criteria for drying beds.

2. Unit Design Criteria.

2.1 Feed Storage and Conveyance. Feed storage and conveyance are integral components of the thermal desorption system materials handling operation. Feed hoppers are used to collect and store contaminated materials for feeding into the thermal desorption unit. Conveyor systems are used to transport solids into and out of the desorption unit.

2.2 Feed Hopper Systems. Feed hopper systems are generally used with mobile construction equipment such as front end loaders and bulldozers to load and temporarily store contaminated materials for conveyance into the thermal desorption unit. Surge hoppers may also be installed at the desorption inlet and used with a conveyor to feed material into the desorption.

Feed hopper components are generally commercially available as preengineered units. The choice of a proper feed hopper system involves consideration of many factors that are to be considered when choosing a conveyor system. Material properties such as particle size, moisture content and temperature are important because they affect the ability of a material to flow and hence the geometry and configuration of the hopper system. Volumetric capacities of the hoppers must be sufficient to accommodate the throughput capacities of the conveyor system and thermal desorption unit.

Components may be added to feed hoppers to assist and control flow from the hopper to the conveyor system or process equipment. Slide gates are available in both manual and automated designs. Bin vibrators and vibrating bottoms may eliminate material

TABLE E-3
Advantages and Disadvantages of
Belt Filter Presses

BELT FILTER PRESS After chemical conditioning, the sludge is deposited onto the moving belt. The readily drainable water is removed in the gravity drainage section. Pressure is applied to the cake, squeezing it between the two belts, and the cake is subjected to flexing in opposite directions as it passes over the various rollers. This action causes increased water release and allows greater compaction of the sludge.	
Advantages	Disadvantages
High pressure machines are capable of producing drier cake than any machine except a filter press	Very sensitive to incoming feed characteristics and chemical conditioning
Low power requirements	Machines hydraulically limited in throughput
Low noise and vibration	Short media (belt) life as compared with other devices using cloth media
Operation is easy to understand for an inexperienced operator because all parts are visible and results of operational changes are quickly and readily apparent	Wash water requirements for belt spraying can be significant
Process controls can be adjusted for optimum dewatering of a variety of sludge types	Frequent washdown of area around press required
Continuous operation	Can emit noticeable odors if the sludge is poorly stabilized

TABLE E-3 (cont)
Advantages and Disadvantages of
Belt Filter Presses

Advantages	Disadvantages
Media life can be extended when applying low belt tension	Requires greater operator attention than a centrifuge
	Condition and adjustment of scraper blades is a critical parameter that should be checked frequently
	Probably requires a chemical polymer system in order to work well, and typically requires greater polymer dosage than a centrifuge
	Requires a skilled operator
Source: Perry's Chemical Engineers Handbook, 6th ed.	

feeders, when mounted below feed hoppers, serve as effective devices for metering material to the conveyor or desorption. Selection of some common feeder types on the basis of material characterization is summarized in Table E-7. Feed hoppers may also be equipped with weigh scales or sensors to measure the weight of the material fed.

TABLE E-4
Advantages and Disadvantages of
Plate and Frame Filter Presses

<table>
<tr><td colspan="2"><u>PLATE AND FRAME FILTER PRESS</u>

A filter cloth is mounted over the two surfaces of each filter plate. Conditioned sludge is pumped into the filter press and passes through holes in the filter plates along the length of the filter and into the chambers. As the sludge cake forms and builds up in the chamber, the pressure gradually increases to a point at which further sludge injection would be counter-productive. The pressure is maintained for a one- to four-hour period, during which more filtrate is removed and the desired cake solids content is achieved. The filter is then mechanically opened, and the dewatered cake dropped from the chambers for removal.</td></tr>
<tr><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td>Filter presses yield higher cake solids concentration than any other class of dewatering technology</td><td>Large quantities of inorganic conditioning chemicals are commonly used for filter presses</td></tr>
<tr><td>Can dewater hard-to-dewater sludges, although very high chemical conditioning dosages or thermal conditioning may be required</td><td>Polymer alone is generally not used for conditioning due to problems with cake release and blinding of filter media</td></tr>
<tr><td>Very high solids capture</td><td>Presses are large and complex</td></tr>
<tr><td>Only mechanical device capable of producing a cake dry enough to meet landfill requirements in some locations</td><td>High capital cost especially for diaphragm filter presses</td></tr>
<tr><td>Does not require a skilled operator</td><td>Labor cost may be high if sludge is poorly conditioned and if press is not automatic</td></tr>
<tr><td></td><td>Replacement of the media is both expensive and time consuming</td></tr>
<tr><td></td><td>Noise levels caused by feed pumps can be very high</td></tr>
</table>

TABLE E-4 (cont)
Advantages and Disadvantages of
Plate and Frame Filter Presses

Advantages	Disadvantages
	Use of precoat and filtration aids result in more sludge for disposal
	Batch operation
	Large area requirements
Source: Perry's Chemical Engineers Handbook, 6th ed.	

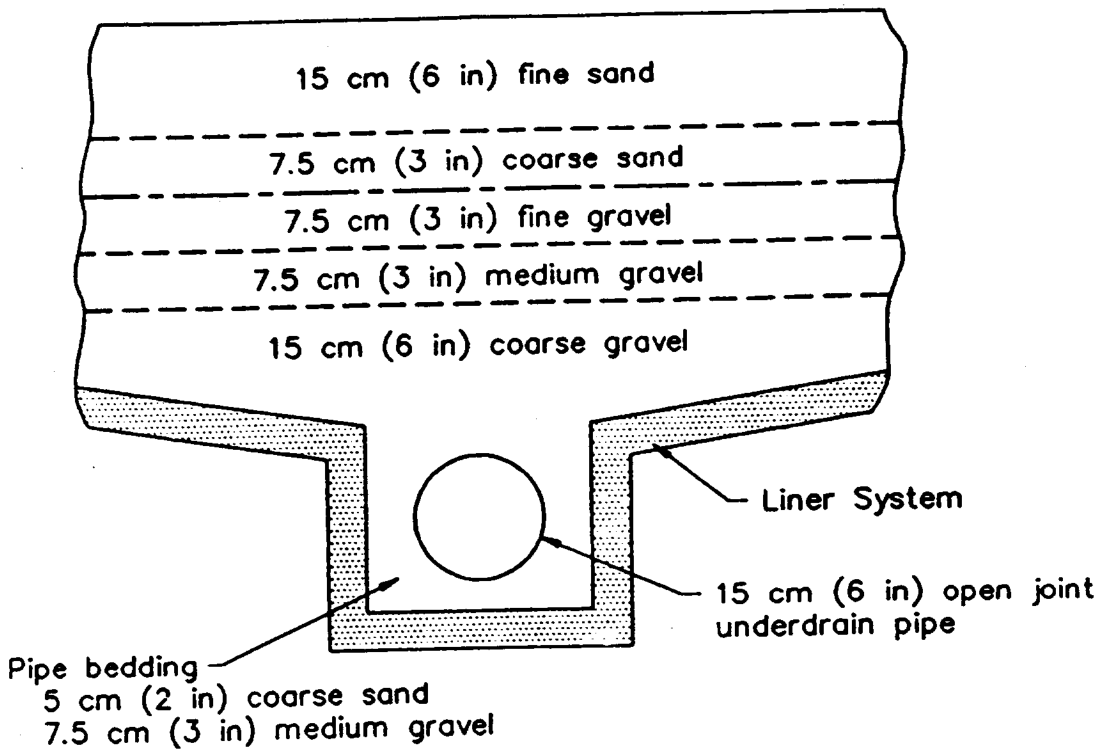


FIGURE E-1

SAND DRYING BED

TABLE E-5
Advantages and Disadvantages of Sand Drying Beds

Advantages	Disadvantages
Low capital cost (excluding land)	Weather conditions such as rainfall and freezing weather have an impact on usefulness
Low operational labor and skill requirement	
Low energy	Requires large land areas
Low maintenance material cost	High labor requirement for sludge removal
Little or no chemicals required	May be aesthetically unpleasing, depending on location
High cake solids content possible	Potential odor problem with poorly stabilized sludge
Source: Standard Handbook of Environmental Engineering by Robert A. Corbitt, McGraw Hill 1990.	

TABLE E-6
Sand Drying Bed Design Data

Parameter	Typical Value
Minimum number	Two
Shape	Rectangular
Length	6-12 m (20-200 ft)
Width	96 m (20 ft)
Sand layer Depth Effective size Uniformity coefficient	 23 cm (9 in) 0.3-1.0 mm Less than 4.0
Gravel layer Depth Grading	 30 cm (12 in) 3.2-25 mm (0.12-1 in)
Underdrain system Pipe size Spacing Slope	 10 cm (4 in) minimum Less than 6.1 m (20 ft) 1%
Freeboard above sand	30-45 cm (12-18 in)
Area requirements Open Covered	 0.09-0.18 m^2/cap (1-2 ft^2/cap) 0.06-0.13 m^2/cap (0.7-1.5 ft^2/cap)
Application depth	20-30 cm (8-12 in)

Source:Standard Handbook of Environmental Engineering, by Robert A. Corbitt, McGraw Hill, 1990.

2.1.2 Conveyor Systems. Pre-engineered conveyor system components are commercially available in a variety of standardized designs. The common conveyor types used in thermal desorption systems are screw auger and belt type conveyors. Dragline conveyors are also used on some systems.

Selection of a conveyor suitable for the material to be handled in a specific application involves the consideration of many factors. Listed below are several important design considerations in choosing a conveyor system:

- Capacity- System throughput requirements may determine the type of conveyor utilized. Belt type conveyors because of their larger size and higher operating speeds are capable of transporting larger quantities of material then screw type feeders. Screw conveyors are available with capacities up to 283 m^3 (10,000 cubic feet) per hour. Belt conveyors can transport up to 142 m^3 (5,000 tons per hour) (Perry, 1984).

- Material Properties- The physical and chemical characteristics of the material to be handled may dictate conveyor type and/or materials of construction. Aggregate size, abrasiveness, corrosion effects, resistance to flow, density, temperature and moisture content are several key material characteristics to consider in choosing a conveyor.

- Length- The length of travel may limit the choice of certain types of conveyors. Belt and screw conveyors are capable of relatively longer travel lengths than pneumatic or vibrating conveyors.

- Lift- Belt and screw type conveyors generally can be arranged to accommodate the vertical travel required in the design of thermal desorption systems. Where only vertical travel is required, bucket elevators or specially designed screw conveyors may be considered.

- Special Processing Requirements- Screw conveyors are particularly adaptable to a variety of processing operations such as heating, cooling, mixing, dewatering, and the transport of sticky and wet materials. Screw conveyors are susceptible to jamming if oversize material is fed into the conveyor.

Selection of common conveyor types on the basis of function is provided in Table E-8. Auxiliary equipment can be added to conveyor systems to satisfy particular requirements. Both electrical and mechanical type torque limiting devices are available to prevent overloads due to jamming. Weigh scales or load cells can be installed to weigh material transported into or out of the desorption unit. Cleaning devices are available to help alleviate problems associated with sticky or non flowing materials. Safety cut off devices such as pull cords may be installed. Screw conveyors may be enclosed or the conveyor equipped with emissions control devices in applications involving transport of materials having a large amount of air borne particulates. Table E-7 provided a general guide to conveyor selection. Table E-8 provides information on feeder selection. Table E-9 provides a material classification coded list.

2.2 Desorption Design/Performance Evaluation Criteria.

To specify an appropriate desorption unit, the designer needs to specify the following design and performance criteria:

- Treatability study results;
- Material throughput capacity kg/hr (lb/hr);
- Characterization of feed stock (type, moisture criteria, organic criteria); and
- Remediation requirements.

Using the above information, desorption efficiency parameters can be developed. These critical parameters include:

- system operating temperature for the primary desorption chamber;
- turbulence induced in the primary chamber;
- solids retention time at the desorption temperature; and
- sweep gas flows through the primary chamber.

While some wide ranges for these parameters are provided in this document (see Table C-2), the specific application will require site-specific data to determine adequate values for each. In some cases, these parameters cannot be monitored directly, and less-than-full scale treatability studies or full scale demonstration tests should be used to determine values for indirect measurement that provide an indicator of adequate performance.

For instance, although monitoring the temperature of treatment effluents (e.g., treated soils) is recommended and desirable for monitoring temperature of the treatment system, this is not currently possible. Research in use of color pyrometers indicates that monitoring solids temperature may be possible in the near future. This requires the measurement of another parameter (e.g., kiln wall temperature or gas temperature). In this case, a pilot or full scale study is

TABLE E-7
Conveyors for Bulk Materials*

Function	Conveyor Type
Conveying materials horizontally	Apron, belt, continuous flow, drag flight, screw, vibrating, bucket, pivoted bucket, air
Conveying materials up or down an incline	Apron, belt, continuous flow, flight, screw, skip hoist, air
Elevating materials	Bucket elevator, continuous flow, skip hoist, air
Handling materials over a combination horizontal and vertical path	Continuous flow, gravity-discharge bucket, pivoted bucket, air
Distributing materials to or collecting materials from bins, bunkers, etc.	Belt, flight, screw, continuous flow, gravity-discharge bucket, pivoted bucket, air
Removing materials from rail cars, trucks, etc.	Car dumper, grain-car unloader, car shaker, power shovel, air

*From FMC Corporation, Material Handling Systems Division.
Source: Perry's Chemical Engineers Handbook, 6th ed.

TABLE E-8
Feeders for Bulk Materials*

Material Characteristics	Feeder Type
Fine, free-flowing materials	Bar flight, belt, oscillating or vibrating, rotary vane, screw
Non-abrasive and granular materials, materials with some lumps	Apron, bar flight, belt, oscillating or vibrating, reciprocating, rotary plate, screw
Materials difficult to handle because of being hot, abrasive, lumpy, or stringy	Apron, bar flight, belt, oscillating or vibrating, reciprocating
Heavy, lumpy, or abrasive materials similar to pit-run stone and ore	Apron, oscillating or vibrating, reciprocating

*From FMC Corporation, Material Handling Systems Division.
Source: Perry's Chemical Engineers Handbook, 6th ed.

TABLE E-9
Classification System for Bulk Solids*

Material Characteristics		**Class**
Size	Very fine - <149μm (100 mesh)	A
	Fine - 149μm to 3.18 mm (100 mesh to ⅛ in)	B
	Granular - 3.18 to 12.7 mm (⅛ to ½ in)	C
	Lumpy-containing lumps >12.7 mm (½ in)	D
	Irregular - being fibrous, stringy, or the like	H
Flowability	Very free-flowing - angle of repose up to 30°	1
	Free-flowing - angle of repose 30 to 45°	2
	Sluggish - angle of repose 45° and up	3
Abrasiveness	Nonabrasive	6
	Mildly abrasive	7
	Very abrasive	8
Special characteristics	Contaminable, affecting use or salability	K
	Hygroscopic	L
	Highly corrosive	N
	Mildly corrosive	P
	Gives off dust or fumes harmful to life	R

recommended to define the adequate temperature ranges for the applicable parameter. Information regarding treatability studies is provided in Section D.5 of Appendix D.

Each of the four parameters and its effect on desorption efficiency is discussed briefly below.

2.2.1 Temperature. A key parameter in ensuring the required material desorption is achieving material temperature. Material temperatures are always associated with a material treatment time. The parameters are dependent on each other for any discussion of thermal desorption. As the concentration of organic increases, the treatment time and/or temperature required to meet the cleanup requirement increases. The optimal temperature for desorption should be determined through previous treatability testing, and operation temperatures can be measured at one of three points:

- The soil discharge temperature, generally in the range of 150-650°C (300-1200°F). Some systems may have problems in monitoring this parameter since measuring a flowing solids temperature on a continuous basis is not presently possible.

- Kiln or dryer wall temperature, generally in the range of 150-650°C (300 to 1200°F). This provides an indirect means of measuring the solids temperature on a continuous basis, however, because the measurement is indirect, the assumption must be made that the thermal transfer to the soils is adequate for volatilization. Again, the data gathered during a demonstration or smaller scale treatability test should be used for determining the optimal temperature for an indirect measurement.

- Off gas temperature, generally 150-760°C (300-1400°F). As with monitoring temperature of the desorption device itself, monitoring off gas temperature provides an indirect means of measuring the solids temperature on a continuous basis, making the same assumption on energy transfer. The data gathered during a demonstration or smaller scale treatability test should be used for determining the optimal temperature for an indirect measurement.

The thermal desorption system should be monitored for malfunction (e.g., inadequate auxiliary firing, poor heat transfer due to fouling, excess sweep air flow) and the waste feed adjusted accordingly. Should excessive temperatures be detected by the system controls processing should cease to protect equipment.

2.2.2 Turbulence. Turbulence of the media in the primary chamber impacts volatilization of the contaminants through two mechanisms:

- By increasing contact time of each particle of the media with the heated portions of the primary chamber, thereby enhancing transfer of thermal energy to the media.

- By increasing contact time of each particle of the media with the sweep gas, both increasing heat transfer from the gas to the media and driving the vapor phase/adsorbed phase equilibrium towards the vapor phase.

In rotary dryer/rotary kiln type systems, the movement resulting from rotation of the kiln is used to enhance this interphase transfer and heat transfer effectiveness. Rotational speeds should be maintained at some prescribed minimum to allow unimpeded heat and material transfers. As with the temperatures, this rotational speed should be determined in a demonstration test or in smaller scale treatability testing. It should be realized that kiln rotational speed also impacts retention time inversely (i.e., the faster the rotational speed, in general the shorter the solids residence time). Therefore, both minimum and maximum kiln speeds should be specified based on the results of the treatability tests. Treatability and pilot scale testing utilizing rotary quartz kiln tubes (described in Appendix D) assist in the determination of operating parameters for full scale operation. Rotary quartz kiln tubes typically have refractory lined kilns with variable rotational speeds and adjustable slopes. Rotational speeds vary from 1 to 12 revolutions per minute, and slopes of the kiln range from 0 to 5.5%. The rotational speed and slope of the dryer is then adjusted to obtain the required solids retention time for a known fixed length of a reaction zone (Hazen Research Inc., 1994). This data is then translated to full scale operation by process engineering principles.

Thermal screw systems rely on direct contact of the media with the auger to transfer heat, minimizing the need for heat transfer from the sweep gas. With these systems, turbulence is induced by the heated augers and serves to increase the contact of each particle with the auger (facilitating heat transfer) and increasing contact time with the sweep gas (facilitating the vapor/solids transfer). As with rotary kiln/rotary dryer systems, an inverse relationship exists between residence time and auger speed, and optimal auger speeds should be determined during treatability tests.

2.2.3 Solids Retention Time. Retention time is the effective residence time that the soil feed remains in the desorption unit and impacts the treatment time for the media. Shorter than adequate retention times will result in incomplete desorption of the contamination due to the lack of adequate time for heat transfer to the soils or mass transfer to the sweep gas to occur. Typical retention times are from 3 to 90 minutes dependent on the type of desorption, feed rate and kiln/auger/conveyor speeds.

Solids retention time is directly related to the kiln rotational speed (for rotary kiln/rotary dryer systems) and to auger speeds (for thermal screw systems). The designer or construction manager should also realize that particles of differing size will move at different speeds through the system (for instance, in general, larger particles will move more quickly through a rotating kiln than smaller particles) making absolute definition of retention time difficult. Although approximate retention times can be determined initially using dyes, retention times may be difficult to monitor directly during operations and the operators may need to rely on indirect controls, such as auger speed or kiln rotational rate.

The required solids retention time and corresponding temperature should be determined by treatability testing or demonstration studies.

2.2.4 Sweep Gas. Sweep gas (a low oxygen carrier gas or air) acts as a carrier to remove volatilized materials from the desorption chamber, driving the solid/vapor equilibrium towards the vapor phase. Sweep gas carrying the soil contaminants is then carried to the gas conditioning system and then either exhausted or recycled to the desorption chamber. As a secondary function, in some systems the sweep gas serves as a heat carrier and transfer agent to heat the soils, as, for instance, in a fluidized bed type system.

Although each system should be capable of adequately handling a wide range of gas flow rates, the rate is critical in affecting the performance of the system. A low flow rate will not allow adequate sweeping of the system, and the solid/vapor equilibrium may favor the solid phase. A flow rate too high may not provide adequate heat transfer time between the gas and solid and higher levels of particulate may be entrained into the gas, overloading the control system. Again, an adequate sweep gas flow should be determined in treatability studies.

Determination of the sweep gas flow rate is dependant on the type of thermal desorption unit (direct fired or indirect fired), type of sweep gas (oxidative or inert) used, the purge gas oxygen concentration, contaminants present in soil, and moisture content of the soil. Specifically, the sweep rate can be determined using the volume or capacity if the thermal desorption, the diameter of the purge gas inlet, and knowing the percent turnover rate within the chamber. Actual sweep rate can be measured using a calibrated rotameter.

Sweep gas flow rates are highly dependent on the specific system in use and a range for acceptable sweep gas flows should be determined during the treatability studies or demonstration testing.

2.3 Particulate Control. As discussed in Appendix C, particulate control devices primarily consist of cyclones, bag houses, and Venturi Scrubbers. The type of particulate control and unit efficiency is dependant on the amount and size of particles entering the system. Methods to estimate what type of particulate control can be determined by knowing both the concentration of influent particulates and the associated size distribution. Note that with the proposed EPA standards of 0.015 gr/cu ft, baghouses may be the only particulate control device capable of meeting this requirement in the future. Table E-10 provides associated efficiencies and particle sizes for cyclones, baghouses and Venturi Scrubbers.

2.3.1 Cyclones. The two main classifications of cyclones are based on efficiency:

- High-efficiency cyclones; and
- High-through put cyclones.

High-through put cyclones are typically used to remove particle sizes greater than 50 μm, and generally have large diameters. High-efficiency cyclones have small diameters (less than 0.3 m (1 foot)).

The factors typically considered when designing cyclones include the following:

- Dust size distribution, particle density, shape, physical chemical properties such as agglomeration, hygroscopic tendencies, stickiness, etc.;
- Contaminated gas stream temperature, pressure, humidity, condensable components, density, etc. ;
- Process variables such as dust concentration, gas flow rate, allowable pressure drop, size to be separated; and
- Structural limitations, temperature and pressure rating, materials of construction, and space limitations.

TABLE E-10
Collection Efficiencies for Particulate Control Equipment

Equipment Type	Percentage Efficiency at		
	50 µm	5 µm	1 µm
Medium-efficiency cyclone	94	27	8
Low-resistance cellular cyclones	98	42	13
High-efficiency cyclone	96	73	27
Venturi scrubber, medium energy	100	>99	97
Venturi scrubber, high energy	100	>99	98
Shaker-type fabric filter (Bag house)	>99	>99	99
Reverse-jet fabric filter (Bag house)	100	>99	99

Source: Lapple, C., Interim Report: Stack Contamination - 200 Areas, HDC-611, August 6, 1948.

It is important to understand the factors that affect the performance of cyclones which are the following:

- Secondary effects: This includes the mass transfer related issues which decrease the efficiency of the cyclone. An example of this type of effect is the bouncing back of particles into the inner vortex of the cyclone;

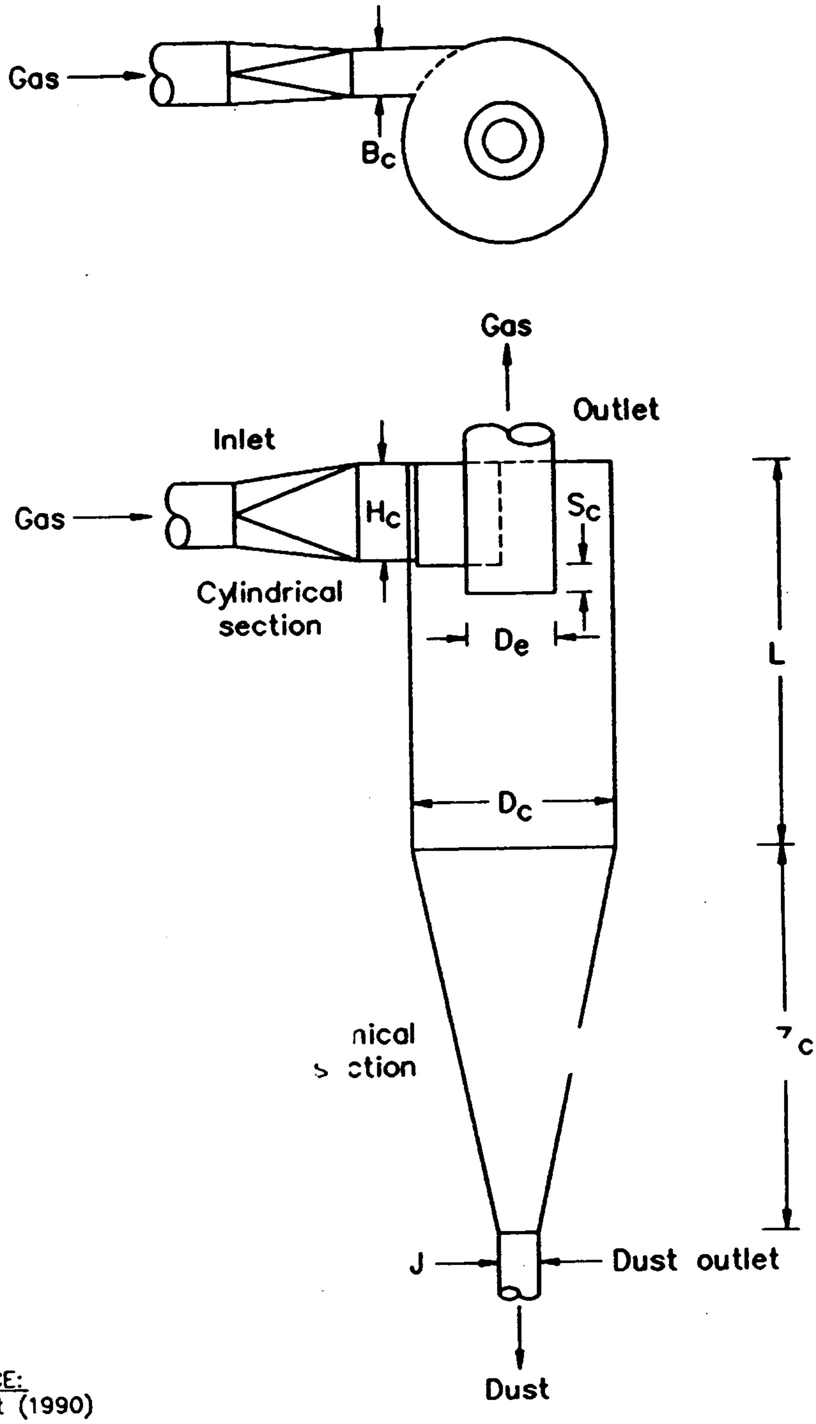
- Proportional Dimensions: High efficiency cyclones have certain dimensional proportions which are based on the results of extensive investigations. Table E-11 is a summary of the performance trends based on cyclone changes. Figure E-2 provides a sketch of the dimensions of a single cyclone separator.

- Physical properties: The physical properties which affect the performance of a cyclone include the specific gravity of the carrier gas, particle size, and viscosity of the carrier gas.

- Process variables: The effect of changes in gas velocity, temperature, dust loading is indicated in Table E-12. It should be noticed that an increase in efficiency also tends to increase the pressure drop. Excessive pressure drop affects the collection efficiency.

TABLE E-11
Performance Trends Based on Cyclone Changes

Proportional Change	Performance Trend		Cost Trend
	Pressure Loss	Effic-iency	
Increase cyclone size	Down	Down	Up
Lengthen cylinder	Slightly lower	Up	Up
Increase inlet area - maintain volume	Down	Down	-
Increase inlet area - maintain velocity	Up	Down	Down
Lengthen cone	Slightly lower	Up	Up
Increase size of cone opening	Slightly lower	Up or down	-
Decrease size of cone opening	Slightly higher	Up or down	-
Lengthen clean gas outlet pipe internally	Up	Up and/or down	Up
Increase clean gas outlet pipe diameter	Down	Down	Up
Source: Control Technologies for Hazardous Air Pollutants, June 1991. EPA-625-691-014.			



SOURCE:
Corbitt (1990)

FIGURE E-2
DIMENSIONS SINGLE CYCLONE SEPARATOR

2.3.2 Baghouses. As discussed in Appendix C baghouses or fabric filters are the most efficient means of separating particles from a gas stream. Important process variables considered in baghouse design include the following:

- Fabric type;
- Cleaning methods;
- Air-to-cloth ratio; and
- Equipment configuration (i.e., forced draft or induced draft).

The fabric type, cleaning method, and air-to-cloth ratio all should be selected concurrently. Equipment configuration is of secondary importance unless the space for the equipment is limited. The operating parameter usually monitored is the pressure drop across the system. Typically baghouses are operated within certain pressure drop range, which is determined based on site experience.

The data required for the design consists of the following:

- Flow rate actual m^3/s (acfm);
- Moisture content (%);
- Temperature °C (°F);
- Particle mean diameter (µm);
- SO_3 content (ppm);
- Particulate content $\mu g/m^3$ (grains/scf); and
- Organic content (%).

Table E-13 is a summary of the characteristics of several fibers used in fabric filtration. Table E-14 is a comparison of fabric filter cleaning methods. Table E-15 is a summary of recommended ranges of air-to-cloth rations by typical bag filters for a variety of dusts and fumes.

TABLE E-12
Effect of Physical Properties Process Variables on Efficiency

	Pressure Loss	Efficiency	Cost Trend
Gas Change			
Increase velocity	Up	Up	Initial cost down, operating cost up
Increase density	Up	Neg	Slightly higher
Increase viscosity	Neg	Down	-
Increase temperature (maintain velocity)	Down	Down	-
Dust Change			
Increase specific gravity	-	Up	-
Increase particle size	-	Up	-
Increase loadings	-	Up	-
Source: Control Technologies for Hazardous Air Pollutants, June 1991. EPA-625-691-014.			

TABLE E-13
Characteristics of Several Fibers Used in Fabric Filtration

Fiber Type[a]	Max. Operating Temp.	Resistance[b]				
		Abrasion	Mineral Acids	Organic Acids	Alkalis	Solvent
Cotton[c]	82°C (180°F)	VG	P	G	P	E
Wool[d]	93°C (200°F)	F/G	VG	VG	P/G	G
Modacrylic[d] (Dynel™)	71°C (160°F)	F/G	E	E	E	E
Polypropylene[d]	93°C (200°F)	E	E	E	E	G
Nylon Polyamide[d] (Nylon 6 & 66)	93°C (200°F)	E[f]	F	F	E	E
Acrylic[d]	127°C (260°F)	G	VG	G	F/G	E
Polyester[d]						
(Dacron[h])	135°C (275°F)	VG	G	G	G	E
(Creslan™)	121°C (250°F)	VG	G	G	G	E
Nylon Aromatic[d] (Nomex™)	191°C (375°F)	E	F	G	E	E
Fluorocarbon[d] (Teflon™, TFE)	232°C (450°F)	F/G	E[f]	E[f]	E[f]	E[f]

TABLE E-13 (cont)
Characteristics of Several Fibers Used in Fabric Filtration

Fiber Type[a]	Max. Operating Temp.	Resistance[b]				
		Abrasion	Mineral Acids	Organic Acids	Alkalis	Solvent
Fiberglass[c]	260°C (500°F)	F/G[g]	G	G	G	E
Ceramics[i] (Nextel 312™)	480+°C (900+°F)	-	-	-	-	-

[a]Fabric limited.
[b]P = poor resistance, F = fair resistance, G = good resistance, VG = very good resistance, and E = excellent resistance.
[c]Woven fabrics only.
[d]Woven or felted fabrics.
[e]Considered to surpass all other fibers in abrasion resistance.
[f]The most chemically resistant of all these fibers.
[g]After treatment with a lubricant coating.
[h]Dacron™ dissolves partially in concentrated H_2SO_4.
[i]The ceramic fiber market is a very recent development. As a result, little information on long term resistance, and acid and alkali performance has been documented.

Source: Control Technologies for Hazardous Air Pollutants, June 1991. EPA-625-691-014.

TABLE E-14
Comparison of Fabric Filter Bag Cleaning Methods

Parameter	Cleaning Method			
	Mechanical Shake	Reverse Air flow	Pulse-jet Individual Bags	Pulse-jet Compartmented Bags
Cleaning on- or off-line	Off-line	Off-line	On-line	Off-line
Cleaning time	High	High	Low	Low
Cleaning uniformity	Average	Good	Average	Good
Bag attrition	Average	Low	Average	Low
Equipment ruggedness	Average	Good	Good	Good
Fabric type[a]	Woven	Woven	Felt/Woven[a]	Felt/Woven[a]
Filter velocity	Average	Average	High	High
Power cost	Low	Low to Medium	High to Medium	Medium
Dust loading	Average	Average	Very high	High
Maximum temperature[b]	High	High	Medium	Medium
Collection efficiency	Good	Good	Good[c]	Good[c]

[a]With suitable backing, woven fabrics can perform similarly to felted.
[b]Fabric limited.
[c]For a properly operated system with moderate to low pressures, the collection efficiency may rival other methods.

Source: Control Technologies for Hazardous Air Pollutants, June 1991. EPA-625-691-014.

TABLE E-15
Air-to-Cloth Ratios[a]

Dust	Shaker/Woven Reverse-Air/Woven[b]	Pulse Jet/Felt[b]
Alumina	0.76 (2.5)	2.4 (8)
Asbestos	0.91 (3.0)	3.1 (10)
Bauxite	0.76 (2.5)	2.4 (8)
Carbon black	0.46 (1.5)	1.5 (5)
Coal	0.76 (2.5)	2.4 (8)
Cocoa, chocolate	0.76 (2.5)	3.7 (12)
Clay	0.76 (2.5)	2.7 (9)
Cement	0.61 (2.0)	2.4 (8)
Cosmetics	0.46 (1.5)	3.1 (10)
Enamel frit	0.76 (2.5)	2.7 (9)
Feeds, grain	1.07 (3.5)	4.3 (14)
Feldspar	0.67 (2.2)	2.7 (9)
Fertilizer	0.91 (3.0)	2.4 (8)
Flour	0.91 (3.0)	3.7 (12)
Fly ash	0.76 (2.5)	1.5 (5)
Graphite	0.61 (2.0)	1.5 (5)
Gypsum	0.61 (2.0)	3.1 (10)
Iron ore	0.91 (3.0)	3.4 (11)
Iron oxide	0.76 (2.5)	2.1 (7)
Iron sulfate	0.61 (2.0)	1.8 (6)
Lead oxide	0.61 (2.0)	1.8 (6)
Leather dust	1.07 (3.5)	3.7 (12)
Lime	0.76 (2.5)	3.1 (10)
Limestone	0.82 (2.7)	2.4 (8)
Mica	0.82 (2.7)	2.7 (9)

TABLE E-15 (cont)
Air-to-Cloth Ratios[a]

Dust	Shaker/Woven Reverse-Air/Woven[b]	Pulse Jet/Felt[b]
Paint pigments	0.76 (2.5)	2.1 (7)
Paper	1.07 (3.5)	3.1 (10)
Plastics	0.76 (2.5)	2.1 (7)
Quartz	0.85 (2.8)	2.7 (9)
Rock dust	0.91 (3.0)	2.7 (9)
Sand	0.76 (2.5)	3.1 (10)
Sawdust (wood)	1.07 (3.5)	3.7 (12)
Silica	0.76 (2.5)	2.1 (7)
Slate	1.07 (3.5)	3.7 (12)
Soap detergents	0.61 (2.0)	1.5 (5)
Spices	0.82 (2.7)	3.1 (10)
Starch	0.91 (3.0)	2.4 (8)
Sugar	0.61 (2.0)	2.1 (7)
Talc	0.76 (2.5)	3.1 (10)
Tobacco	1.07 (3.5)	4.0 (13)
Zinc oxide	0.61 (2.0)	1.5 (5)

[a]Generally safe design values - application requires consideration of particle size and grain loading.
[b]A/C ratio units are $(m^3/min)/m^2$ of cloth area $[(ft^2/min)/ft^2$ of cloth area]

Source: Control Technologies for Hazardous Air Pollutants, June 1991. EPA-625-691-014.

2.3.3 Venturi Scrubbers. Venturi scrubbers are designed to collect particles between 0.5 to 5.0 µm in diameter. The data necessary to perform design consists of the following:

- Flow rate actual m^3/sec (acfm);
- Moisture content (%);
- Temperature °C (°F);
- Particle mean diameter (µm);
- Required collection efficiency (%);
- Particulate content µg/m^3 (grains/scf); and
- Organic content (%).

The temperature range for venturi scrubber should be within 5 to 38 °C (50 to 100 °F). If the temperature does not fall within the stated range then pretreatment of the stream may be necessary (i.e., stream cooling).

The two most import considerations for evaluating a venturi scrubber are the pressure drop across the scrubber and the material of construction. Typical pressure drops for venturi scrubbers for a variety of applications are listed in Table E-16. Materials of construction for various industries are listed in Table E-17 and serve as a general guide as to the types of material used in the industry.

2.4 Air Pollution Control Devices Design and Performance. Air pollution control devices are designed to remove organics/THC/ VOC/POHC from the thermal desorption unit discharge gas flow. These unit operations include:

- Thermal afterburners
- Catalytic afterburners
- Adsorption
- Baghouses
- Wet scrubbers

Performance is based on criteria developed to meet stack emission (regulatory requirements) criteria and/or process recycle requirements.

This section details the design and performance of these unit operations.

2.4.1 Afterburners. To ensure satisfying stack emission requirements, thermal or catalytic afterburners may be required. The process principle involves the combustion and oxidation of hydrocarbons/VOC's. The unit design (process and equipment) is based on the following four key criteria:

TABLE E-16
Pressure Drops for Typical

Venturi Scrubber Applications

Application	Pressure Drop	
	kPa	in H_2O
Boilers		
Pulverized coal	3.7 - 10	15 - 40
Stoker coal	2.5 - 3	10 - 12
Bark	1.5 - 2.5	6 - 10
Combination	2.5 - 3.7	10 - 15
Recovery	7.5 - 10	30 - 40
Incinerators		
Sewage sludge	4.5 - 5	18 - 20
Liquid waste	12.4 - 13.7	50 - 55
Solid waste		
Municipal	2.5 - 5	10 - 20
Pathological	2.5 - 5	10 - 20
Hospital	2.5 - 5	10 - 20
Kilns		
Lime	3.7 - 6.2	15 - 25
Soda ash	5 - 10	20-40
Potassium chloride	7.5	30
Coal Processing		
Dryers	6.2	25
Crushers	1.5 - 5	6 - 20
Dryers		
General spray	5 - 15	20 - 60
Food spray	5 - 7.5	20 - 30
Fluid bed	5 - 7.5	20 - 30

Source: Control Technologies for Hazardous Air Pollutants, June 1991.
EPA**-625-691-014.**

TABLE E-17
Construction Materials for Typical Venturi Scrubber Applications

Application	Construction Material
Boilers	
Pulverized coal	316L stainless steel
Stoker coal	316L stainless steel
Bark	Carbon steel
Combination	316L stainless steel
Recovery	Carbon steel or 316L stainless steel
Incinerators	
Sewage sludge	316L stainless steel
Liquid waste	High nickel alloy
Solid waste	
Municipal	316L stainless steel
Pathological	316L stainless steel
Hospital	High nickel alloy
Kilns	
Lime	Carbon steel or stainless steel
Soda ash	Carbon steel or stainless steel
Potassium chloride	Carbon steel or stainless steel
Coal Processing	
Dryers	304 or 316L stainless steel
Crushers	Carbon steel

Source: Control Technologies for Hazardous Air Pollutants, June 1991. EPA-625-691-014.

- Temperature: for a thermal unit a range of 760-982°C (1400-1800°F) is required to support the destruction of the hydrocarbon molecular structures; for a catalytic unit a range of 320-650°C (600-1200°F) is adequate; however, temperatures of 1204°C (2200°F) have been used for difficult-to-oxidize organics.

- Residence time: unit sizing is based on providing residence times ranging from 0.5 to 2.0 seconds - this allows for the time required for complete combustion.

- Catalyst and contact turbulence: thorough gas mixing to insure gas phase interaction and temperature uniformity is required - this is achieved by proper selection of chamber velocities 3.05 - 6.1 m/sec (10 to 20 ft/sec), burner arrangement in the chamber to allow for flame/gas flow interaction (which may reflect a direct or tangential entry) and the use of pinch points (narrowing/obstruction of the gas flow path).

- Oxygen concentration: to ensure proper reaction/conversion, minimum oxygen concentrations of 3-5% should be maintained in the flue gas with the sources being the desorption flue, burner supply and supplementary air fan as needed. Maximum values of 7-9% O_2 should not be exceeded due to the generation of excess flue gas flow.

Design of the afterburner chamber should include, consistent with the above criteria, the following considerations:

- Chamber volume based on the maximum gas flow and maximum required residence time, with the width of the chamber computed from the gas velocity and the chamber length.

- Afterburners may be provided in horizontal or vertical configurations. Vertical is the preferred arrangement should solids drop out be a concern. Provisions for removal of solids should be provided (i.e., bottom hopper, manway access).

- Afterburner chambers are typically refractory-lined units with the shell being of a carbon steel. The selection of a refractory type should widen (a) the operating temperature constructed including the temperature profile at the burner zone which may dictate refractor type due to elevated flame temperatures, (b) the presence of acid gases or corrosive materials, and (c) material thicknesses including insulation, if required, to maintain a shell temperature of less than 260°C (500°F).

- To conserve energy, heat exchange between the influent and effluent streams may be incorporated including (a) recirculating a portion of the exit flow and mixing this flow with the inlet stream and (b) using a non-contact heat exchanger, internal to the afterburner unit, or as a separate stand alone device.

A burner arrangement should be selected to support the above design criteria (e.g., temperature requirements). The burner design may include the following considerations:

- Use of an appropriate fuel supply (fuel oil, natural gas and/or propane).
- Use of single or multiple units for back up.
- Burner thermal duty with consideration given to the flue gas inlet flow rate, flue gas composition (complimenting combustion of the organics present) and the maximum design combustion mix temperature.
- Flame/gas flow interaction (e.g., direct, tangential) and gas phase turbulence to promote the combustion reaction.
- Use of a low NO_x design.

Within the limits of the overall air pollution control system train, thermal afterburners need to achieve the following performance criteria:

- Organics/THC/VOC/POHC: destruction and removal efficiency (DRE) of 95-99.9+% or 10-100 ppmv concentration.
- CO: 2-100 ppmv (rolling average).
- Nitrogen oxides (NO_x): less than 100 ppmv.

The performance of afterburners should also meet the specific operational requirements - most notably combustion zone temperature, gas discharge oxygen levels, and negative pressure (via the APL system ID fan) to meet regulatory requirements.

2.4.2 Catalytic Afterburner. To meet stack emission regulations, catalytic afterburners may be required. Catalytic afterburners use a noble metal catalyst to promote the rate of reaction and decrease the activation energy needed for oxidation, allowing operation at lower temperatures and thereby yielding lower fuel usage.

Key matters to note regarding the application of catalyst afterburners are:

- Catalyst materials normally used are platinum, palladium, and rhodium. Others include copper chromite and the oxides of copper, chromium, manganese, nickel and cobalt.

- Common commercially available catalyst configurations include mat (similar in appearance to an air filter), porcelain assemblies and plates with connected rods and honeycomb (ceramic or refractory) supported catalysts, where the catalyst material is deposited in layers on an inert substrate.

The gas stream should be free of particulate matter to protect the catalyst from fouling. In addition, catalysts are sensitive to many substances, including platinum poisons (heavy metals), suppressants (halogens), and fouling agents (iron oxides).

The design of catalytic afterburners is based on the following four key criteria:

- Temperature: to support ignition and combustion an operating temperature range of 320-650°C (600-1200°F) is required - achieved through the combustion reactions and auxiliary fuel firing.

- Residence time: unit/catalyst bed sizing is based on residence times ranging from 0.08 to 1.0 seconds to allow time for complete reaction.

- Turbulence: the shell and catalyst should be configured to provide intimate mixing of the gas phase flow and contact with the catalyst structure.

- Oxygen concentration: sufficient oxygen must be present to insure oxidation of the contaminants; minimum levels of 3-5% O_2 should be maintained in the gas flow with the sources being the desorption flue burner supply and supplementary air fan as needed, and maximum oxygen concentrations of 7-9% should not be exceeded due to the generation of excess flue gas flow.

The precise value of each of these parameters is dependent on the catalyst employed plus the flue stream properties.

Design of the afterburner chamber should consider:

- Catalyst volume based on the maximum gas flow and maximum required residence time.

- Chamber construction for operating temperatures: below 540°C (1000°F) heat treated steels have been used successfully, at temperatures near 540°C (1000°F) stainless steels may be use, and above 540°C (1000°F) refractory linings are used.

- To conserve energy recuperative heat recovery schemes may be provided integral to the afterburner unit or as a separate stand along device including:(a) recirculating part of the exit flow and mixing with the inlet stream and (b) using a non-contact heat exchanger.

- Noble metal catalysts are susceptible to the following:poisons (arsenic compounds, halogens, phosphates and heavy metals); fouling agents (silicones, iron oxides and alumina dusts); and suppressants (halogens and sulfur compounds)(Brunner, 1988).

A burner arrangement should be selected to support the above design criteria (e.g., temperature requirements). The burner design should consider

- Use of an appropriate fuel supply (fuel oil, natural gas and/or propane).
- Use of single or multiple units for back up.
- Burner thermal duty with consideration given to the flue gas inlet flow rate, flue gas composition (complimenting combustion of the organics present) and the maximum design combustion mix temperature.
- Flame/gas flow interaction and gas phase turbulence and promote the combustion reaction.
- Use of a low NO_x design.

Within the limits of the overall air pollution control system train, catalytic afterburners typically need to achieve the following performance criteria:

- Organics (THC/VOC/POHC): destruction and removal efficiency (DRE) of 90-99%.
- CO: 2-100 ppmv (rolling average).
- Nitrogen oxides (NO_x): less than 100 ppmv.

The performance of catalytic afterburners should also meet the specific operational requirements; most notably of which are reaction zone temperature, gas discharge oxygen concentrations and negative pressure (via the APC system ID fan) to meet regulatory requirements.

2.4.3. Adsorption. Vapor phase activated carbon or resin adsorption may be employed within the APC train to further remove organic constituents in the cooled flue gas stream and satisfy emission requirements.

Characterization of the organic contaminants is a key consideration in the selection of an appropriate adsorbent. Organic contaminants are characterized as follows:

- Compound name
- Formula and/or molecular weight
- Specific gravity
- Inlet concentration
- Boiling point
- Vapor pressure curve
- Adsorption isotherms
- Refractive index

Impurities and safety must be considered (e.g., dust may clog the adsorbent bed, ketones may oxidize or polymerize, both of which will liberate heat with a potential for ignition of the adsorbent).

In addition to the above, to select an appropriately sized adsorption unit the following criteria must be known:

- Air flow rate m^3/s, (cfm)
- Air pressure atm, (psig)
- Air relative humidity, %
- Temperature, °C (°F)
- Capture efficiency, %
- Characterization of constituents of concern

Design considerations for the selection of a carbon absorber are:

- Relative humidity of off-gas. Off-gas normally has a relative humidity of 100%. Uncontrolled humidity reduces the efficiency and effectiveness of carbon adsorption.
- Materials of construction for the vessels and internals are lined (high solids epoxy, polyethylene) carbon steel, stainless steel, fiberglass, polypropylene, etc. and that the fabrications are readily available to the site.
- Arrangement of air distributors to maximize flow patterns to support interphase contact and reduce the gas side pressure drop.
- Clean and fouled pressure drops to support the system draft profile.

- Upflow, downflow or crossflow configuration requirements.
- Pre-filters to avoid unwanted fugitive particulate build up in the adsorbent bed.
- Accessories such as blowers or fans, premixing, skid mounting, control panels, post-filters, flame arrestors, sample ports, lifting lugs, pressure relief valves, rupture disks, condensate traps, separators, dehumidifiers.
- Code requirements (e.g., ASME pressure testing) and/or leakage testing.
- Provisions for carbon replacement.
- Provisions for carbon regeneration
- Regeneration system requirements (e.g., boilers, heated pressure air/steam flow, stripped material collection and separation, treatment and routing).

While dependent on the overall air pollution control system train, the adsorption system needs to achieve the performance criteria for organics (THC/VOC/POHC) of 50 to 99% removal primarily as a function of the outlet temperature, chemical types, inlet concentration, adsorbent bed depth and bed velocity.

Additional performance criteria may also be required to conform with regulatory requirements (e.g., inlet temperature).

2.5 Treated Material Handling. Thermal desorption systems typically employ screw or belt type conveyor systems to transport treated material residuals from the desorption outlet to a truck or storage area. Conveyor arrangements may include a single conveyor or multiple conveyors involving changes in both horizontal and vertical direction.

The design criteria used in the selection of an appropriate solids effluent conveyor system is generally similar to that for the desorption inlet conveyor system. Material temperatures, however, warrant closer consideration in selecting conveyors for solid effluents. Soil discharge temperatures of certain types of thermal desorbers may approach 650°C (1200°F) and may affect the materials of construction and/or type of conveyor chosen. In rotary dryer and thermal screw type desorption systems, water may be sprayed unto the hot soil in a screw conveyor for cooling and dust control.

As with the desorption inlet conveyor systems, auxiliary devices may be added to satisfy particular requirements.

2.6 Oversized Material Handling. Depending on the hazardous/nonhazardous nature of the oversized material, there are several management options available. If hazardous, stone clumps and aggregate can be reprocessed in a pug mill or crusher and then treated in the desorption unit. Boards, plastic, and miscellaneous debris can be decontaminated and sent to a solid waste landfill for disposal. The liquid generated and residue can be treated in the facility wastewater treatment plant.

If nonhazardous, all oversized material can be sent off-site for disposal in a solid waste landfill.

3. Process Controls. This section will present (1) the instrumentation and control elements used in a thermal desorption system design, (2) different degrees of automation and (3) a list of minimal process control components that may be used in a thermal desorption system.

3.1 Description of Design Elements. A full thermal desorption system design will include, at a minimum, the following process control elements:

3.1.1 Process Flow Diagram. Flow and material balances showing the general arrangement of the equipment, the flow rate of each process stream, the operating temperature and pressure for each unit process, and the composition of materials on each process stream.

3.1.2 P&I Diagrams. Piping and instrumentation diagrams show the interrelationship between process components, piping and process control devices. ISA and ANSI standards (ANSI/ISA-S5.1) govern the preparation of P&I diagrams. These diagrams show all major process components organized according to process flow. The instrumentation symbols are shown in "bubbles."

3.1.3 Electrical Wiring Diagram. This diagram shows the wiring of all physical electrical devices, such as transformers, motors and lights. If appropriate, the diagram is organized in ladder logic form.

3.1.4 Description of Components. The specifications must include a description of instrumentation and control components including installation and mounting requirements.

3.1.5 Sequence of Control. The sequence of control must be included in both the design submittal and the operation and maintenance manual. Control information concerning system start-up, system shutdown and response to malfunctions must be included.

3.1.6 Control Panel Layout. A control panel layout must be designed. This drawing will show, to scale, all electrical components and the associated wiring. This control item is normally submitted as a shop drawing.

3.1.7 Logic Diagram. If the process control logic is not apparent from the P&I Diagram a logic diagram should be included. The diagram shows the logical (and, or, nor, if-then) relationships between control components but does not show interconnecting process flow. For example, the diagram may show that if switch #2 is placed in the on position and there are no alarm conditions, then the blower will turn on and activate a green indicator light.

3.1.8 Legend and Standard Symbols. The set of documents must have a legend to explain the symbols used. Despite the existence of the legend, standard symbols must be used wherever applicable.

3.2 Degrees of Automation. The degree of automation is generally dependent on the complexity of the treatment system, the remoteness of the site, and monitoring operations, and control requirements. Typically, there is a trade off between the initial capital cost of the instrumentation and control equipment, and the labor cost savings in system operation.

Generally, there are three forms of process control: local control, centralized control, and remote control. In a local control system, all control elements (i.e., indicators, switches, relays, motor starters) are located adjacent to the associated equipment. In a centralized control system, the control elements are mounted in a single location. These systems may include a hard-wired control panel, a programmable logic controller (PLC) or a computer. Remote control can be accomplished several ways including by means of modems or radio telemetry.

To select the appropriate control scheme, the advantages and disadvantages of each control scheme must be considered. A localized control system is less complex, less expensive and easier to construct. For example, if a level switch in a tank is controlling an adjacent discharge pump, it would obviously be simpler to wire from the tank directly to the adjacent pump than to wire from the tank to the centralized control panel and then from the panel back to the pump. As the control system becomes more complex, it quickly becomes advantageous to locate the control components in a central location. Centralized control systems are also easier to operate. Instrument interlocks can be used for both safety and equipment protection considerations. Centralized data acquisition and control may include the use of computers or PLCs.

TABLE E-18
Instrumentation Summary

Equipment	Parameter	Instrument
Desorber	Temperature	Thermocouple or Infrared Sensor
	Pressure	Pressure Transducer
	Rotational/Linear Speed	AC Variable Speed Drive or Sensing Head
	N_2 Concentration	N_2 Analyzer
	Fuel Feed Rate	Volumetric Flowmeter
	Gas Residence Time/Sweep Gas Velocity	Averaging type pitot tube
Condenser	Temperature	Thermocouple/Level Switch
Particulate Removal (Cyclone)	Differential Pressure	Differential Pressure Transducer
Air Pollution Control		
Afterburner (if used)	Temperature	Thermocouple or infrared sensor
	Fuel Feed Rate	Volumetric Flowmeter
	O_2 Concentration	Zirconium Oxide
	Burner Control	Burner Management System
Quench Chamber	Temperature	Thermocouple
	Liquor Flow	Volumetric Flowmeter
Scrubber	Differential Pressure	Differential Pressure Transducer
	Temperature	Thermocouple
	pH (Neutralization Tank)	pH Cell

TABLE E-18
Instrumentation Summary

Equipment	Parameter	Instrument
Scrubber (Cont.)	Density (Neutralization Tank)	Density Meter
Baghouse	Temperature	Thermocouple
	Differential Pressure	Diff Press Transducer
Carbon Adsorber	Temperature	Thermocouple
	Differential Presure	Differential Presure Transducer
	HC Concentration	HC Analyzer
Material Handling Desorber	Waste Feed Rate	Variable speed drive
		Load cell, weight sensor
		Programmable Logic Controller
	Residual Discharge Feed Rate	Load cell, weight sensor
		Programmable Logic Controller
Stack	CO Concentration	Infrared Analyzer
	SO_2 Concentration	Ultra Violet Photometric Detector
	NO_x Concentration	Chemiluminescent Analyzer
	Total HC	CEMS
	Opacity	Opacity Meter
	Temperature	Thermocouple
Special Equipment	Regenerate Flow Rate	Volumetric Flowmeter
Ion Exchange Unit (Wastewater)	Conductivity	Conductivity Cell
	Temperature	Thermocouple or RTD
	Pressure	Pressure Transducer

The greater the number of control inputs, the more worthwhile it is to use computer or PLC control. For thermal desorption systems, the inputs may include signals from speed indicators, pressure switches or thermocouples. The threshold for using PLCs or computers is generally between five and ten inputs, depending on the type of input and operator background. Often plant operators will be more familiar with traditional hard-wired control logic than with control logic contained in software. However, process logic contained in software is easier to change than hard-wiring. Therefore, if extensive future modifications to the proposed system may be anticipated, avoid hard-wiring the process logic.

Modems and radio telemetry can be used to control these systems remotely. Radio telemetry is typically used over shorter distances when radio transmission is possible. Modems are used with computerized control systems. Systems can also be equipped with auto dialers to alert the operator of a malfunction by telephone or pager. Considerations such as site location, capital cost, standardization, operator background and system complexity govern the selection of these devices.

3.3 Process Control Components. A listing of typical process control components typically installed in a thermal desorption system can be found in Table E-18.

3.4 Feed Storage and Conveyance.

3.4.1 Feed Hopper Systems. Bin level controls may be used on larger hoppers to monitor the contents of the hoppers. Rotary airlocks and feeders may be equipped with speed and torque overload controls similar to those used on conveyor systems. Vibrating bottoms may be controlled manually or automatically via preset timers. Signals from weight sensors together with bin level and feeder speed and torque overload sensors may be processed through programmable logic controllers to provide for the complete automation of weighing, feeding and conveying functions.

3.4.2 Conveyor Systems. Process controls are installed on conveyor systems to monitor and control one or more of the following parameters:

3.4.2.1 Conveyor Speed. Conveyor systems can be equipped with both fixed speed and variable speed drives. Fixed speed drives are used when the speed of the conveyor does not require adjustment during operation. Fixed speed drives may include the use of motor speed reducers alone or in combination with chain and sprocket drives or V-belt drives. Fixed drives are used when major changes to processing feed rates and high feed rate accuracies are not required. Variable speed drives will yield a much greater accuracy and variability in processing feed rate and speed adjustment than fixed speed drives. Variable speed drives include variable frequency drives for use with AC induction motors and silicone controlled rectifiers for use with DC motors. DC drives are preferred when speed adjustments are required over a wide range at extremely accurate settings.

3.4.2.2 Material Weight. Conveyor systems can be equipped with sensing elements (e.g., load cells, strain gauges or weigh belts or platforms) to weigh materials during processing. Material weighing may be done on a batch or continuous basis. Batch weighing is effective when material densities are constant and uniform flow can be maintained. Batch weighing devices such as additive weight and loss of weight scales can achieve accuracies of ± 0.1 percent under such conditions and when they are augmented with proper flow controls. Continuous weighing devices such as weigh platforms sense both material flow rate and changes in flow rate. Continuous weighing devices are suitable for continuous processes and can achieve weighing accuracies of ± 1 percent.

3.4.2.3 Material Feed Rate. With the use of automated process control devices such as programmable logic controllers, signal outputs from weighing devices can be combined with those of the conveyor speed controls to yield highly accurate measurement and control of material feed and discharge rates.

3.4.2.4 Torque Overload. Torque overload devices are installed on conveyor systems to prevent damage to conveyor components in the event the conveyor jams. Torque overload devices may be mechanical or electrical in design. Mechanical devices such as shear pins and slip clutches provide an immediate positive disconnection of the conveyor and drive. The conveyor system must remain inoperative, however, until the shear pins are replaced. Electrical devices include motor current sensing devices; these devices may not shut the conveyor down immediately upon increased torque and thus may not be suitable protection in some applications.

3.5 Desorption Design/Performance Evaluation Criteria. Four basic parameters can be used to monitor the performance of a thermal desorption on a continuous (or intermittent) basis. These parameters are:

- system operating temperature for the primary desorption chamber;
- turbulence induced in the primary chamber;
- retention time (can be estimated); and
- sweep gas flows through the primary chamber.

Temperature of the media in the primary chamber is ideally monitored by direct measurement of the treated materials, however, this is not possible on a continuous basis. Two alternate temperature measurements are suggested:

- Kiln or dryer wall temperature; or
- Exhaust (i.e., back end of the desorption chamber) gas temperature.

Again, each of these provides an indirect means of measuring the solids temperature on a continuous basis, but because the measurement is indirect, the assumption must be made that the thermal transfer to the soils is adequate for volatilization.

No direct manner of measuring turbulence or solids retention time can be made, however, indirect turbulence monitoring can be performed by monitoring kiln rotational speed or auger speeds (for a thermal screw system). Again, minimum and maximum speeds should be established during the treatability or demonstration testing.

Sweep gas flow rates may be measured via feed flows, recirculating gas flows and/or thermal discharge flue rate - using line velocities to determine mass and volumetric rates.

3.6 Particulate Control. The primary process control parameter monitored for cyclones, bag houses, and Venturi Scrubbers is the pressure drop across the unit. Differential pressure may be sensed by a diaphragm or similar type pressure transducer.

Temperature is also monitored in the baghouse to ensure that damage to the fabric filter does not occur.

Temperature is monitored using thermocouple sensors.

3.7 Air Pollution Control Devices Controls. Air pollution control devices provided to remove organics/THC/VOC/POHC from the thermal absorber unit discharge gas flow include the following:

- Thermal afterburners
- Catalytic afterburners
- Adsorbers
- Baghouses
- Wet scrubbers

Monitoring and controls are provided for each operation and among the overall processes to support performance and safety.

This section details the monitoring and controls of these unit operations.

3.7.1 Thermal Afterburners. Process controls required to monitor and control the thermal afterburner unit performance include the following:

- Temperature: to support combustion, a minimum temperature (e.g., 650°C (1200°F) must be maintained. Also, to protect equipment and conserve fuel, a maximum temperature is established (e.g., 980°C (1800°F)). For monitoring, generally redundant back-up thermocouples are provided in the combustion zone. This temperature range is achieved by modulating the burner firing rate for heat input and the supplemental air fan (dampers may be employed) for cooling control

- Oxygen: To support reaction chemistry a minimum oxygen level is desired (e.g., 3%) and to limit the mass flow generated a maximum oxygen concentration (e.g., 9%) is set. Monitoring is provided via the use of oxygen sensors in the combustion zone. Control within this concentration range is achieved by modulating a supplemental air fan arrangement (dampers may be employed).

- Draft: A proper system draft/pressure profile shall be maintained by monitoring different point(s) along the process train: where one of these locations may be the afterburner. Minimum pressure should be maintained to ensure a negative draft profile in the entire system to avoid fugitive releases via a modulating damper arrangement on the fan. The required draft is dependent on the system design with the afterburner itself generally requiring a 0.01 to 0.5 kpa (0.05 to 2 inch water column) pressure drop.

- Carbon Monoxide.

- Burner fuel use - an in-line flow measuring device is typically included to provide flow rate and totalization data for overall operational evaluation and inventory control purposes.

To insure the protection of the equipment, a waste feed cut-off to the thermal desorption unit should be initiated upon the following occurrences:

- low or high temperature
- low oxygen concentration
- low draft and
- related power failure.

3.7.2 Catalytic Afterburners. Specific process controls for the catalytic unit are required to monitor and control the operation of the unit. These include the following:

- Temperature: To support initiation of reactions, a minimum temperature (e.g., 316°C (600°F)) must be maintained. In addition, to protect the catalyst and equipment (recognizing their respective design temperatures) and conserve fuel, a maximum temperature is set (e.g., 649°C (1200°F)). For monitoring, generally redundant back-up thermocouples are provided in the catalyst bed zone. This temperature range is achieved by modulating the burner firing rate for heat input and the supplemental air fan (dampers may be employed) for cooling control

- Oxygen: To support reaction chemistry a minimum oxygen level is desired (e.g., 3%) and to limit the mass flow generated a maximum oxygen concentration (e.g., 9%) is set. Monitoring is provided via the use of oxygen sensors in the catalyst bed zone. Control within this concentration range is achieved by modulating a supplemental air fan arrangement (dampers may be employed).

- Draft: A proper system draft/pressure profile shall be maintained by monitoring different point(s) along the process train where one of these locations may be the afterburner. Minimum pressure should be maintained to ensure a negative draft profile in the entire system to avoid fugitive releases via a modulating damper arrangement on the fan. The required draft is dependent on the system design with the afterburner itself generally requiring a 0.0 to 0.5 kPa (0.00 to 2 inch WC) pressure drop.

Monitoring of the catalytic afterburner operation shall include - in addition to the above control parameters -the following key items:

- Burner fuel use - an in-line flow measuring device is typically included to provide flow rate and totalization data for overall operational evaluation and inventory control purposes.

- CO monitor - an on-line analyzer shall be located at the discharge of the catalyst to indicate loss of catalyst effectiveness (e.g., due to poisoning, fouling) chamber.

To protect the equipment, a waste feed cut-off to the thermal desorption unit can be initiated upon the following occurrences:

- low or high temperature
- low oxygen concentration
- low draft
- high CO discharge
- high pressure drop in the baghouse and
- related power failure.

3.7.3 Adsorption. Adsorption systems are typically provided with process controls to monitor and control performance. Components may include the following:

- Saturation Indicators: analyzers may be provided at the absorber(s) discharge to indicate the presence of organics and adsorbent bed saturation, hence the need for replacement/regeneration. Should parallel or series unit arrangements be provided, analyzers at the different unit discharge points can dictate gas routing or flow to allow for absorber servicing.

- Pressure Monitoring: pressure indicators may be provided on the inlet and outlet flow lines of the absorber or alternatively differential pressure indication may be specified.

- Temperature Monitoring: temperature indicators (with thermowells) may be placed in the absorber beds - the number required dependent on the unit size and design; the purpose is to indicate the high temperatures (due to adsorption exotherms, contaminant oxidation, polymerization reactions, etc.) which could lead to bed fires. Set points should be established which initiate on high (emergency) condition an alarm activation of the fire suppression water system and purging of the absorber bed.

Series and parallel absorber unit arrangements can be provided to allow for placing individual units out-of-service for regeneration and to maintain overall operation on-line availability.

3.8 Treated Material Handling. Process controls for the treated material handling conveyor systems are generally similar to those of the desorption inlet conveyor systems with the addition of flow controls for water sprays, if used. Control may be manual via a hand valve in applications where material throughput and temperature vary infrequently during processing; automated flow controls may be needed in applications where these parameters require frequent adjustment.

4. Site Requirements.

4.1 Equipment Plot Requirements. Space requirements for the thermal desorption processing equipment are generally less than 45 m by 45 m (150 feet by 150 feet) exclusive of materials handling equipment (EPA, 1994). Site areas required for conveyance and heavy construction equipment will vary depending upon the capacity of the treatment system and the complexity of the remediation operation. The space available for materials handling and the location of treatment and support facilities can be determined from the pre-construction survey.

4.2 Material Stockpiles. An adequate stockpile of contaminated material is necessary to allow for continuous operation. A treated material stockpile is required to allow for sampling and analyses prior to final placement.

4.3 Construction Zones. Refer to ER 385-1-92 Safety and Occupational Health Document Requirements for Hazardous, Toxic and Radioactive Wastes (HTRW) which covers construction zones to the extent required for investigation, design and construction.

4.4 Easements. Easements may be required from the local municipalities having jurisdiction over the site area. Permits and site inspections may be required for the construction of buildings and the connection to electrical, gas, water and sanitary sewer facilities.

4.5 Utility Requirements. Utility requirements (electric power, water, fuel, air, steam, etc.) will be site and contractor specific and dependent upon the capacity, type and complexity of the treatment system used. Applicable codes (military or state and local) governing the installation of utilities will be incorporated.

APPENDIX F
TREATMENT SYSTEM OPERATIONS

1. Facility Operations Plan. The facility operations plan is prepared by the contractor if required by the Contract. Prior to system start-up and operation, the operations plan should be thoroughly reviewed and understood by all operations personnel. The facility operations plan generally includes information relating to equipment set-up, and system start-up, normal operation, normal and emergency shutdown procedures and routine maintenance requirements. Installation, operation and maintenance manuals for equipment items, if available, should also be incorporated into this plan.

2. Utility Requirements. Utility requirements and consumption rates are site specific and dependent upon the desorption system the Contractor selects. Utilities required at the remediation site to support the thermal desorber unit, air pollution control system, materials handling equipment and auxiliary facilities:

- Electric power (440 volt three phase service is typical for thermal desorber units).
- Water, used typically for cooling of the processed solids and for quench and scrubber makeup.
- Fuel, typically natural gas, propane or fuel oil for supply to burners.
- Compressed air for operation of construction equipment, air driven pumps and process controls. Instrument air must be dry and oil free.
- Nitrogen, purge gas used by some units.
- Chemicals: Lime or caustic soda for wet scrubbers.
- Activated carbon, if used for polishing of off gas or wastewater streams.

The literature of several manufacturers or desorption contractors should be reviewed to estimate the utility requirements.

3. System Start-up. Prior to system start-up, adequate materials handling procedures should be established. Materials handling is discussed in Appendix C.2.

3.1 System Check-Out and Debugging. Thermal desorption systems are generally preassembled and prewired, and transported on flatbed trailers. Most systems are comprised of three primary components: a desorber unit, a particulate removal device and an gas pollution control system.

Check-out and debugging of the thermal desorption system would generally involve inspection and verification of utility tie-ins, and interconnecting piping, wiring and ductwork. Inspection and verification of proper set-up of items unique to a particular thermal desorption system would also be performed at this time. A summary of process control elements can be found in Appendix E. A summary of representative checklist items for thermal treatment systems located in the following documents can be used to develop a checklist for incorporation in the thermal treatment specification:

- CEGS 02288 Remediation of Contaminated Soils and Sludges by Incineration

3.2 Start-Up Procedures. The detailed start-up procedures are included in the contractor prepared operations plan. Start-up procedures define the step by step sequence of activities required to bring the thermal desorption system up to normal operating conditions. The sequence of activities typically would include the following:

- Powering up of system equipment and controls.
- Adjustment of speed controls.
- Setting of control devices to their normal operating points.
- Adjustment of feed rate valves to normal operating set points (e.g.: fuel, water, etc.).
- Adjustment of mechanical components for normal operation (e.g.: dampers, pressure regulators, etc.).
- Operation of the system in both manual "hand" and automatic "auto" mode.
- Monitor and verify normal operation of the system.

3.2.1 Pre Start-Up Inspection. Prior to the start-up of the thermal desorption system leak testing should be performed on each of the system valves; valved segments of piping and ductwork; drain valves; secondary containment systems; and pumps. Valves should be checked to ensure that they remain closed. Spill response supplies are to be inspected and restocked when needed.

Prior to system operation, it is necessary to verify the following items:

- Feed material is appropriately conditioned and characterized;
- Adequate supplies of fuel, makeup water and cylinder gases exist;
- Adequate storage space for treated materials and residuals; and
- Cleanliness of material handling equipment (feed system, off-gas treatment system, and condensate tanks).

A generic start-up procedure follows: The desorber and off-gas treatment systems are to be started in a sequence that does not allow contaminant release. Specifics of dryer startup involve establishing flame in the furnace of the dryer, warming the cylinder to the desired operating temperature, and charging the feed system. The off-gas treatment system startup procedure should be initiated at least one hour prior to the start of feed to the dryer. A specific sequence of starting the off-gas treatment system is to be observed. The sweep gas system is started first, then the gas monitors (CO, Organics, and O_2) should be started to allow for a warm up period. Specifics regarding the sequence of the off-gas treatment unit are system specific and dependent on the system design.

Start up procedures for a thermal desorption system are established to ensure that operation of the treatment system does not compromise the safety of the personnel, of the process, or create any damage to the system.

General components of a thermal desorption system which require specific procedures for start-up include the following:

- Electric power source;
- Fuel sources/supply;
- Sweep gas supply/system;
- Off gas blowers;
- Temperature alarms and monitors;

- Pressure alarms and monitors;
- Oxygen alarms and monitors;
- Off-gas treatment alarms and monitors for pressure and temperature;
- Product handling system; and
- Dryer system.

System specific detailed operating procedures for thermal desorption unit startup, normal operation, shutdown and emergency situations are established by the thermal desorption contractor and or unit manufacturer. The system operating manual should be made available at the site.

3.3 Start-Up Sampling Plan. CEGS 01450 Chemical Data Quality Control should be edited to include the appropriate requirements for start-up. Sampling to verify the normal processing rates and contaminant concentrations of waste feed to the thermal desorber unit and the normal production rates and contaminant concentrations of process residuals should be performed prior to placing the thermal desorption system into continuous operation. The frequency of routine quality control sampling may be reduced during continuous operation on materials from the same contaminated area.

Start-up sampling may include the following:

- Sampling and analysis of waste feed stockpile.

- Sampling and analysis of residual solids at the stockpile. Treated materials should be analyzed in accordance with the Toxicity Characteristic Leachate Procedure (TCLP) for the presence of metals above threshold limits as defined in 40 CFR § 261.

- Sampling and analysis of scrubber blowdown and fabric filter solids.

- Sampling and analysis of the stack gas.

- Sampling of all temperatures, pressure, flow rates (where possible) and chemical analysis of the solids, liquids and gases at the inlet and outlet of each unit in the process. This will be used to determine if each unit is operating as designed.

If analysis of any of these streams indicates that the desorption system is not meeting performance requirements, the appropriate adjustments can be made to the control set points before placing the system into normal operation.

ER 1110-1-263, Chemical Data Quality Management for Hazardous Waste Remedial Activities; and EM 200-1-3, Requirements for Preparation of Sampling and Analysis Plans contain requirements governing quality assurance requirements for sampling and analysis.

4. Treated Materials Management Plan. Treated materials not found to be a characteristic hazardous waste by toxicity may be used for backfill on-site or disposed of in a non hazardous landfill. Treated materials that fail the TCLP metals will need to be stabilized by solidification and/or disposed of at an approved RCRA landfill. Applicable requirements regulating the transport of such materials must be met.

5. Site Safety and Health Plan. CEGS 01110 Safety Health and Emergency Response (HTRW/UST) contains the Contract requirements for the Site Safety and Health Plan.

Information relating to USACE safety and health requirements can be found in the following documents:

- Safety and Health Requirements Manual: EM 385-1-1
- Safety and Occupation Health Document Requirements for Hazardous Toxic and Radioactive Wastes: ER-385-1-92

The safety and health plan will incorporate requirements for employee training, protective equipment, medical surveillance, and the contingency plan for workers entering the exclusion and contamination reduction zones.

6. Shutdown Procedures.

6.1 Normal Shutdown. Normal shutdown procedures will vary with the particular thermal desorption system selected and are generally included in the facility operations plan. Normal shutdown procedures define the detailed sequence of activities required to cease waste feed, fuel feed and power to the thermal desorption system and enable the thermal desorber to safely cool down.

6.2 Emergency Shutdown. Emergency shutdown procedures are generally included in the facility operations plan and typically consists of the following sequence of activities:

- Shut off of both feed and burners (If a hot kiln is stopped from rotating, it could warp).

- Sound the appropriate facility emergency alarms.

- Disconnect the main power feed to the thermal desorption system.

- Follow the Site Safety and Health Plan.

- Investigate and report the cause of the incident.

- Modify operations in accordance with the incident findings and recommendations

7. <u>Labor Requirements</u>. Construction and operating labor requirements are site specific and will vary depending upon the size and complexity of the thermal desorption system selected and the quantity of contaminated material to be treated. Labor requirements may include the following:

- Mobilization and demobilization.

- Erection and set-up of processing equipment and site auxiliary facilities.

- Excavation and transport of contaminated materials and transport of process residuals.

- Feed operation.

- Start-up and operation of processing equipment.

- Maintenance of processing equipment and auxiliary facilities.

- Sample collection, preservation, shipment and analysis.

- Backfill operation.

- Construction Quality Assurance.

- Security personnel.

- Supervisory personnel.

- Site Safety and Health Officer.

8. <u>Sampling Plan</u>. The sampling plan should be detailed enough to monitor the operation of the thermal desorber and to demonstrate compliance with applicable regulations. Sampling programs for thermal desorbers are not required to be as comprehensive as sampling programs for incinerators.

A thermal desorber quality control sampling plan may include:

Process Control Monitoring - The process controls required to maintain quality during the remediation include pressure measurements, flow measurements, temperature measurements, and air pollution control sampling and measurements.

Data acquisition and collection systems collect data, process it in a desired fashion, and record the results in a form suitable for storage, presentation, or subsequent processing. For example, a record potentiometer is a simple data acquisition system that may be used for collecting temperature data from thermocouples.

9. Analytical Accuracy. Data evaluation should be conducted according to project specific plans (contractor and government) produced in accordance with CEGS 01450 and ER 1110-1-263.

10. Corrective Action Plan. Corrective action procedures are implemented for on activities which do not meet the specifications outlined in the design and construction package. Corrective actions are usually addressed on a case-by-case basis for each project. The need for corrective actions is based on predetermined limits for acceptability. For example, activities which result in the implementation of a corrective action plan include the following:

- Samples which do not meet the specifications;
- Activities are substantially behind schedule;
- Treated soil does not meet specified requirements; or
- Incidents causing injury or down time.

The corrective action would include activities to rectify the problem. A corrective action should include resampling and reanalyzing samples for analytical problems and retreating contaminated materials that contain residual organics. The Corrective Action Plan Report would outline activities to be executed to rectify the specified problem and to preclude recurrence.

11. Maintenance Requirements. Equipment operation and maintenance instructions will generally include information regarding routine maintenance and troubleshooting. These

instructions should be incorporated into the overall facility operations plan.

The frequency of routine maintenance will vary depending upon the type and throughput of the materials handled and the complexity of the equipment item.

11.1 Cleaning. Maintenance procedures may specify the periodic cleaning of the desorber inlet and discharge ports and transport belt, if furnished, residue collection devices, conveyor belts and screws, feed hoppers and meters, particulate removal devices and filter media.

11.2 Lubrication. Maintenance procedures will typically specify the periodic lubrication of rotating and moving parts of equipment and machinery components including bearings, shafts, chain drives, gearing, and any friction producing components.

11.3 Inspection. Routine inspection procedures will vary widely depending upon the thermal desorption system selected. Operations personnel should refer to the facility operations plan for details.

11.4 Media Regeneration or Replacement. Routine maintenance procedures will typically include instructions for the periodic regeneration of ion exchange media and the regeneration or replacement of activated carbon if such equipment is incorporated into the particular thermal desorption system used.

11.5 Spare Parts. The operation and maintenance instructions furnished by the contractor will generally include recommended spare parts lists. The inventory of spare parts that must be maintained at the remediation site will depend upon the complexity of the particular thermal desorption system used and the projected life of the remediation project. Parts of the technology that are prone to break down or have high wear and tear demands should have readily available replacements onsite or in a nearby locations. Parts associated with materials handling, such as auger or screw conveyors that move soil in and out of the unit, are particularly susceptible to break down.

APPENDIX G
DESIGN AND CONSTRUCTION PACKAGES

The Corps design team, or an A/E under contract, prepares the Design and Construction package which consists of the Design Analyses and the Contract Documents (plans and specifications). Contractor requirements regarding the preparation of documentation are incorporated into the specifications prepared from the appropriate CEGSs.

This Appendix provides guidance for the type of information required, for preparation of a design and construction package for a thermal desorption remediation project. As discussed in the Introduction, it is not the intent of this document to provide a step-by-step procedure of this package, but rather to provide general guidance on the type of information that should be provided in this package. The documents used to prepare specifications fall into two categories: criteria (TM's, ER's, ETL's) and specifications (CEGS). Criteria documents (TM's, ER's and ETL's) are used to help prepare plans and specifications for the package and edited CEGSs are used in the construction contract.

All activities previously conducted on a project culminate in the preparation of a design and construction package. Since thermal desorption specifications are generally performance based rather than design based, the amount of detail provided in the package is subject to the discretion of the design engineer managing the project. There may be portions of the project that are design based such as civil engineering components.

1. Design Analysis. The design analysis is prepared by the AE or Corps design team to document the design decisions. ER 1110-345-700 Design Analysis, establishes the requirements and procedures for preparation of design analyses for military construction projects. For the purposes of this document a design analysis is defined as an assembly of all functional and technical requirements, and all design provisions and calculations applicable to the project design.

The Design Analysis is produced concurrently with the project Specifications, and is complete prior to the contract being awarded. Therefore, the Design Analysis should include only generic thermal treatment unit specifications, such as; types of contaminants treated, range of feed rates, types of systems, and generic removal efficiencies of various contaminants will be used to conduct the evaluation.

Site specific selection criteria to be used in the design analysis of a thermal desorption treatment system include: pretreatment requirements of the soil, concentrations and types of contaminant(s) of concern in the soil, moisture content of the soil, heat value of the soil, USGS soil classification, origin/source of the contaminated soil, quantity (tonnage) of soil to be thermally treated, analytical tests confirming status of the soil as either hazardous or nonhazardous waste, treatment criteria for each parameter/contaminant of concern after thermal desorption remediation, disposal requirements for treated soil, and analytical methods required for each parameter (U.S. EPA, 1994). Also, the Design Analysis should include criteria such as thermal treatment unit and support equipment location, pretreatment equipment location, soil staging areas (treated and untreated), and availability of utilities.

2. Treatability Studies. In order to provide additional information to potential bidders, a Treatability Study, or pilot scale test, may be performed on the site soils. These studies incorporate various combinations of temperature, retention time and contaminant removal rates. Depending on the type of thermal desorption unit/process selected for non-fuel contaminated soils, a treatability study, consisting of pilot scale test burn of the soil material would be required to identify the exhaust gasses resulting from the thermal process.

Results from the treatability studies are used to establish system performance criteria to be met by the designated thermal contractor. Based on this information, modifications of an existing thermal desorption unit's system operating parameters can be optimized to meet the specified performance criteria. System performance criteria is included in the performance specification for the thermal treatment unit for any and all contractors to bid on.

3. Plans for Bidding and Construction. This section reviews drawing information needed for preparation of a design and construction package. For a thermal desorption remediation project, the following types of drawings are essential for bidding and construction:

- Title Sheet, and Index of drawings
- Vicinity Map and Location Plan,
- Site Plan showing existing ground elevations and contours,

- Site Plans showing locations of adjacent buildings, utility line locations, wetlands, and surface water bodies,

- Plans and Cross Sections showing extent of contamination, groundwater flow, direction and elevation,

- Plan indicating the location of thermal treatment system, soil stockpile storage, staging area for treated and untreated soils, pretreatment area (materials handling), office trailers, other necessary support equipment,

- Plan and Cross Sections showing the area and depths of excavation,

- Soil Stockpile Details,

- Plan and Cross Sections showing the site after remediation with final grading after backfill.

- Flow Diagram of the thermal treatment process including all pre/post treatment process steps and all pre/post sampling points

EM 1110-1-1807 (Standards Manual for U.S. Army Corps of Engineers Computer Aided Design and Drafting CADD Systems) provides standards and procedures for CADD uses and applications and ER 1110-345-710 (Drawings) details the requirements and procedures for preparation and approval of drawings for military construction projects.

In addition to the previously listed drawings required for preparation of a design and construction package, the analytical test methods used to illustrate compliance with: performance specifications for soil treatment, residuals from the thermal desorption treatment system, and air methods to demonstrate compliance with air emissions should also be identified. Table G-1 is a summary of typical methods used in sample analysis and the appropriate method required for the remediation project should be included in CEGS 01554 Sampling and Analysis Requirements.

TABLE G-1
Typical Methods
for Sampling and Analysis

Constituent	Analytical Method
Solids Methods to Demonstrate Compliance with Performance Specifications	
Total Petroleum Hydrocarbons	EPA 418.1
TCLP Extract Concentration	EPA 1311 (extraction), EPA 6010/7000 (metals), EPA of metals or organics 8240 (volatile), EPA 8270 (semi-volatile), EPA 8080/8150 (pesticides/herbicides)
Metals Concentration	EPA 3050 (acid digestion), EPA 6010 (metals) (As,Ba,Cd,Cr,Pb,Hg,Se,Ag)
PCB	EPA 8080
Moisture Content	ASTM D 2216
Soil Bulk Density	ASTM D 2937, or ASTM D 1556, or ASTM D 2922, or ASTM D 2167
USCS Soil Classification	ASTM D 2487
Air Methods to Demonstrate Compliance with Air Emissions Standards	
Stack emissions (continuous): CO,CO_2,O_2,Opacity,HC,NOx,SOx	Continuous Emissions Monitors
Stack emissions (routine):	Multiple Metals Train by EPA Method 29
Arsenic (total)	EPA Method 7060/7060 SW 846
Lead (total)	3020/7421
Stack emissions (compliance):	Multiple Metals Train by EPA Method 29
Total Arsenic	7060/7060
Total Barium	3005/7080
Total Cadmium	3005/7130

TABLE G-1 (cont)
Typical Methods
for Sampling and Analysis

Constituent	Analytical Method
Total Chromium	3005/7190
Total Lead	3020/7421
Total Mercury	7470/7470
Total Selenium	7740/7740
Total Silver	7760/7760
Particulate	EPA Method 5
HCl	EPA Method 5 with Na_2CO_3 impinger
Volatile	VOST/0030, SW846 5040
Base Neutral/Acid Extractable	EPA modified Method 5/0010 SW846 3540/8270 Impinger (water) catches to be retained for analysis
Pesticide	EPA modified Method 5/0010 SW846 3540/8080 Impinger (water) catches to be retained for analysis
Dioxin (2,3,7,8-TCDD)	EPA Modified Method 5/0010 SW846 3540/8280
Dioxins and Furans	EPA Method 23
Ambient Air/Quality Testing/TWA Monitoring:	
Benzene	NIOSH 1501
Toluene	NIOSH 1501
Xylenes	NIOSH 1501
Naphthalene	NIOSH 1501
Lead	NIOSH 1501
Arsenic	NIOSH 1501
Chlordane	NIOSH 1501

TABLE G-1 (cont)
Typical Methods
for Sampling and Analysis

Constituent	Analytical Method
Ambient Air, Compliance (EPA)	
Volatile	TO-14
Naphthalene	TO-13
Chlordane	TO-10
Dioxins	TO-9
Lead	40 CFR 50 Appendix G
Arsenic	40 CFR 50 Appendix G
Particulates	40 CFR 50 Appendix G

4. Specifications. Specifics regarding the preparation, processing and obtaining approval for specifications are set forth in ER 1110-345-720 Construction Specifications. A publication entitled Index to Standard Specifications for Civil Works Construction is issued quarterly as an aid in checking such references in the civil works guide specifications. Three indexes, Civil Works, Military, and Abridged Military are available for Guide Specifications. Depending on project requirements, these indexes could serve as an additional information source.

4.1 Corps of Engineers Guide Specifications and Criteria Documents. The project Specifications will be developed in accordance with, but not limited to, the following list of guide specifications (CEGS). A guide specification for thermal desorption with the CEGS number 02289 is currently (April 1996) under development.

- 01110 Safety, Health, and Emergency Response (HTRW/UST)
- 01440 Contractor Quality Control;
- 01450 Chemical Data Quality Control;
- 02210 Grading;
- 02288 Remediation of Contaminated Soils and Sludges by Incineration;
- 02445 Solidification/Stabilization of Contaminated Material.

USACE criteria documents which provide detail for thermal desorption remediation projects include, but not limited to, the following:

- TM 5-818-1 — Soils and Geology Procedures for Foundation Design of Buildings and Other Structures (Except Hydraulic Structures)
- TM 5-818-4 — Backfill for Subsurface Structures
- ER 1110-1-263 — Chemical Data Quality Management for Hazardous Waste Remedial Activities
- ER 1110-345-700 — Design Analysis

4.2 Specification Requirements. The submittals requirements of the specifications should require the contractor to provide technical information on the execution of the project including a summary of experience and the technical approach to completing the following plans. After award of contract, the contractor obtains necessary permits and completes the project. The following bulleted items are relevant to the operation of thermal treatment units and may be part of a Remedial Action Work Plan.

- To ensure that the selected contractor addresses all chemical quality control management details associated with the site, and that all technical data generated is accurate and representative, contractor submittals regarding chemical data quality should be produced in accordance with 01450 - Chemical Data Quality Control. Analysis programs may include, but are not limited to the following: soil sampling program, sampling and analysis of feed material, sampling and analysis of residuals from treatment system, sampling and analysis of thermal unit by products (e.g. scrubber water), sampling and analysis of exhaust gases, sampling and analysis of ambient air conditions at the perimeter of the site, sampling and analysis of all of all foundations or structures utilized in the remediation before disposal, and characterization of soils for restoration of the site.

  As part of the SAP, the Contractor shall prepare a Field Sampling Plan and a Quality Assurance Project Plan in accordance with the USACE document EM 200-1-3 Requirements for the Preparation of Sampling and Analysis Plans. These two items shall provide a comprehensive sampling plan for all matrices sampled, identify the procedures to be used to obtain representative data. The plan should contain a comprehensive sampling plan for all matrices sampled, identify the procedures to be used to obtain representative data. The plan should contain descriptions of sampling equipment, sample containers, sample size, sample preservation, sample shipment, and sample program organization. The QAPP shall also describe the Quality Management Organization which will define the organization, and the authority and responsibility of persons performing quality management activities.

- Site, Safety and Health Plan. (CEGS 01110 Safety, Health, and Emergency Response (HTRW/UST))

- Contractor Quality Control Plan (CQC Plan CEGS 01440 Contractor Quality Control). This is a contractor supplied document which organizes all measurement and testing phases of the remediation starting from the point the contractor receives authorization to proceed. The CQC Plan may be broken down into the following subsections: excavation, thermal desorption unit erection (if on-site), thermal treatment of contaminated soils, backfilling, site restoration, site closure, and quality control and quality assurance operations.

  The CQC Plan must demonstrate an understanding of the site remediation project and summarize the contractors decision making processes that impact the eventual cleanup and closure of the site.

- Thermal Treatment Unit Operation. The Specifications shall include the conditions under which the thermal desorption unit shall operate, as determined in the Treatability Study or Demonstration Test. The contractor is required to operate the thermal desorption unit under conditions that are proven to meet performance standards. The plan is broken down into the following subsections: normal operation, system operating limits, waste feed cut-off system, normal start-up and shut-down procedures, emergency shut-down procedures, and system alarms. The Contractor shall also provide a Demonstration Test Plan which details the procedures for conducting the Demo Test, and the associated sampling requirements.

- Materials Handling Plan. The contractor shall identify and address issues concerning the handling procedures for the residuals from the thermal treatment unit which include: treated and untreated soil, scrubber water, decon water, pretreatment process water, stabilization chemicals, and APC residuals.

4.3 Project Specifications. In addition the following specifications are also required:

- Concrete structure construction specifications (TTU pad, decon pad, pre-treatment pad),
- Desorption performance criteria (see Appendix E), analytical equipment, and process controls (see Appendix E),
- Closure (see Appendix H).

The civil related specifications such as the excavation, backfill, pavement and concrete structure construction are detailed in the Corps of Engineers Guide Specification (CEGS) series.

4.3.1 Support Systems and Utilities. Support systems required for thermal desorption remediation activity include: trailers for contractor personnel and equipment, parking space for contractor and site personnel, portable toilets, site security (if required), communications (telephones, computers, and fax machines), contingency area for additional storage of soil stockpiles, decontamination area and a hazardous materials storage area.

Utility requirements include telephone lines to the trailers, electrical connection for thermal desorption treatment process power requirements, heating, lights and computers, and water for decontamination and treatment purposes, and natural gas connections for thermal treatment fuel requirements.

4.3.2 Reporting Requirements. Detailed reporting requirements should be included in the appropriate project specifications described above. Reporting requirements during the construction activities should include, but not be limited to:

- Contractor Weekly Data Quality Control Report - This report should contain as a minimum, a discussion on the location of work, weather information, quality management inspections and results, problems identified during the work week and any corrective actions.

- Notification of Problem Report - This report should be written in the event a problem at the site occurs which results unexpected in deviation from the schedule. Types of problems include unexpected difficulties with excavation and analytical laboratory conflicts. The report is intended to define the problem, present a corrective action plan, and identify impacts on the schedule. The report should be typically be written within 2 to 3 days of a significant incident.

- Health & Safety Incident Report - This report should be written in the event an OSHA reportable accident or incident occurs.

- Backfilling Reports - This report shall provide execution details of the systematic plan developed in the CQC Plan in which soils will be deemed safe for backfilling on site.

- Thermal Treatment Unit Bi-weekly Progress Reports - These reports should document the contractor's progress during all stages of thermal treatment operations (i.e. start-up, shakedown, and production burn). The contractor shall also submit monthly operating data reports documenting the operating data captured during the month of operation.

- Demonstration Test - These reports shall document the findings and analytical results of the demo test.

APPENDIX H
CLOSURE

1. Closure Requirements. Upon completion of waste treatment, the site will undergo closure activities. Closure can be separated into two categories: "clean closure" and "closure in place." Clean closure signifies that all waste was removed from the site and clean fill substituted to restore the site to its original condition. "Closure in place" signifies that some amount of hazardous waste or residue remains at the site.

Typical information included in a closure plan are:

- Closure requirements;
- Inventory of hazardous wastes at the site;
- Methods for disposing hazardous waste and treatment residuals;
- Procedures to decontaminate facility equipment;
- Planned monitoring activities (monitoring is required for 30 years for Superfund and RCRA sites); and
- Estimate of closure costs.

In some cases completion/closure of one activity will prepare the site for the next activity. For many site closures this may include a possible groundwater remediation phase. Activities may also include decontamination, if necessary, and demobilization of the desorber unit, water treatment unit, buildings, foundations, equipment and support facilities. To properly manage any treated residuals remaining at the site after completion of closure activities, a combination of deed restrictions, institutional controls and ground cover can be used to limit future site access and land use.

2. Disposal of Treated Materials and Residuals. Thermal desorption processes are ineffective for removing inorganic compounds and most metals from contaminated solids. The treated material must be analyzed in accordance with the Toxicity Characteristic Leachate Procedure (TCLP) for the presence of metals above threshold limits as defined in 40 CFR § 261. Residues generated from management of air emissions would only have to comply with land disposal restrictions if the ash/dust exhibits a hazardous waste characteristic, regardless of whether the original soil exhibited a characteristic. This would be the case because the air emissions residues could be considered to be a newly generated waste rather than the original treated soil. Even if the original soil was non-hazardous, there is the potential that

treatment residues may exhibit one or more hazardous waste characteristic, principally the metallic TCLP characteristics. As concentrations could vary by residue source, the treated soils should be analyzed separately from air emissions residues.

3. Backfilling of Treated Solids On-site. Providing that the treated solids meet all cleanup criteria and any applicable land disposal restrictions, it may be used on-site as backfill. This will avoid additional costs associated with transporting off-site backfill to the site and transporting and disposing of the treated solids. Also, to limit the amount of treatment residuals leaving the site, it is preferable to use the treated solids on-site as backfill.

Compaction specifications adhered to during backfilling activities will depend on the future use of the site. It is possible that there will be no compaction requirements if the site has future land use restrictions. The backfill area must be graded to provide stable slopes and to allow for adequate surface water drainage. Even if treated solids are used as backfill, off-site soil may still be required as a supplement to provide the desired grades.

Refer to the following document for guidelines on compaction and grading activities:

- TM-5-803-8, Land Use Planning, August 26, 1994. This manual provides guidance for Army personnel and consulting firms that prepare land use plans at Army Installations.

- TM 5-818-4, Backfill for Subsurface Structures, June 1983. Manual provides guidance for design, planning and execution of earthwork around deep seated or subsurface structures.

4. Landscaping. Gravel covering may be required to prevent environmental or human exposure to treated materials and remediated areas. A gravel cover is also used to promote surface water infiltration into the ground to facilitate a groundwater remediation system. A clay cap may be required if there is any material left on-site which does not meet cleanup criteria. The clay cap would prevent surface water from carrying contaminants from the materials into the groundwater. Uncovered areas and slopes, in particular, may have loam and seed applied to them for erosion and dust control. Wetlands which were disturbed or destroyed during remediation activities must be restored by bringing in approved backfill

and plants. Non-wetland areas that were disturbed by remediation activities may be restored with plantings for community relation purposes.

Refer to the following document for guidelines on planting:

- TM-5-803-13, Landscape Design and Planting, August 1988. This manual provides planting design guidelines
- CEGS 02110 Clearing and Grubbing
- CEGS 02210 Grading
- CEGS 02935 Turf
- CEGS 02950 Trees, Shrubs, Ground Covers and Vanes
- CEGS 02955 Crown Vetch

5. Demobilization. Demobilization will include activities required to disassemble and remove the desorber unit, buildings, foundations, equipment, supports and all auxiliary facilities from the site. If remediation work (e.g. groundwater remediation) is to continue at the site, some equipment and buildings may be left behind after the demobilization phase. Institutional controls, such as fencing and lighting, may be required around the perimeter of the site. These institutional controls will provide security for future remediation activities and to help prevent trespassers from coming in contact with remediated materials.

6. Site and Equipment Decontamination. Demobilization will include the decontamination of any buildings, foundations , supports or equipment that were located within the exclusion zone. The decontamination stations will be left intact until all necessary decontamination is completed. Once the water treatment unit, if any, is taken out of service, all decontamination water will need to be transported off-site for disposal.

7. Long Term and Short Term Monitoring Requirements. Monitoring requirements are generally determined on a site-by-site basis. Compliance monitoring occurs when hazardous wastes constituents have been detected in groundwater down gradient of the site. Monitoring wells may be required within and outside of the site if groundwater contamination is a concern. The frequency, duration and type of monitoring will depend on the extent and type of contamination at the site.

If groundwater monitoring is required, periodic reports showing analytical and depth to water data will need to be submitted to the appropriate agencies.

In addition to the groundwater monitoring, the site should be monitored to assure that the perimeter fencing and lighting are in good condition. Gravel or soil coverings should not have any damaged areas. If any of the institutional controls, gravel covering or clay caps are damaged, repairs should to be made.

Restored wetlands would require periodical monitoring inspections by regulatory agencies. To assure that an adequate percentage of the plantings are surviving, these inspections will include vegetation coverage estimates. Photographs are generally taken to document the progress of the restoration.

APPENDIX I
DESIGN EXAMPLE FOR THERMAL DESORPTION ACTIVITIES

1. Overview. Following is a typical approach and basic information that is useful for design considerations and decisions for a thermal desorption application.

2. Quantity. Determine the quantity of soil in place requiring treatment.

Given:

- A site with soils contaminated with polyaromatic hydrocarbons. An investigation consisting of soil borings and analytical sampling was conducted at the site to delineate the areas of contamination. Based on information collected from the site investigation, the site has been divided into the following discrete areas of contamination:

Area No.	Dimensions	Depth of Contamination
1	76.2 m X 76.2 m (250 ft X 250 ft)	0.6 m (2 ft)
2	76.2 m X 76.2 m (250 ft X 250 ft)	6.1 m (20 ft)
3	76.2 m X 61 m (250 ft X 200 ft)	0.6 m (2 ft)
4	36.6 m X 137.2 m (120 ft X 450 ft)	0.6 m (2 ft)
5	45.7 m X 45.7 m (150 ft X 150 ft)	5.5 m (18 ft)
6	15.2 m X 15.2 m (50 ft X 50 ft)	0.6 m (2 ft)

Solution:

- In-Place Volume of Contaminated Material(soil): 56,600 m^3 (74,000 cy)

3. Unit Treatment Time. Determine the treatment time for an on-site thermal desorption unit to desorb the organic contaminants from the contaminated material, collect and condense the organic vapor.

Given:

- 56,600 cubic meters (74,000 cy) of contaminated material
- Unit process rate of 81,600 kg/day (90 ton/day)
- Down time of 30%
- Density of contaminated material 1780 kg/m^3 (1.5 ton/cy)

Assumptions:

- Feasibility study of site identified in (a) concluded on-site thermal desorption most effective technology for remediating 56,600 m^3 (74,000 cy) of contaminated material.
- Contractor submitting the lowest bid will utilize a thermal desorption unit capable of processing 81,600 kg/day (90 ton/day) of contaminated material.
- Density of contaminated material is 1780 kg/m^3 (1.5 ton/cy)
- Functional operation of the unit is 70% of rated capacity.

Solution:

- 100.748 X 10^6 kg (111,000 ton) contaminated material; [(100.748 X10^6 kg)/(81,600 kg/day)] = 1,234 days without downtime. Including downtime: 1,234 days * 1.3 = 1,604 days
- Treatment time for thermal desorption unit: 54 months

4. Unit Power Requirement. Determine the power requirement to thermally desorb 100.748 X 10^6 kg of contaminated material. Contaminant to be thermal desorbed: benzo(a)anthracene.

Given:

- Process rate of 81,600 kg/day (90 ton/day)
- Water content of soil 25%
- Boiling point of benzo(a)anthracene 435°C (815°F)

- Initial Temperature of Soil 20°C (68°F)
- Specific heat of soil 200 cal/kg°C
- Specific heat of water 1000 cal/kg°C
- Installation of heat recovery limited by temporary nature of system

Solution:

- Energy to heat 1 kg of soil to 100°C
  (1 kg)(100°C-20°C)(200 cal/kg°C) = 16,000 cal
- Energy to heat water (at 25%) to 100°C
  (0.25 kg)(100°C-20°C)(1000 cal/kg°C) = 20,000 cal
- Energy to boil off water
  (0.25 kg water)(5.4×10^5 cal/kg water) = 135,000 cal
- Energy to bring dry soil at 100°C to benzo(a)anthracene boiling point (435°C)
  (1 kg) (435°C-100°C)(200 cal/kg°C) = 67,000 cal
- Total energy to raise 1 kg of soil to boiling point of benzo(a)anthracene
  16,000 cal + 20,000 cal + 135,000 cal + 67,000 cal = 238,000 cal per kg soil

Condensation and condensate cooling system requirements

- To condense water
  (0.25 kg water)(5.4×10^5 cal/kg water) = -135,000 cal
- To cool water to 20°C
  (0.25 kg)(20°C - 100°C)(1000 cal/kg°C) = -20,000 cal

Due to the field set up with consequent energy recovery limitations, this energy will not be recovered.

Total energy requirement

- Total power required for 81,600 kg/day (90 ton/day) operation
  (81,600 kg/day)(238,000 cal/kg)(4.168 J/cal) (2.7778×10^{-7} kWhr/J)(1 day/24 hr) = ~ 942 kW

Assumptions:

- Feasibility study of site identified in (a) determined benzo(a)anthracene as the poly aromatic hydrocarbon compound of concern present in contaminated site soils which exceeded applicable cleanup goals.

- Data on the ability of low temperature thermal desorption to treat poly aromatic hydrocarbons reported the following results for an indirectly fired kiln: total poly aromatic hydrocarbons were reduced from approximately 4500 mg/kg to below 1.58 mg/kg and benzo(a)anthracene concentrations were reduced from 175 mg/kg to below 0.023 mg/kg.

- Contractor data exist indicating successful thermal treatment of similar contaminated material (benzo(a)anthracene) using unit capable of treating 81,600 kg/day (90 ton/day)

5. Process Residual Components. Determine the process residual components:

5.1 volume of water recovered from thermal desorption treatment

5.2 volume of organics (polyaromatics) recovered from thermal desorption treatment

5.3 flow rate to wastewater treatment plant

Given:

- 100.748 X 10^6 kg (111,000 ton) contaminated material

- 25% moisture content for contaminated material

- Average concentration of polyaromatics present in contaminated material 5000 mg/kg

- 54 months of operation

- density of water 1000 kg/m^3

Assumptions:

- Condensate from thermal desorption treatment contains 90% organics and 10% water by volume

- Wastewater flows to treatment plant during operation of thermal desorption system only

Solution:

- water present in soil
  (0.25 kg water/kg soil) (100.748 X10^6 kg soil)
  / (1000 kg/m^3) = 25,187 m^3 (6.66 X 10^6 gal) water

- condensate generated
  (0.005 kg organic/kg soil)(100.748 X10^6 kg)
  /(1000 kg/m^3) = 504 m^3 (133,000 gal) organics

- total liquid
  25,187 m^3 water + 504 m^3 organics
  = 25,691 m^3 (6.73 X 10^6 gal) liquid

- volume of organics recovered
  (504 m^3)/0.9 = 560 m^3 (148,000 gal) organics

- volume of water recovered
  25,691 m^3 - 560 m^3 = 25,131 m^3 (6.64 X 10^6 gal) water

- flow rate to wastewater treatment plant
  (25,131 m^3/1620 day) =~ 11 l/min (2.8 gal/min)

APPENDIX J
TREATABILITY SCOPE OF WORK

SCOPE OF SERVICES
FOR THERMAL TREATABILITY STUDY
[______]

[__] [MONTH] 19[__]

EXAMPLE
LOW TEMPERATURE THERMAL DESORPTION

TABLE OF CONTENTS

1. General.

1.1 General Statement of Services. The U.S. Army Corps of Engineers (USACE), [_____] District, is contracting for services, including analytical support, to execute a treatability study for desorption of HTRW contaminants from the contaminated materials from [_____ (site name)] and to prepare a treatability study report.

1.2 Qualifications.

1.2.1 Laboratory Validation/Certification. [_____ (certification for contaminants of concern)]

1.2.2 Chief Chemist. Qualifications of the chief analytical chemist designated oversee the analytical work shall be included in the work plan submittal. The chief chemist(s) shall have a minimum of six (6) years of experience, including four (4) years of organic chemical analyses.

1.2.3 Bench Chemists and Laboratory Technicians. Qualifications of the chemists designated to work on these tasks shall be included in the work plan submittal.

1.2.4 Quality Assurance Laboratory Validation/Certification. [_____ (certification for contaminants of concern)] shall be included in the work plan submittal

1.2.5 Chemical/Environmental/Process Engineer. Qualifications of the chief engineer designated to oversee these tasks shall be included in the work plan submittal. The engineer shall have a minimum of six (6) years of experience.

1.2.6 Project Manager. This scope will be assigned a project manager (PM), to serve as the single point of contact for submittals, schedules and information regarding the status of the work. Deviations, changes, inadequacies of any kind, and any questions related to compliance with this delivery order shall be immediately reported to [_____], at the [_____] District ([_____] AC) [_____]-[_____] (CE[_____]-[_____]-[_____]).

2. Reference Documents and Publications. Guidance and publications containing pertinent information include the following:

ETL 1110-1-173	Thermal Desorption
EM 385-1-1	Safety and Health Requirements Manual
ER 385-1-92	Safety and Occupational Health Document Requirements for Hazardous, Toxic and

Radioactive Waste (HTRW) Activities
ER 1110-1-12 Quality Management
ER 1110-1-263 Chemical Data Management for Hazardous Waste Activities

3.0 Information.

3.1 Quality. Quality management shall be in accordance with ER 1110-1-263 and ER 1110-1-12. The AE is responsible for completeness and accuracy of work performed under this scope, and for compliance with all parts of the scope. Comprehensive quality control reviews shall be performed for accuracy, completeness of the work, compliance with the scope and satisfaction of the scope requirements.

3.1.1 Completeness of Work. All deficiencies identified by the quality control review and/or by the Government shall be corrected.

3.1.2 Accuracy of Work. All data shall be verified and all calculations shall be checked in the quality control review. The Inaccuracies and errors identified either by the Government or the quality control review shall be corrected.

3.2 Confidentiality. Documents and information developed or obtained in performance of the work shall be considered privileged information of the United States Government. Information shall not be released to anyone other than the officers, employees and agents who need to have access to the information to perform the work and U.S. Government officers designated by the POC. Requests for release of any of the information shall be referred to the POC for reply. The obligation to maintain the confidentiality of this information shall extend beyond the completion of this scope until released by the POC or determined by a federal court of competent jurisdiction.

3.3 Conflict of Interest. Prior to proposal submission, AE and subcontractor(s) employees with access to the information and documents shall identify any potential conflicts of interest (COI) with the requirements of this scope. Any past or on-going work conducted by, or involving, the Contractor, subcontractor(s), or respective personnel, for the Corps of Engineers, EPA, or other regulatory agencies regarding services required by this scope, may be considered as a COI. If the potential for a conflict exists, the USACE must be notified when it is discovered for a determination of eligibility for award of this scope. A statement on the potential for conflicts must be provided with the initial proposal for this scope.

3.4 Services and Materials. All labor, travel and work described in the scope shall be supplied. All services, supplies, materials, materials, equipment, plants, labors, and travel necessary to perform the work and render the data required under this scope are required to be furnished. Included are laboratory equipment, micro computers, commercial software packages, modems and facsimile (FAX) machines required to perform the work.

4.0 Progress and Payments. Progress reports showing scheduled and actual performance and task completion dates shall accompany each payment request. Each listed task shall be completed and approved prior to commencing work on the next listed task. Final payment on delivery orders will be made after all work is completed in compliance with the delivery order, after all required documentation has been submitted, and after all government audits and reviews have been completed.

5.0 Submittals, Meetings and Travel. Personnel may be required to travel to attend meetings scheduled at the [_____] Offices, [____ (city)], [_____ (state)], as part of this delivery order. Responsible representatives, approved by USACE for participation in the pilot study, shall attend the indicated meetings. The representatives shall annotate comments and prepare meeting notes for each review meeting. Costs associated with travel shall be separately itemized in the delivery order cost. The AE shall assume, for purposes of negotiation, that two people from the firm will attend each meeting.

5.1 Task 1: Treatability Study Work Plan. The work plan will include an execution plan for development of the treatability study in accordance with the criteria with explanatory text and notes and a detailed outline of the suggested technical requirements for each of the sections. The plan shall identify the equipment and personnel for accomplishing each effort.

5.2 Task 2: Treatability Study Work Plan Review, Coordination, and Meeting Number 1. Appropriate personnel shall attend a review meeting to address various subjects pertaining to the treatability study after receiving USACE comments on the work plan. Comments will be forwarded in advance to allow annotation prior to the meeting. A copy of the annotated comments shall be forwarded along with major points requiring discussion prior to the review meeting. Appropriate personnel shall make a presentation of the plan, the outline, total effort, content and the work accomplished to date. Appropriate personnel shall participate in discussion designed to ensure understanding of the agency goals. The result of this meeting will be further USACE guidance and direction to proceed. Responsible team personnel shall be identified to be approved in this preliminary meeting.

Revisions to the execution plan may be required as a result of this meeting.

5.3 Task 3: Task 3: Sample Collection, Preservation, Transportation, Treatability Study Execution and Draft Report. The study shall be performed and a full draft of the treatability study report shall be prepared, in accordance with guidance and direction received at the initial submittal meeting, which shall be submitted for USACE review and approval.

5.4 Task 4: Draft Review, Coordination, and Meeting Number 2. Appropriate personnel shall attend a review meeting to address various subjects pertaining to the treatability study after receiving USACE comments on the draft report. Comments will be forwarded in advance to allow annotation prior to the meeting. A copy of the annotated comments shall be forwarded along with major points requiring discussion prior to the review meeting. Appropriate personnel shall make a presentation of the report and participate in discussion designed to ensure understanding of the agency goals. Revisions to the report may be required as a result of this meeting. Technical personnel shall participate in discussion with USACE personnel regarding comments and revisions to the draft report. The meeting will result in USACE direction for the AE to complete the final report.

5.5 Task 5: Final Treatability Study Report. The report shall be completed for implementation and record purposes in accordance with this scope of services. The final report will incorporate all approved comments generated by review of previous submittals, any revisions in the format, technical content, grammar or as otherwise required to ensure the documents are in the proper form.

5.6 Schedule.

Scheduled Task	Day of Required Completion
Notice to Proceed	CD [_____]
Task 1: Work Plan	CD [_____]
Task 2: Work Plan Review, Coordination, and Meeting Number 1	CD [_____]
Task 3: Sample Collection, Preservation, Transportation, Treatability Study Execution and Draft Report	CD [_____]

Task 4: Draft Review, Coordination, and Meeting Number 2 CD [_____]

Task 5: Final Report CD [_____]

Total calendar days [_____]

6.0 Format and Presentations.

6.1. A cover page shall identify the Corps of Engineers, [_____] District, Control Number and the date.

6.2 This statement of work shall be attached to the work plan and draft reports. Submittals shall include incorporation of all previous review comments and the disposition of each comment. Submittals shall be complete and not just copies of affected pages. Disposition of comments submitted with the final submittals shall be separate from the documents.

7. Technical Requirements. (See attached outline)

8. Project Records and File.

8.1 Project File. All memos and records obtained or developed in the performance of this scope shall be assembled with a complete index at the completion of this scope. Records shall be organized using a chronological method with a supplementary topic index. Originals of project records, including the index, shall be placed in secure boxes, marked with the control number and sent to the POC. Copies of any of the correspondence and records shall not be retained without written permission from USACE.

8.2 Meeting Notes. Notes and reports for meetings shall be prepared in typed form and the original furnished tothe POC (within ten working days after the date of the meeting) for concurrence and distribution.

Meeting reports shall include the following items as a minimum:

- Project name and control number.
- Date and location of the meeting.
- Attendance list including each name, organization, telephone and FAX numbers.
- Written comments with the action noted shall be attached to each copy of the report. Action shall be "A" for an approved comment, "D" for a disapproved

comment, "W" for a comment that has been withdrawn by the government with the approval of the commenter, and "E" for a comment that has an exception noted.

- Discussion items.

8.3 Record Memos. A record or file memo of each contact, meeting, conference, discussion, telephone conversation, or verbal directive regarding the subject documents irrespective of who the other participants may have been will be prepared. Records and memos shall be dated and shall identify participating personnel, subjects discussed and conclusions reached. Memos shall be numbered sequentially and shall be incorporated in the project file. Any distribution of these memos shall be made by the Government.

8.4 Correspondence. A record of each piece of written correspondence related to the performance of this Delivery Order shall be kept. The pieces of correspondence shall be numbered sequentially and shall be incorporated in the project file as described in paragraph 8.1. Any distribution of said correspondence shall be made by the Government.

8.5 Issues. Issues requiring Corps action or response and issues regarding the schedule shall be highlighted by a letter to the POC.

9. Document Distribution. Unless otherwise directed, submittals and review material shall be submitted to the following addresses:

Number of Copies	Item	Addressee
[_____]	Memos Work Plan Draft Final	Commander U.S. Army Engineer District, [_____] ATTN: [_____] [_____] [_____] [_____] [_____ (City)], [_____ (St)] [_____]-[_____]
[_____]	Memos Work Plan Draft Final	Commander U.S. Army Engineer District, [_____] ATTN: [_____] [_____] [_____] [_____] [_____ (City)], [_____ (St)] [_____]-[_____]

(Enclosure 12 ETL 1110-1-154)

10. Treatability Studies And Treatability Studies Reports

****

Treatability studies are performed as necessary and appropriate for the waste materials and evaluation of treatment options. If any treatability studies are performed, the report should be completed and submitted, even if the recommendation is not to use the process. Contracting for treatability studies is difficult and inappropriate before the contaminants and contaminated media are identified and quantified. It is a good idea to include an option for treatability studies in most predesign scopes. Treatability studies are not always required.

See the EPA "Guidance for Conducting Treatability Studies Under CERCLA," EPA/540/R-92/071a October 1992 for general guidelines.

The process engineer (either an environmental engineer with process design experience or a chemical engineer with design experience), the geologist (if the treatability study would be testing the withdrawal of ground water or soil vapor), the geotechnical engineer (if the contaminated media is soil), and the chemist need to be involved in development of the scope of any treatability study.
****

1. Identifying Sources for Results of Previous Treatability Studies on Similar Materials

1.1 Literature Search/Expert Judgment

****

Reports and Documents
Guidance for Conducting Remedial Investigations and Feasibility Studies
Superfund Treatability Clearinghouse Abstracts
The Superfund Innovative Technology Evaluation Program: Technology Profiles
Summary of Treatment Technology Effectiveness for Contaminated Soil
****

1.2 Electronic Data Bases

****

Alternative Treatment Technology Information Center (ATTIC)

Computerized On-Line Information System (COLIS)
OSWER Electronic Bulletin Board System (BBS)
RREL Treatability Data Base
****

1.3 EPA Personnel Consultations through EPA RPM

****

Robert S. Kerr Environmental Research Laboratory Ground-Water Fate and Transport Technical Support Center Ada, OK
Risk Reduction Engineering Laboratory Engineering Technical Support Center Cincinnati, OH
****

2. Treatability Study Work Plan Outline

****

The treatability study Work Plan should be submitted and approved before initiation of the sampling for treatability studies. Chemists, geologists, geotechnical engineers, industrial hygienists, process design engineers, and regulatory personnel should review the Work Plan for a treatability study. This plan would be considered an attachment to the project Work Plan and would not, to the extent practical, reiterate information presented in the project Work Plan.
****

2.1 Background
2.1.1 Project Description

****

This should be presented in the project Work Plan unless the treatability study is scoped separately.
****

2.1.2 Remedial Technology Description and Process Flow Diagrams

****

Consider the consequences if the sequence of unit process is rearranged. Consider the ultimate disposal requirements of all phases and all side streams. Cross media transfer without neutralization of the toxicity is discouraged by the National Contingency Plan.

****

2.1.3 Previous Results with Similar Influent Materials

****

List references and describe the limitations of similarity.
****

2.2 Treatability Test Objectives

****

Refer to section 1 of the RI/FS outline for the appropriate approach to determining objectives. Also refer to section 2.1 of the RI/FS for information on scoping Contractor involvement in developing objectives. See Enclosure 11, Alternative Development and Selection.
****

2.2.1 Remedy Screening - Qualitative
2.2.2 Remedy Selection - Quantitative
2.2.3 Establishing Data Quality Objectives (DQOs)- Precision, Accuracy, Representativeness, Completeness, and Comparability (PARCC)
2.3 Approach
2.4 Reporting Requirements
2.5 Schedule and Level of Effort
2.5.1 Schedule

****

The draft treatability study should be submitted for review and comment before disassembly of the equipment. Bench scale tests should be performed before the ROD is prepared.

Bench scale test: laboratory validation of treatment processes. Tests are normally batch or equilibrium adaptations of the steady state processes. Tests may be performed on actual or simulated waste material. Spiking of actual waste or simulation is frequently necessary to test for worst conditions.

Screening tests should be performed early in the alternative development process. There are some new, quick and inexpensive, methods and facilities available for preliminary screening at EPA RREL in Cincinnati. If these EPA facilities are considered, RREL may have an SOP that is adequate for the scope. Ask for a copy and review it to see if it meets the needs of the project.

Other batch tests should be performed after the site has been characterized, late in the RI or early in the FS, for appropriate sample selection.

Analyses for interferences are easily performed in the batch mode. Most divalent metal ions interfere with continuous operation of oxidation processes and air stripping. Accuracy of plus or minus 0.05 ppm is appropriate for the prevalent cations and hardness.

Pilot tests are demonstration tests that simulate a process closely enough to determine design parameters for full scale unit operations. A pilot test is normally conducted on actual waste material, although some spiking is used to determine capacity or to simulate worst anticipated field conditions. Pilot tests often attempt to simulate worst conditions. Pilot studies may be performed to determine equipment capacity and range of operation parameters (i.e. concentration, temperature, contact, residence, or detention time) required to obtain the performance objectives.
****

2.5.2 Level of Effort

****

Remedy screening
Study scale: bench
Data generated: qualitative
Process type: batch
Waste stream volume: small
Number of replicates: single/duplicate
Time required: days
Cost range: $10,000-$50,000
Remedy selection
Study scale: bench-full
Data generated: quantitative
Process type: batch or continuous
Waste stream volume: medium to large
Number of replicates: duplicate/triplicate
Time required: days/months
Cost range: $50,000-$250,000
****

2.5.3 Budget
2.6 Experimental Design and Procedures

****

Treatability studies should be designed to obtain the data that is needed to assess the effectiveness of a specific process in remediation.

****

2.6.1 Experimental Design
2.6.2 Detailed Outline of the Procedures

****

The treatability study Work Plan should include step-by-step detail of the procedures to be used in performing the treatability study.
****

2.6.2.1 Methods
2.6.2.2 Procedures
2.6.2.3 Sample Material Handling
2.6.2.4 Treated Material Handling
2.6.2.5 Process Residuals Handling
2.7 Equipment and Materials

****

Equipment and instrumentation to be used in the treatability study should be completely identified.
****

2.7.1 Equipment
2.7.2 On-line Monitors
2.7.3 Other Instrumentation

****

Field type instrumentation is satisfactory for most pilot scale work with full laboratory data quality management implemented only on selected samples before and after treatment. The Work Plan should indicate the instrumentation to be used.

Measure parameters that affect field implementation; ultimate disposal; mechanical stability of residual solids; effects of freeze thaw cycles; dust generation; water absorption or loss pH and pH changes; temperature and temperature changes; heat loss; heat gain.

****

2.8 Chemical Data Acquisition Plan/Sampling and Analysis Plan (SAP)

****

This does not replace the RI/FS sampling requirements, it merely cites special considerations for treatability studies. This plan will essentially incorporate the elements of the EPA's Field Sampling Plan, Quality Assurance Project Plan, and Data Management Plan. Depending on the nature of the field activities needed for the treatability study, a Monitoring Well Installation and Drilling Plan may be required.

The handling of gross samples should be as similar as possible to the handling of the analytical samples. See Enclosure 13: Chemistry Technical Requirements.

As an option, the sample collection section and the sample analysis and validation sections can be broken out as separate tasks. Given the limited nature of the sampling in many studies and the important role chemical analysis may have in treatability studies, they are discussed under the treatability study task.

The chemist should consult with the process engineer to determine what analytical parameters are to be monitored during the treatment process. Analytical levels II, III, IV, or V may apply to these studies. Data reporting format and turnaround time may need to be specified in this section, depending upon users needs.

Field samples may not represent the predicted worst case. Analyze portions of the samples before shipment to the treatability study laboratory. At a minimum, treatability testing should be performed under worst case conditions and under typical or average conditions. It may be necessary to provide supplemental contaminants.

Volume estimates on the amount to be treated should be provided or a cross reference to the appropriate part of the treatability study plan be provided.

Field sample waste streams for characterization and testing, conduct treatability tests, analyze samples of treated materials and residuals

The SOW should have the Contractor estimate the projected volume of material to be treated to determine equipment capacity.

For appropriate sample selection, pilot tests should be performed after overall site characterization (QA/QC documentation need not be complete), concurrent with alternative selection and ROD development, before initiation of design.

Final Treatability Study Reports may be submitted concurrently with the RI/FS or separately.

For Quality Assurance issues, coordinate with and refer to the project Work Plan quality assurance section. Quality assurance needed for remedy screening is the least stringent; for remedy selection, moderately stringent QA is appropriate.

For data analysis and data interpretation, see Enclosure 11: Alternative Development and Selection for a discussion of alternatives.
****

2.9 Site Safety and Health Plan/ Health and Safety Plan

****

The site safety and health plan for the RI characterization activities may cover all of the types of activities required. Append new procedures to the existing plan.
****

2.10 Residuals Management and Compliance with the Regulatory Requirements

2.10.1 Residuals Management

2.10.1.1 On Site

2.10.1.2 Off Site

****

The regulatory specialist must confirm that off-site lab facility to run treatability tests is permitted or plans to operate under the RCRA treatability exclusions in 40 CFR 261.4 (e) and (f). If the treatability exclusion is to be used, state regulations must be considered and the CFR must be carefully read to minimize adverse impacts on the project. Some impacts can be handled through scoping.
****

2.11 Community Relations

****

The community relations plan for the pilot study must be in concert with the project community relations plan.
Remedy screening: low profile/few activities
Remedy selection off site: generally not controversial and low profile/few activities

An on site remedy selection may be controversial and high profile/significant activities.

****

2.12 Management and Staffing
2.13 Outline for the Treatability Study Report

3. Treatability Study Report Format Outline
3.1 Introduction
3.1.1 Site Description
3.1.2 Waste Stream Description
3.1.3 Treatment Technology Description
3.1.4 Previous Treatability Studies at the Site
3.2 Conclusions and Recommendations
3.2.1 Conclusions
3.2.2 Recommendations
3.3 Treatability Study Approach
3.3.1 Test Objectives and Rationale
3.3.2 Experimental Design and Procedures
3.3.2.1 Design
3.3.2.2 Procedures
3.3.2.3 Discussion of any Variations from the Work Plan
3.3.3 Equipment and Materials
3.3.4 Sampling and Analysis
3.3.4.1 Analyses or Reference to the Appropriate Report
3.3.4.2 QA/QC Report or Reference to the Appropriate Report
3.3.5 Data Management
3.3.6 Derivatives from the Work Plan
3.4 Results and Discussion
3.4.1 Data Analysis and Interpretation
3.4.2 Quality Assurance/Quality Control
3.4.3 Identification of Additional Testing Needs
3.4.4 Cost/Schedules for Performing the Treatability Study
3.4.5 Key Contacts

****

All Superfund/NPL treatability reports are submitted to the RREL Treatability Data Base Repository, organized by the EPA Office of Research and Development.
Attn: Mr. Glenn Schaul
RREL Treatability Data Base
U.S. EPA ORD Risk Reduction Engineering Laboratory
26 West Martin Luther King Drive
Cincinnati, OH 45268
****

3.4.6 References
3.4.7 Standard Operating Procedures
3.4.8 Data Summaries
3.4.9 All Side Notations from Laboratory Books

****

These notes may have significant value.

****

4. Appendices to the Treatability Study
4.1 Sample Calculations Showing
4.1.1 Use of generated Data
4.1.2 Identification of all Variables
4.1.2.1 Measured
4.1.2.1.1 Range of Experimentally Determined Values for the Variables.
4.1.2.1.2 Sensitivity to Variation
4.1.2.2 Calculated
4.1.2.3 Assumed
4.1.2.2 Unknown
4.2 Process Flow Diagrams
4.2.1 Flow Diagram
4.2.2 Material Balance Showing Average Values
4.3 Summary of the Data
4.4 Scale-up Considerations
4.4.1 Performance
4.4.2 Operation and Maintenance
4.5 Identification of the Limits of the Process as Indicated by the Results

5. Specific Process Recommendations
5.6 Thermal Desorption/Incineration

****

CEWES has a low temperature pilot unit and will perform treatability studies. Obtain a copy of the WES protocol to get an understanding of how they will do the study and what the report will be like. The Contractor and the design district process engineer both need to understand what WES will do and if the information will be adequate for design. If there are any Contractor requested changes to the WES protocol the district process engineer should be involved in the changes.

"Guide for Conducting Treatability Studies under CERCLA: Thermal Desorption Remedy Selection" is being prepared by EPA contract.

Obtain an adequate and representative sample. The Contractor should be responsible for sample collection, packaging and shipping to WES if WES does the study.

Characterize/analyze a sample of the sample prior to shipment. Consider parameters that affect VOC removal rates:

Undisturbed moisture content of sample
BTU content of sample
Temperature
Air and/or oxygen flow
Residence time
Time and temperature curves
Consider problems
Slag formation

Partitioning of the metals: Keep track of where the metal are. Materials handling: Soil characterization including liquid limit, plastic limit, etc.

If the feed material contains significant amounts of heavy metals, produce enough ash for solidification/stabilization tests while the thermal treatment test is going. Provide adequate material for the unit to achieve steady state before measurements are made to determine the operating parameters. Enough samples to represent the entire site should be processed.
****