

HOCHTIEF UMWELT THERMAL DESORPTION SYSTEM

**HOCHTIEF UMWELT GmbH FACILITY
HERNE, GERMANY**

**EPA - BMBF BILATERAL SITE DEMONSTRATION
INNOVATIVE TECHNOLOGY EVALUATION REPORT**

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Prepared for:

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NOTICE

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FOREWORD

The Superfund Innovative Technology Evaluation (SITE) program was authorized by the Superfund Amendments and Reauthorization Act (SARA) of 1986. The program is administered by the U.S. Environmental Protection Agency (EPA) Office of Research and Development. The purpose of the SITE program is to accelerate the development and use of innovative remediation technologies applicable to Superfund and other hazardous waste sites. This purpose is accomplished through demonstrations designed to provide performance and cost data on selected technologies.

This technology demonstration evaluated the Hochtief Umwelt thermal desorption system developed by Hochtief Umwelt GmbH, Essen, Germany. The demonstration was conducted in Herne, Nordrhein-Westfalen, Germany. Treatment of soils from the Gaswerke Hannoversch Münden site, a former coal-gasification plant located in Hannoversch Münden, Germany, was evaluated. Soils from the site are contaminated with high levels of total recoverable petroleum hydrocarbons (TRPH); fluoranthene, pyrene, phenanthrene, naphthalene, and other polynuclear aromatic hydrocarbons (PAHs); benzene, toluene, ethylbenzene, and total xylenes (BTEX); and some metals. The demonstration was focused on the technology's ability to remove TRPH, PAHs, and BTEX from soil. This innovative technology evaluation report provides an interpretation of the data collected during the demonstration and discusses the potential applicability of the technology to other contaminated sites.

A limited number of copies of this report will be available at no charge from the EPA's Center for Environmental Research Information (CERI) by calling (513) 569-7562 or by fax at (513) 569-8695. Requests should include the EPA document number found on the report cover. Additional copies can be purchased from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia 22168, (703) 487-4650. Reference copies will be available at the EPA libraries in the Hazardous Waste Collection.

Timothy Oppelt, Director
National Risk Management Research Laboratory

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ACRONYMS AND ABBREVIATIONS

ARARs	Applicable or relevant and appropriate requirements
ArGe	Arbeitsgemeinschaft (focon Probiotec)
ASTM	American Society for Testing and Materials
ATTIC	Alternative Treatment Technology Information Center
BMBF	Federal Republic of German Ministry for Research and Technology
BS/BSD	Blank spike/blank spike duplicate
BTEX	Benzene, toluene, ethylbenzene, and xylenes
CEM	Continuous emissions monitor
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERI	Center for Environmental Research Information
CLU-IN	Clean-up Information (on-line database)
cm	Centimeters
°C	Degrees Celsius
DM	Deutsche Mark
EPA	U.S. Environmental Protection Agency
g/g	Grams per gram
GHM	Gaswerke Hannoversch Münden
ITER	Innovative Technology Evaluation Report
kg/h	Kilograms per hour
kW	Kilowatt
kW/h	Kilowatt per hour
m	Meter
m ²	Square meter
m ³ /h	Cubic meter per hour
mbar	Millibar
mg/kg	Milligrams per kilogram
mg/m ³	Milligram per cubic meter
MS/MSD	Matrix spike/matrix spike duplicate
mt	Metric tonnes

ACRONYMS AND ABBREVIATIONS (Continued)

mt/h	Metric tonnes per hour
m-xylene	meta-xylene
NaOH	Sodium hydroxide
nm ³ /h	Normal cubic meters per hour
NPL	National Priorities List
NRMRL	National Risk Management Research Laboratory
o-xylene	ortho xylene
ORD	U.S. EPA Office of Research and Development
OSWER	U.S. Office of Solid Waste and Emergency Response
p-xylene	para xylene
PAH	Polynuclear aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
PSD	Particle size distribution
QA/QC	Quality assurance and quality control
QAPP	Quality assurance project plan
RCRA	Resource Conservation and Recovery Act
RPD	Relative percent difference
%R	Percent removal
SARA	Superfund Amendments and Reauthorization Act (of 1986)
SITE	Superfund Innovative Technology Evaluation (program)
SO ₂	Sulfur dioxide
SVOC	Semivolatile organic compound
TRPH	Total recoverable petroleum hydrocarbons
μg/dscm	Micrograms per dry standard cubic meter
μg/L	Micrograms per liter
UCL	Upper confidence limit
VISITT	Vendor Information System for Innovative Treatment Technologies
VOC	Volatile organic compound
VOST	Volatile organic sampling train

CONVERSION TABLE
(Metric to English Units)

<u>To Convert</u>	<u>Into</u>	<u>Multiply By</u>
Centimeters	Feet	0.0328
Centimeters	Inches	0.39
Cubic meters	Cubic feet	35
Cubic meters	Gallons	264
Cubic meters	Cubic yards	1.31
Degrees Celsius	Degrees Fahrenheit	multiply by 1.80 and add 32
Hectopascals	Atmosphere	0.000986
Kilograms per square meter	Pounds per square inch, absolute	0.00142
Kilograms	Pounds	2.21
Kilograms per liter	Pounds per cubic foot	12.8
Kilometers	Miles (statute)	0.62
Liters	Gallons	0.26
Liters per second	Cubic feet (standard) per minute	2.12
Meters	Feet	3.28
Millimeters	Inches	0.039
Square meters	Square feet	10.8

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EXECUTIVE SUMMARY

This innovative technology evaluation report (ITER) summarizes the results of an evaluation of the Hochtief Umwelt thermal desorption technology conducted under a bilateral agreement between the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) program and the Federal Republic of Germany Ministry for Research and Technology (BMBF). The Hochtief Umwelt thermal desorption system was demonstrated from February 22, 1995 through February 25, 1995 at the Hochtief Umwelt facility in Herne, Germany. Soil contaminated with total recoverable petroleum hydrocarbons (TRPH), polynuclear aromatic hydrocarbons (PAH), and benzene, toluene, ethylbenzene, and xylenes (BTEX) was used for the demonstration.

The Hochtief Umwelt Thermal Desorption Technology

The Hochtief Umwelt thermal desorption system was developed by Hochtief Umwelt GmbH, Essen, Germany. The technology is a full-scale commercial treatment system developed to treat contaminated soil using a three-part process including (1) mechanical preparation, (2) thermal desorption, and (3) flue gas treatment. The technology is designed to reduce contaminant concentrations in excavated soil. The system is fully automated and can process a maximum of 6.5 metric tonnes per hour (mt/h) with 20 weight percent moisture.

Waste Applicability

The Hochtief Umwelt technology effectively reduced TRPH, PAH, and BTEX concentrations in soil that consisted of a silty sand. The developer claims that the technology can also remove dioxins and furans, polychlorinated biphenyls (PCBs), and other halogenated hydrocarbons as well as volatile heavy metals (for example, mercury).

Demonstration Objectives and Approach

This bilateral SITE demonstration of the Hochtief Umwelt technology was designed with three primary and four secondary objectives. The objectives were chosen to provide potential users of the technology with the information necessary to assess the applicability of the Hochtief Umwelt technology for treatment of soil

from other contaminated sites. The following primary and secondary objectives were selected to evaluate the technology:

Primary Objectives:

P-1 Determine the removal efficiency of the Hochtief Umwelt thermal desorption system for the following critical compounds:

- | | |
|---------------------|-------------------------|
| -TRPH | -Benzo(b)fluoranthene |
| -Naphthalene | -Benzo(k)fluoranthene |
| -Acenaphthene | -Benzo(a)pyrene |
| -Acenaphthylene | -Indeno(1,2,3-cd)pyrene |
| -Fluorene | -Dibenzo(a,h)anthracene |
| -Phenanthrene | -Benzo(g,h,i)perylene |
| -Anthracene | -Benzene |
| -Fluoranthene | -Toluene |
| -Pyrene | -Ethylbenzene |
| -Benzo(a)anthracene | -Xylene |
| -Chrysene | |

P-2 Document the critical contaminant concentrations in the treated soil at a confidence level of 95 percent

P-3 Document critical compound concentrations in stack emissions

Secondary Objectives:

S-1 Document the moisture content and the particle size distribution of the feed and treated soil in the thermal desorption process

S-2 Document key nonproprietary system operating parameters

S-3 Document remediation costs per metric ton of soil

S-4 Document stack emission characteristics for informational purposes only

Demonstration Conclusions

This demonstration was limited to an evaluation of the technology's ability to remove TRPH, PAHs, and BTEX from soil. Specific conclusions include the following:

- The average removal efficiencies achieved were 99.0 percent for TRPH, 99.7 percent for PAHs, and 99.0 percent for BTEX.
- The 95 percent upper confidence limit of concentrations in treated soil for Test Run 1 was 16.1 milligrams per kilogram (mg/kg) for TRPH, 34.0 mg/kg for PAHs, and 2.17 mg/kg for BTEX. The 95 percent upper confidence limit of concentrations in treated soil for Test Run 2 was 17.5 mg/kg for TRPH, 35.7 mg/kg for PAHs, and 1.01 mg/kg for BTEX. The 95 percent upper confidence limit of concentrations in treated soil for Test Run 3 was 16.8 mg/kg for TRPH, 33.3 mg/kg for PAHs, and 1.16 mg/kg BTEX.
- The three test runs yielded average total PAH concentrations ranging from 78.4 to 240 micrograms per dry standard cubic meter ($\mu\text{g}/\text{dscm}$) and average BTEX concentrations ranging from 181 to 350 $\mu\text{g}/\text{dscm}$ in the stack gas. The specific average contaminant concentrations for each test run are presented in [Section 2.3.2.1](#).
- The moisture content of the contaminated feed soil ranged from 17.4 to 18.8 percent by weight and the moisture content of the treated soil ranged from 8.00 to 8.28 percent by weight. Soils treated during the demonstration were identified as silty sand.
- The average feed soil flow rate for each test run was 6.5 mt/h. The stack gas flow rate ranged from 19,700 to 19,900 normal cubic meters per hour (nm^3/h) and averaged 19,800 nm^3/h during the demonstration. The temperature of soil exiting the dryer unit ranged from 125 to 131 degrees Celsius ($^{\circ}\text{C}$) and averaged 128 $^{\circ}\text{C}$ during the demonstration. The temperature of the thermal desorption unit ranged from 737 to 742 $^{\circ}\text{C}$ and averaged 740 $^{\circ}\text{C}$ during the demonstration. The temperature of the soil exiting the thermal desorption unit ranged from 488 to 535 $^{\circ}\text{C}$ and averaged 511 $^{\circ}\text{C}$ during the demonstration. The temperature of the gas stream exiting the thermal desorption unit ranged from 593 to 605 $^{\circ}\text{C}$ and averaged 598 $^{\circ}\text{C}$. The temperature of soil exiting the cooling unit ranged from 66 to 78 $^{\circ}\text{C}$ and averaged 70.3 $^{\circ}\text{C}$.
- The concentration of the total organic carbon in stack emissions ranged from 5.10 to 6.00 milligrams per cubic meter (mg/m^3) and averaged 5.70 mg/m^3 ; hydrochloric acid was not detected in any of the samples; carbon monoxide concentrations ranged from 11.5 to 15.0 mg/m^3 and averaged 13.6 mg/m^3 ; sulfur dioxide concentrations ranged from less than 1.00 to 1.30 mg/m^3 ; particulate matter concentrations ranged from 1.00 to 1.10 mg/m^3 and averaged 1.03 mg/m^3 .
- The commercial cost, as provided by Hochtief Umwelt, for application of the Hochtief technology at the Herne site, is 430 Deutsche Mark (DM) per metric ton (\$286 per metric ton assuming a 1.5 DM to \$1 U.S. exchange rate).

It should be noted that soil PAH results were compromised by some noncompliant recoveries in the matrix spike and matrix spike duplicate analyses, indicating that a potential high or low bias may exist for some individual PAH analytes. As a result, the soil PAH results described above should be considered estimates.

Technology Applicability

The Hochtief Umwelt technology was evaluated to identify its advantages, disadvantages, and limitations. The evaluation was based on the nine criteria used in the Superfund feasibility study process. The criteria are as follows:

Overall Protection of Human Health and the Environment

The Hochtief Umwelt technology provides both short-term and long-term protection to human health and the environment by reducing the concentrations of TRPH, PAH, and BTEX in soil. Furthermore, the soil vapor extract is processed through an afterburner and flue gas treatment train to minimize organic emissions in the stack gas. If required, exposure to organic air emissions is further minimized by passing the stack gas through carbon adsorption units prior to discharge to the atmosphere.

Compliance with ARARs

Although general and specific applicable or relevant and appropriate requirements (ARARs) were not identified for the Hochtief Umwelt technology, compliance with chemical-, location-, and action-specific ARARs should be assessed on a site-specific basis. While location- and action-specific ARARs can usually be met, compliance with chemical-specific ARARs depends on the efficiency of the Hochtief Umwelt system in removing contaminants from the soil and on the site-specific cleanup level.

Long-Term Effectiveness and Permanence

The Hochtief Umwelt system permanently reduces levels of TRPH, PAH, and BTEX in soil using a continuous thermal desorption process. Potential long-term risks to treatment system workers, the community, and the environment from emissions of treated gas and discharge of treated soil are mitigated by meeting established standards.

Reduction of Toxicity, Mobility, or Volume Through Treatment

The Hochtief Umwelt thermal desorption technology permanently removes TRPH, PAH, and BTEX. As such, the toxicity, mobility, and volume of contaminants are also significantly reduced.

Short-Term Effectiveness

The permanent removal of TRPH, PAH, and BTEX from soils is achieved relatively quickly, providing for short-term as well as long-term effectiveness. Potential short-term risks focus on air emissions and include potential exposures of workers, the community, and the environment to various toxins in air emissions from the process. However, in the Hochtief process, soil vapors from the thermal desorption of soils pass through an afterburner and extensive flue gas treatment system, which minimize the ultimate emission of toxins in the stack gas.

Implementability

Implementation of the Hochtief Umwelt system involves (1) site preparation, (2) facility construction, and (3) operation, monitoring, and maintenance. Minimal adverse impacts to the community, workers, or the environment are anticipated during site preparation and system installation.

Site preparation and access requirements for the technology can be significant. The site must be accessible to large trucks. The Hochtief Umwelt thermal desorption system is a large fixed treatment facility with three major components. Construction of the facility requires several months. Supplemental structures are also required to house, integrate, and control all the components. Operation and maintenance of the facility require technical and engineering personnel around the clock. Contaminated soils must be excavated and transported to the facility. Depending on the distance from the contaminated site to the facility, transportation efforts can be significant.

Cost

For the application of the Hochtief Umwelt technology at the Herne site, the commercial treatment cost per metric ton of soil is 430 DM (\$286, assuming a 1.5 DM to \$1 U.S. exchange rate). This is the commercial treatment cost provided by Hochtief Umwelt.

State Acceptance

State acceptance is anticipated because the Hochtief Umwelt system uses well-documented and widely accepted processes to remove TRPH, PAH, and BTEX from soil and to treat stack gas emissions. If remediation is conducted as part of Resource Conservation and Recovery Act (RCRA) corrective actions, state regulatory agencies will require that permits be obtained before implementing the system. For example, a permit to operate the treatment system, an air emissions permit, and a permit to store contaminated soil for greater than 90 days if these items are considered hazardous wastes may be required.

Community Acceptance

The system's size and space requirements, as well as the principle of operation, may raise concern in nearby communities. However, proper management and operational controls should ensure that the surrounding community is subjected to only minimal short-term risks. Furthermore, the capability of this process to provide permanent removal of soil contaminants through *in situ* techniques makes this technology likely to be accepted by the public.

1.0 INTRODUCTION

This report documents the findings of an evaluation of the Hochtief Umwelt thermal desorption system developed by Hochtief Umwelt GmbH, Essen, Germany. This evaluation was conducted under a bilateral agreement between the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) program and the Federal Republic of Germany Ministry for Research and Technology (BMBF). The Hochtief Umwelt technology demonstration was conducted on February 22, 1995 through February 25, 1995 in Herne, Germany (see [Figure 1](#)). The demonstration evaluated the technology's effectiveness in remediating soil contaminated with total recoverable petroleum hydrocarbons (TRPH), polynuclear aromatic hydrocarbons (PAH), and benzene, toluene, ethylbenzene, and xylenes (BTEX). The soil was from the Gaswerke Hannoversch Münden (GHM) site, a former coal-gasification plant in Hannoversch Münden, Germany. Soil and stack gas was sampled by Arbeitgemeinschaft (ArGe) focon-Probiotec and Institut Fresenius with assistance from Tetra Tech EM Inc. System operating parameters were monitored by Hochtief Umwelt. All samples were analyzed by Institut Fresenius. All demonstration activities were conducted in accordance with the February 1995 quality assurance project plan (QAPP) (PRC 1995). ArGe focon-Probiotec, Hochtief Umwelt, and Institut Fresenius contributed to the development of this document.

This report provides information from the bilateral SITE demonstration of the Hochtief Umwelt technology that is useful for remedial managers, environmental consultants, and other potential technology users in implementing this technology at contaminated sites. [Section 1.0](#) presents an overview of the SITE program and bilateral agreement, describes the Hochtief Umwelt technology, and lists key contacts. [Section 2.0](#) presents information relevant to the technology's effectiveness, including contaminated soil characteristics and site background, demonstration procedures, and the results and conclusions of the demonstration. [Section 3.0](#) presents information on the costs associated with applying the technology. [Section 4.0](#) presents information relevant to the technology's application, including assessment of the technology related to nine feasibility study evaluation criteria used for decision making in the Superfund process. [Section 4.0](#) also discusses applicable wastes/contaminants and limitations of the technology. [Section 5.0](#) summarizes the technology status, and [Section 6.0](#) lists references used in preparing this report.

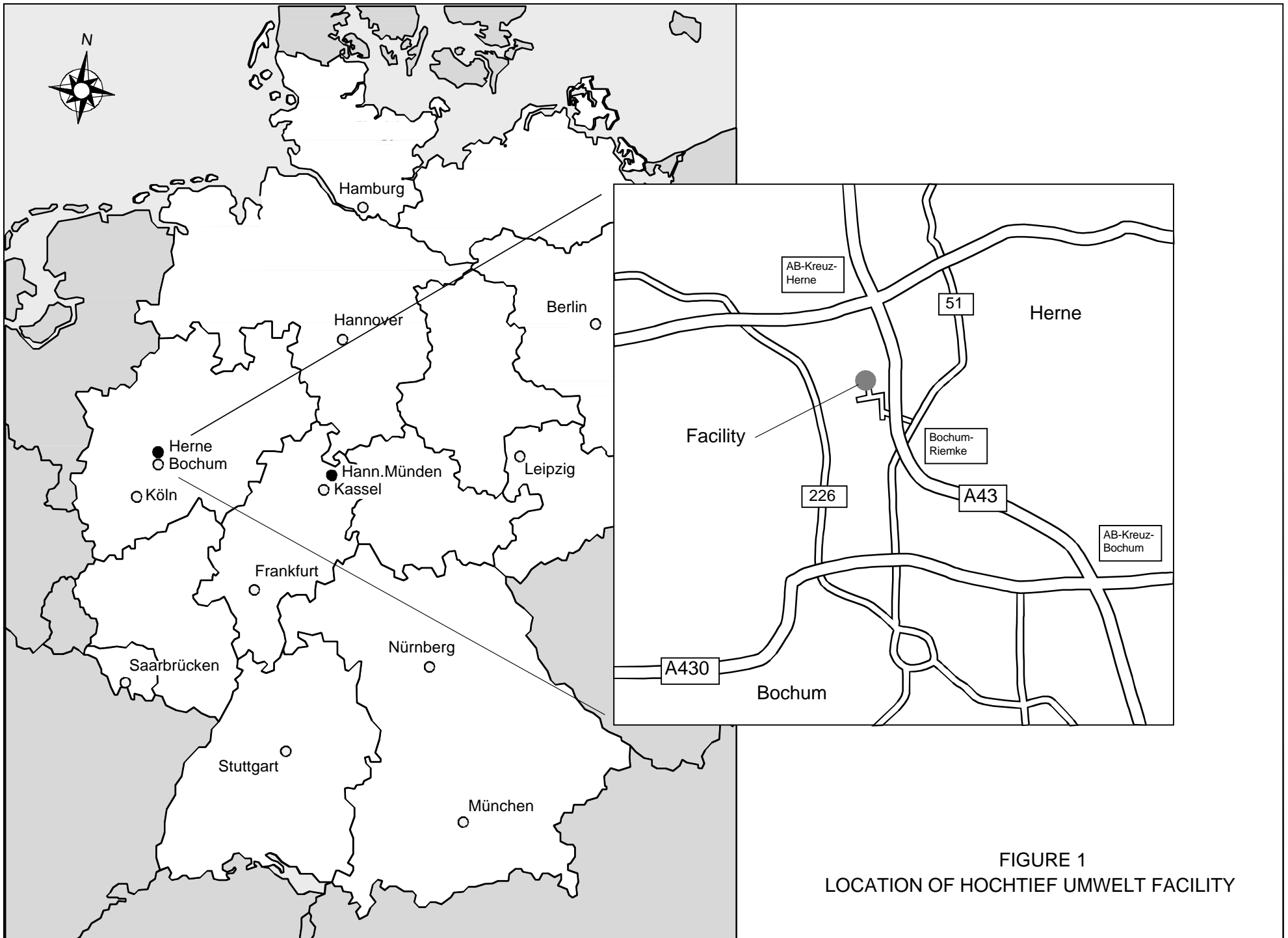


FIGURE 1
LOCATION OF HOCHTIEF UMWELT FACILITY

1.1 SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION PROGRAM

This section provides background information about the EPA SITE program. Additional information about the SITE program, the Hochtief Umwelt technology, and the technology demonstration can be obtained by contacting the key individuals listed in [Section 1.4](#).

EPA established the SITE program to accelerate the development, demonstration, and use of innovative technologies to remediate hazardous waste sites. The demonstration portion of the SITE program focuses on technologies in the pilot-scale or full-scale stage of development. The demonstrations are intended to collect performance data of known quality. Therefore, sampling and analysis procedures are critical. Approved quality assurance and quality control (QA/QC) procedures are stringently applied throughout the demonstration.

Past hazardous waste disposal practices and their human health and environmental impacts prompted the U.S. Congress to enact the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 (PL96-510). CERCLA established a Hazardous Substance Response Trust Fund (Superfund) to pay for handling emergencies at and cleaning up uncontrolled hazardous waste sites. Under CERCLA, EPA has investigated these hazardous waste sites and established national priorities for site remediation. The ultimate objective of the investigations is to develop plans for permanent, long-term site cleanups, although EPA initiates short-term removal actions when necessary. EPA's list of the nation's top-priority hazardous waste sites that are eligible to receive federal cleanup assistance under the Superfund program is known as the National Priorities List (NPL).

As the Superfund program matured, Congress expressed concern over the use of land-based disposal and containment technologies to mitigate problems caused by releases of hazardous substances at hazardous waste sites. As a result of this concern, the 1986 reauthorization of CERCLA, called the Superfund Amendments and Reauthorization Act (SARA), mandates that EPA "select a remedial action that is protective of human health and the environment, that is cost effective, and that utilizes permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable." In response to this requirement, EPA established the SITE program to accelerate development, demonstration, and use of innovative technologies for site cleanups. The SITE program has four goals:

- Identify and remove impediments to development and commercial use of innovative technologies, where possible
- Conduct demonstrations of the more promising innovative technologies to establish reliable performance and cost information for site characterization and cleanup decision-making
- Develop procedures and policies that encourage selection of effective innovative treatment technologies at uncontrolled hazardous waste sites
- Structure a development program that nurtures emerging technologies

Each year EPA selects the best available innovative technologies for demonstration. The screening and selection process for these technologies is based on four factors: (1) the technology's capability to treat Superfund wastes, (2) expectations regarding the technology's performance and cost, (3) the technology's readiness for full-scale demonstrations and applicability to sites or problems needing remedy, and (4) the developer's capability for and approach to testing. SITE program demonstrations are administered by EPA's Office of Research and Development (ORD) through the National Risk Management Research Laboratory (NRMRL) in Cincinnati, Ohio.

SITE demonstrations are usually conducted at uncontrolled hazardous waste sites such as EPA removal and remedial action sites, sites under the regulatory jurisdiction of other federal agencies, state sites, EPA testing and evaluation facilities, sites undergoing private cleanup, the technology developer's site, or privately owned facilities. In the case of the Hochtief Umwelt technology demonstration, the site was selected cooperatively by EPA and BMBF. The EPA-BMBF bilateral agreement is discussed in [Section 1.2](#).

SITE and bilateral SITE demonstrations provide detailed data on the performance, cost effectiveness, and reliability of innovative technologies. These data will provide potential users of a technology with sufficient information to make sound judgments about the applicability of the technology to a specific site or waste and to allow comparisons of the technology to other treatment alternatives.

1.2 UNITED STATES AND GERMAN BILATERAL AGREEMENT ON REMEDIATION OF HAZARDOUS WASTE SITES

In April 1990, EPA and BMBF entered into a bilateral agreement to gain a better understanding of each country's efforts in developing and demonstrating remedial technologies. The bilateral agreement has the following goals:

- Facilitate an understanding of each country's approach to remediation of contaminated sites
- Demonstrate innovative remedial technologies as if the demonstrations had taken place in each country
- Facilitate international technology exchange

Technologies in the U.S. and in Germany are evaluated under the bilateral agreement. Individual or, in some cases, multiple remedial technologies are demonstrated at each site. Technology evaluations occurring in the U.S. correspond to SITE demonstrations; those occurring in Germany correspond to full-scale site remedial activities and are referred to as bilateral SITE demonstrations. In the case of the U.S. evaluations, demonstration plans are prepared following routine SITE procedures. Additional monitoring and evaluation measurements required for evaluation of the technology under German regulations will be specified by the German partners. For the demonstrations occurring in Germany, the German partners will provide all required information to allow the U.S. to develop an EPA Category II QAPP. An EPA Category II QAPP, "Quality Assurance Project Plan for the Hochtief Umwelt Thermal Desorption System Demonstration in Herne, Germany," dated February 1995 was prepared for this demonstration (PRC 1995).

ArGe focon-Probiotec (a partnership of two German environmental consulting firms) was commissioned by BMBF to compile summary reports for the German technologies and sites, to evaluate the U.S. demonstration plans, and to facilitate the bilateral agreement on behalf of BMBF. The ArGe focon-Probiotec technical consulting partnership is not directly involved in the German remedial actions, and the partnership does not influence actual site remediation activities. The bilateral project organization is presented in [Figure 2](#).

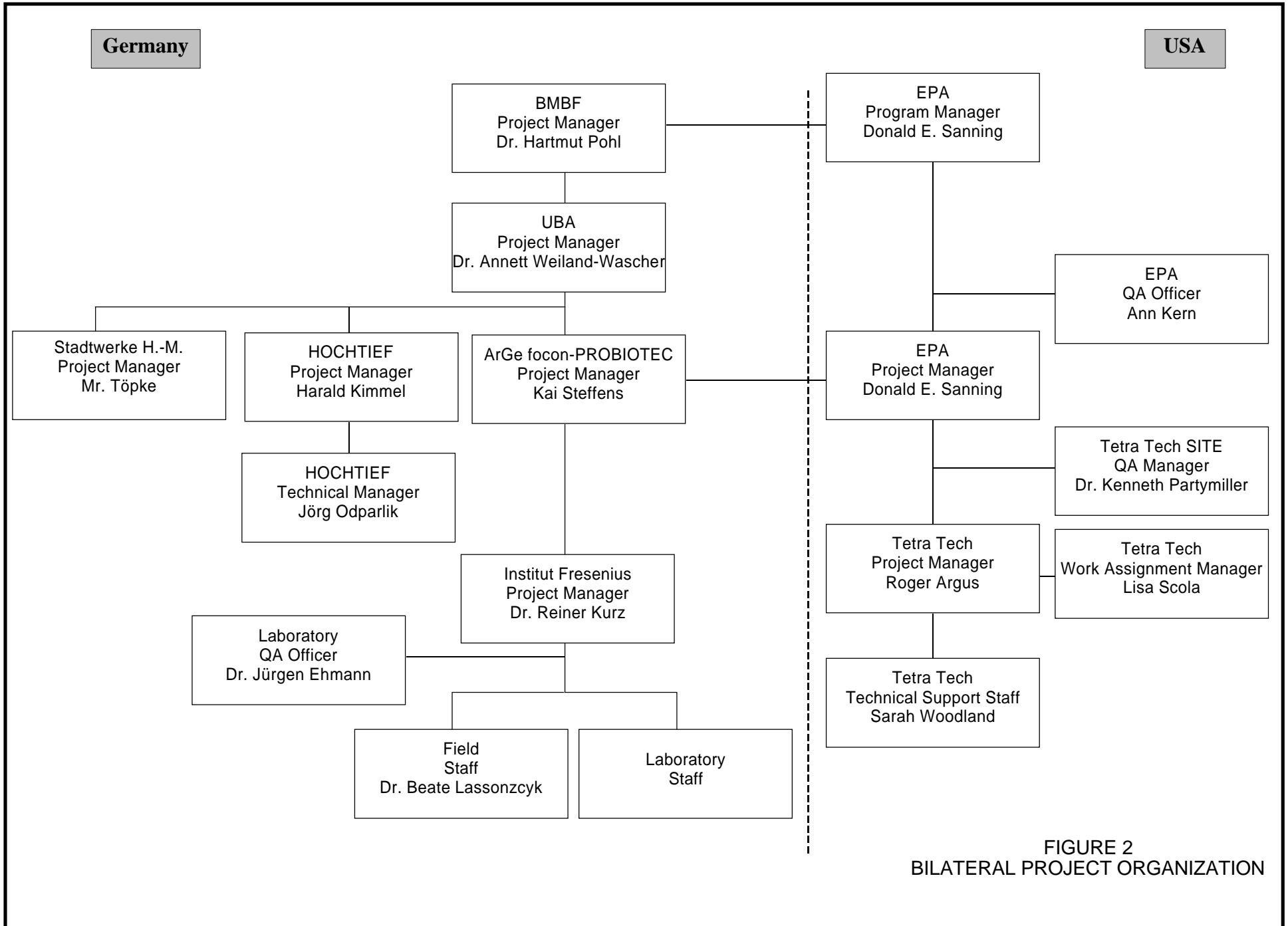


FIGURE 2
BILATERAL PROJECT ORGANIZATION

1.3 HOCHTIEF UMWELT TECHNOLOGY DESCRIPTION

This section describes the process equipment and system operations of the Hochtief Umwelt thermal desorption facility. The information provided in this section is limited because Hochtief Umwelt claims as proprietary much of the process design and system operating data. However, an effort has been made to present enough information so that the technology's concept of operation and the results of the demonstration can be understood.

1.3.1 Process Equipment

Hochtief Umwelt operates a full-scale, commercial soil remediation facility in Herne, Germany (see [Figure 1](#)). The facility houses a continuous thermal desorption system capable of remediating soil contaminated with organic chemicals and some inorganic chemicals. The system consists of three main processes: (1) mechanical preparation (sieving and crushing), (2) thermal desorption, and (3) flue gas treatment. Each of these processes are described below.

1.3.1.1 Mechanical Preparation Process

Soil contaminated with high levels of volatile organic compounds is stored in a container storage area at the Hochtief Umwelt facility. Front-end loaders are used to introduce soil into a three-step size reduction process that reduces the material from a maximum grain size of 40 centimeters (cm) in diameter to a grain size of smaller than 2.0 cm in diameter. Slowly rotating blade-shredders crush concrete and debris and break clumps of clayey and loamy soil. Scrap metal is removed by a magnetic device. After size reduction, the soil is transported by an enclosed conveyor belt to an interim storage pile. From the interim storage pile, the soil is transported by front-end loaders to the feed hopper of the thermal desorption unit.

1.3.1.2 Thermal Desorption Process

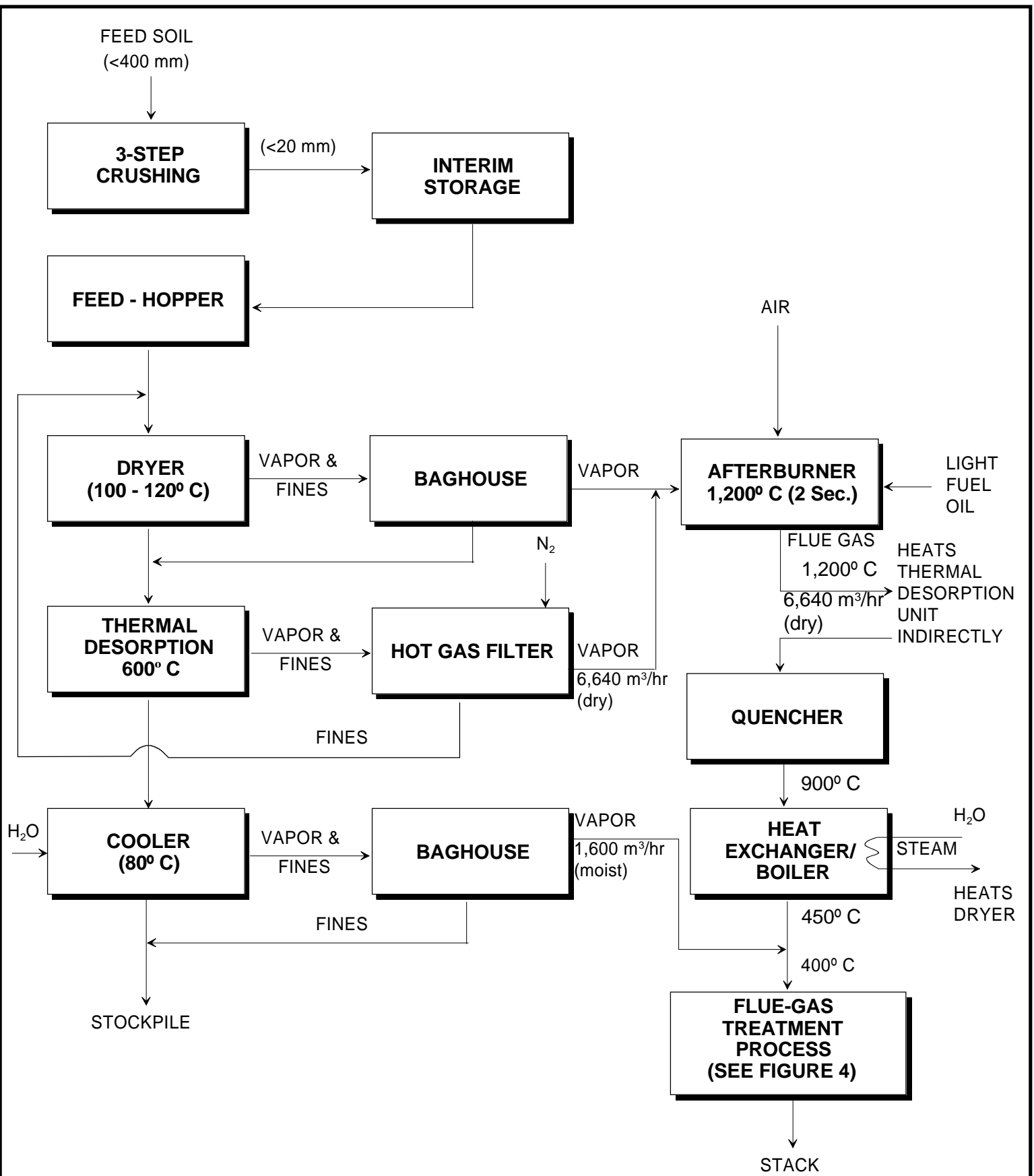
A process flow diagram for the thermal desorption process is shown in [Figure 3](#). The thermal desorption process heats feed soil to a temperature high enough to volatilize organic contaminants and volatile metals. The thermal desorption process occupies a 40-square-meter (m²) area and consists of three primary units: (1) a dryer unit, (2) a thermal desorption unit, and (3) a cooler unit. The dimensions of the three process units are provided in [Table 1](#).

**TABLE 1. DIMENSIONS OF THERMAL DESORPTION PROCESS UNITS
HOCHTIEF UMWELT THERMAL DESORPTION TECHNOLOGY**

Drying Unit	
Outside Diameter	3 meters
Overall Length	23 meters
Thermal Desorption Unit	
Outside Diameter	2 meters
Overall Length	13 meters
Cooling Unit	
Outside Diameter	1.5 meters
Overall Length	7 meters

From the feed hopper, untreated soil moves by conveyor belt to a rotating drum soil dryer. A constant feed rate of 6.5 metric tons per hour (mt/h) (maximum) is maintained and controlled by a belt scale. The dryer is steam-heated to 100 to 120 degrees Celsius (°C), but is also equipped with standby burners that may be used during system start-up or during nonroutine operation. The soil residence time in the dryer is between 30 and 40 minutes. The dryer evaporates water and some volatile contaminants from the soil. Soil exiting the dryer has a residual moisture content of about 8 percent by weight.

Dried soil is fed to the thermal desorption unit via a bucket-chain conveyor. The desorption unit operates at an average temperature of 600 degrees Celsius (°C), which causes contaminants to volatilize from the solids. The desorption unit is a rotating cylinder heated indirectly by flue gas from the afterburner unit. The rotational speed of the desorption unit controls the residence time of the soil in the unit. Trial runs on GHM soil in a pilot-scale unit showed the best removal efficiencies occurred at temperatures of 600°C with residence times of approximately 30 minutes in the desorption unit. The unit is operated under a vacuum of 0.2 to 0.4 millibar (mbar) to minimize fugitive emissions.



Note: Temperatures and flow rates shown in this figure are typical operating conditions only. See Section 2.3.1 for a discussion of operating conditions during the demonstration.

FIGURE 3
HOCHTIEF UMWELT
THERMAL DESORPTION SYSTEM

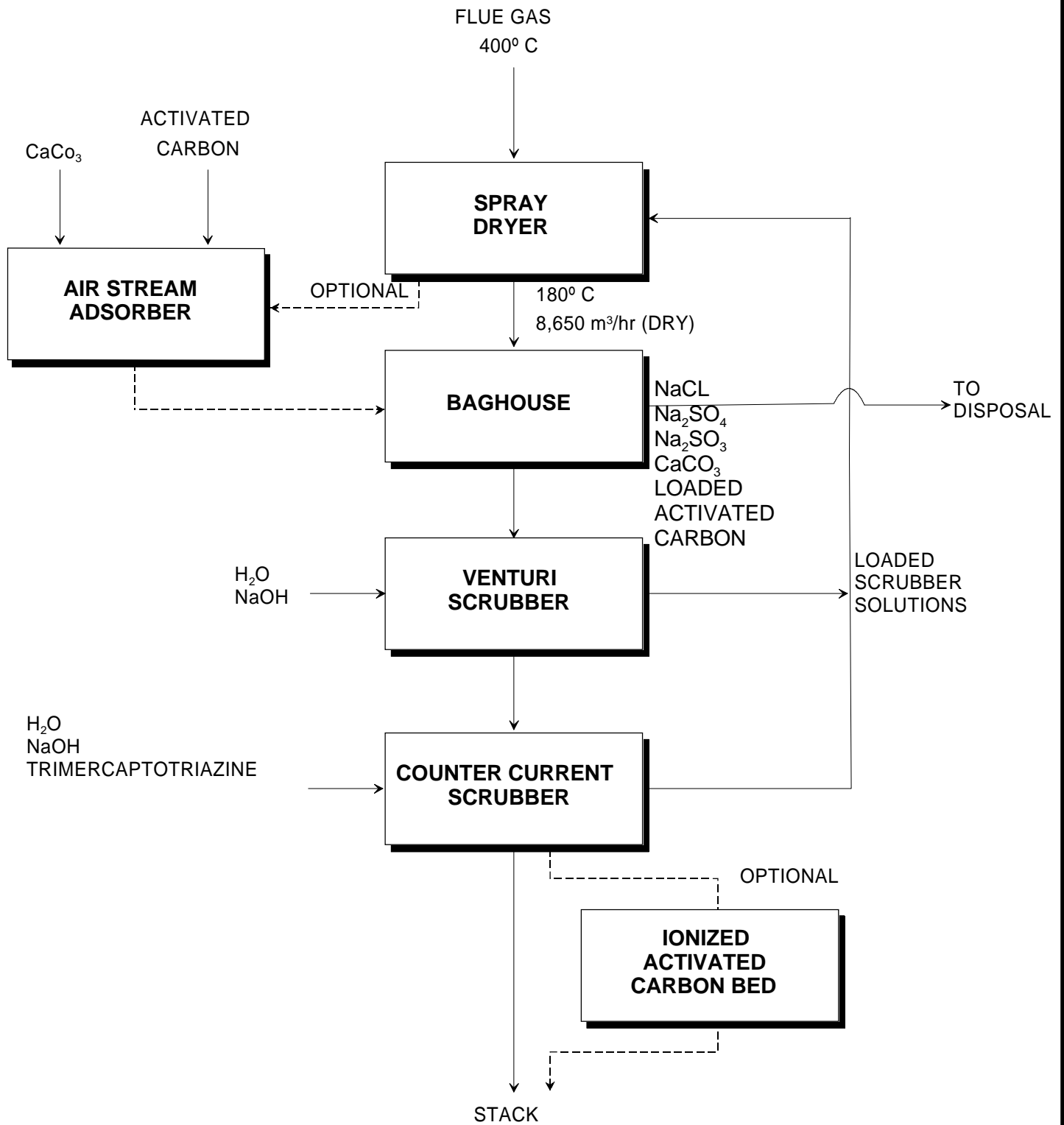
The outer shell of the desorption unit is divided into eight heating zones. The temperature of each zone is controlled by automatic flaps; the flaps allow different volumes of flue gas to enter the zones at 1,200°C to maintain a surface temperature of 600°C in the unit. Temperature is continuously monitored using probes in the inner walls of the desorption unit.

After exiting the desorption unit, soil is transported to the cooler by an enclosed vibratory duct. The cooler is a rotating drum equipped with water sprayers to spray water onto the soil. The cooled soil (at approximately 80°C) is transported out of the plant and stockpiled. The final water content of the treated soil is maintained at 10 to 15 percent by weight to control fugitive dust emissions and to improve handling of the treated soil.

1.3.1.3 Flue Gas Treatment Process

The flue gas treatment process is shown in [Figures 3 and 4](#). Flue gas from the drying and desorption units flows to the afterburner through heated pipes. First, however, organic and metallic vapors and dust particles, or “fines,” are removed by a “hot gas filter” and a baghouse. The ceramic elements of the “hot gas filter” are periodically shock flushed with nitrogen to loosen the fines retained in the filter. These fines are returned to the untreated soil entering the dryer. Fines from the baghouse are fed to the thermal desorption process.

The afterburner consists of a 9-meter (m) long horizontal cylindrical incineration chamber with an outside diameter of 5 m. The afterburner is designed to operate at a flue gas residence time of 2 seconds, a temperature of 1,200°C, and an excess oxygen content of 1.5 percent at a minimum. The afterburner meets the standards defined by the German Emission Control Act for Incineration Facilities (*17. BImSchV*). The plant also meets the emission standards of the 17. BImSchV-Regulation, as listed in [Table 2](#). Fuel oil is used to operate the afterburner, and in case of nonroutine operation, the unit may also be run with propane.



Note: Temperatures and flow rates shown in this figure are typical operating conditions only. See Section 2.3.1 for a discussion of operating conditions during the demonstration.

FIGURE 4
FLUE-GAS TREATMENT PROCESS

**TABLE 2. EMISSION STANDARDS OF THE GERMAN 17. BimSchV-REGULATION
HOCHTIEF UMWELT THERMAL DESORPTION TECHNOLOGY**

Compound	Concentrations (Daily Average) ¹
Carbon Monoxide	50 mg/m ³
Particulate Matter	10 mg/m ³
Total Organic Carbon	10 mg/m ³
Inorganic Chlorine (HCl)	10 mg/m ³
Inorganic Fluorine (HF)	1 mg/m ³
Sulphur Oxides (as SO ₂)	50 mg/m ³
Nitrogen Oxides (as NO ₂)	0.2 mg/m ³
Cadmium and Thallium	0.05 mg/m ³
Mercury	0.05 mg/m ³
Dioxins or Furans	0.1 mg/m ³

Notes:

¹ Calculated as milligrams per cubic meter (mg/m³) at standard conditions:
273 K, 1.013 bar, dry, 11 percent O₂

Flue gas leaves the afterburner at 1,200°C and at an average flow rate of 8,650 cubic meters per hour (m³/h). This flue gas is returned to the desorption unit where it is circulated through the outer shell for heat recovery purposes. After heating the desorption unit, flue gas flows to a quencher unit, which cools the flue gas to approximately 900°C prior to feeding to the boiler.

The saturated steam boiler operates at a steam pressure of 16 bar and a temperature of 200°C. Steam is generated at a rate of 4 m³/h and is used to heat the soil dryer. Flue gas exits the boiler at a temperature of 450°C and is combined with the gas from the soil cooler baghouse.

Flue gas exiting the boiler is cooled to 450°C. The 450°C exit temperature for the flue gas leaving the boiler is the minimum required to avoid generation of dioxins if chlorinated organic compounds and carbon are present in the gas phase. Between about 200 and 450°C, dioxins can be formed by chemical reactions known as De-Novo-Synthesis. Therefore, to avoid the De-Novo-Synthesis reaction, flue gas must be quenched from 400°C to less than 200°C very rapidly.

In the Hochtief Umwelt system, flue gas exiting the boiler or heat exchanger is quenched in a spray dryer to 180°C. The spray dryer uses alkaline scrubber water from the flue gas scrubber units as quenching water. The quenching water evaporates in the spray dryer, leaving fine particles of alkaline salts and dust entrained in the flue gas. These particles are removed from the flue gas by a baghouse, and baghouse solids are disposed of as hazardous waste. The solid residue amounts to about 50 kilograms per hour (kg/h) during routine operation, which is 0.3 to 0.4 percent of the hourly throughput of soil.

After the baghouse, flue gas, which flows at about 8,650 m³/h at this point in the process, enters a series of gas scrubbers. First, in the venturi scrubber, the acidic components (for example, hydrochloric acid) are removed from the flue gas using a sodium hydroxide (NaOH) solution. The spent scrubber solution exiting the venturi scrubber flows to the spray dryer. In the next scrubbing step, slightly acidic components such as sulfur dioxide (SO₂) are removed from the flue gas in a countercurrent scrubber. The resulting solution is neutralized with NaOH; after adding trimercaptotriazine to precipitate metals as sulfides (at a rate of 1 kg/h), the wash solution flows to the spray dryer.

Flue gas from the scrubbers is additionally treated by carbon polishing. When treating soil contaminated with organic compounds, the activated carbon bed may be bypassed and the scrubbed flue gas (about 9,000 m³/h dry) can be directed to the 40-m high stack. The carbon unit was not used during the demonstration. Therefore, a detailed description of this unit is not provided here.

The Hochtief Umwelt facility holds a permit to treat soil contaminated with dioxins and furans, polychlorinated biphenyls (PCB), and other halogenated hydrocarbons. For special emission control when treating soil that contains or may generate dioxins, a flue gas treatment system with an air stream adsorber may be added to the process. This system is on standby during normal operation and can be operated as needed. When the air stream adsorber is used, the flue gas exiting the spray dryer is fed to the adsorber prior to the baghouse. In the air stream adsorber, a mixture of powdered lime and activated carbon is sprayed into the flue gas stream at a maximum rate of 50 kg/h. Organic components and heavy metals are adsorbed by this mixture and are removed together with the solids in the baghouse. During this technology demonstration, the optional air stream adsorber unit was not used because of the low likelihood of dioxin generation in the thermal desorption system flue gas.

1.3.2 System Operation

Hochtief Umwelt has a permit to commercially operate the thermal soil treatment pilot plant in Herne. The permit is valid for operation when treating soil that does not exceed the contaminant levels listed in [Table 3](#). In addition, for each batch of soil, Hochtief Umwelt is required to perform trial runs with a small-scale desorption unit to prove to the permitting authorities that the soil can be treated successfully.

Excavated soil from the GHM site was transported to the Hochtief Umwelt facility in Herne in air-tight containers of 15-metric tonne (mt) capacity. The containers were emptied, and front-end loaders transferred the soil to the size reduction unit. Air from the truck-lock and soil feed area where the containers were emptied was captured by a vacuum and treated by activated carbon adsorption.

The throughput capacity of the system depends on the contaminant concentrations in the feed soil. The soils used for this demonstration contained high concentrations of TRPH, PAH, and BTEX, as well as some metals. This demonstration focused only on the technology's ability to remove TRPH, PAH, and BTEX from soils. The maximum capacity of the soil treatment system is 6.5 mt/h of soil containing 20 weight percent moisture. The primary limiting factor is the throughput capacity of the desorption unit. For this demonstration, the soil treatment process was run at the maximum throughput rate.

The residence time of the soil is 30 to 40 minutes in each of the units of the thermal desorption process. The residence time of the soil in the entire process ranges from 100 to 120 minutes.

The Hochtief Umwelt system is fully automated to allow for 24-hour operation. The facility is equipped with automatic systems that allow the safe shutdown of the plant in case of electrical power black-out or other emergency. The safe operation of the afterburner and the functioning of the control systems are guaranteed by redundant energy supply systems and control system design. In case of a breakdown in the fuel-oil supply, the afterburner can be run with propane burners. In case of an electrical blackout, rotating processors and conveyor systems can be run by pressurized air. The system is also equipped with an emergency buffer battery, and after a maximum of 1 minute, diesel-generators begin to supply electrical power. In case of a breakdown in the water supply system, service water is supplied by emergency water containers.

TABLE 3. MAXIMUM CONTAMINANT CONCENTRATION LEVELS PERMITTED FOR THE HOCHTIEF UMWELT FACILITY

Parameter	Maximum Concentration in Dry Soil (mg/kg)
Arsenic	500
BTEX	20,000
Benzene	5,000
Toluene	10,000
Ethylbenzene	10,000
Xylenes	10,000
Cadmium	200
Chlorobenzene	2,000
Chlorophenols	1,000
Cyanides (Non-Complex)	5,000
Halogenated Hydrocarbons	20,000
Hexachlorodibenzo-Dioxin	0.005
Hydrocarbons	100,000
Lead	6,000
Mercury	500
PAH	100,000
Phenols	10,000
PCB	1,000
Sulphur-compounds	2,000
2,3,7,8-Tetrachlorodibenzo-Dioxin	0.002
Tetra- and penta-bromodibenzo-Dioxin	0.002

Notes:

mg/kg Milligrams per kilogram
 BTEX Benzene, toluene, ethylbenzene, and xylenes
 PAH Polynuclear aromatic hydrocarbons

The operation characteristics of the Hochtief Umwelt facility are listed in [Table 4](#).

Highly contaminated residuals from the flue gas treatment unit (consisting of 50 to 100 kg/h dry salts and dust from flue gas treatment) are disposed of at subsurface storage facilities for hazardous wastes.

Stack emissions of total carbon, hydrochloric acid, carbon monoxide, sulfur dioxide, particulate matter, and temperature are monitored continuously, and data are recorded automatically. If dioxins and furans are present in the feed soil or may be generated during the treatment, additional stack gas sampling and analysis by an independent laboratory is conducted for these compounds.

1.4 KEY CONTACTS

Additional information on the Hochtief Umwelt technology and the EPA-BMBF bilateral technology evaluation program can be obtained from the following sources:

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EPA-BMBF Bilateral Technology Evaluation Program

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513-569-7875

Technical Project Manager
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TABLE 4. OPERATION CHARACTERISTICS OF THE HOCHTIEF UMWELT THERMAL DESORPTION TECHNOLOGY

Throughput	
Hourly	6.5 mt
Yearly	35,000 mt
Electrical Energy	
Installed Power Supply	550 kW
Consumption	400 kW/h
Fuel Oil Consumption	80 to 280 kg/h
Water	
Feed Water	0.1 m ³ /h
Service Water	3.0 m ³ /h
Compressed Air	
Maximum	1,100 m ³ /h
Average	320 m ³ /h
Others	
Sodium Hydroxide (33 Percent)	50 kg/h
TMT 15 (Organic Mercapto-Compound)	1 kg/h
Nitrogen	70 m ³ /h
Solid Residuals	
Routine Operation	
Salts and Dusts (Hazardous Waste)	50 kg/h
With Optional Air Stream Adsorber	
Salts and Dusts (Hazardous Waste)	100 kg/h
Liquid Residuals	
None	

Notes:

mt Metric tonnes
 kW Kilowatt
 kW/h Kilowatt per hour
 kg/h Kilograms per hour
 m³/h Cubic meters per hour

Information on the SITE program is available through the following on-line information clearinghouses:

- The Alternative Treatment Technology Information Center (ATTIC) System (operator: 703-908-2137) is a comprehensive, automated information retrieval system that integrates data on hazardous waste treatment technologies into a centralized, searchable source. This database provides summarized information on innovative treatment technologies.
- The Vendor Information System for Innovative Treatment Technologies (VISITT) (Hotline: 800-245-4505) database contains current information on nearly 350 technologies submitted by nearly 210 developers, manufacturers, and suppliers of innovative treatment technology equipment and services.
- The Office of Solid Waste and Emergency Response (OSWER) Clean-up Information (CLU-IN) electronic bulletin board contains information on the status of SITE technology evaluations. Its web site is www.clu-in.com.

Technical reports may be obtained by contacting the Center for Environmental Research Information (CERI), 26 West Martin Luther King Drive in Cincinnati, Ohio 45268 at (513) 569-7562.

2.0 HOCHTIEF UMWELT TECHNOLOGY EFFECTIVENESS

This section documents the background, field and analytical procedures, results, and conclusions used to evaluate the ability of the Hochtief Umwelt thermal desorption system to remove TRPH, PAH, and BTEX from contaminated soil. This evaluation is based on data collected during the Hochtief Umwelt bilateral SITE demonstration.

2.1 BACKGROUND

The bilateral SITE demonstration of the Hochtief Umwelt thermal desorption system was conducted at the Hochtief facility in Herne, Germany (see [Figure 1](#)). Contaminated soil for the demonstration was obtained from the GHM site in Hannoversch Münden, Lower Saxony, Germany, which is about 210 kilometers from the Hochtief Umwelt facility (see [Figure 5](#)). The site background is described in the following section. An overview of demonstration objectives and approach is presented in [Section 2.1.2](#).

2.1.1 GHM Site Background

The GHM site is a 28,000-m² area previously operated as a coal gasification facility. The site is located near the city center of Hannoversch Münden, Lower Saxony, Germany (see [Figure 5](#)). The first coal gasification plant at the site was established in the 1860s and was located in the western portion of the site. When a new gasification facility was installed on the eastern portion of the site in 1908, the buildings in the western portion of the site were demolished, but the gas tanks remained in operation. Demolition debris was used to level the site. The tar pits were covered during the site leveling process and remained partly filled with liquids. Over time, other industries were established in the western portion of the site.

In 1954, coal gasification at GHM was shut down, and the city was connected to a regional gas supply network. The buildings in the eastern portion of the site were demolished or remodeled to be used as garages and workshops for the Municipal Water and Power Supply Department of the City of Hannoversch Münden. Again, debris was used to level the site, and the tar pits were covered. In the late 1980s, contaminated soil and debris were found during construction of a new school building on the western portion of the site. Subsequent site investigations conducted in 1989 and 1990 indicated high levels of TRPH, PAHs, and BTEX throughout the site. The highest readings were found in the vicinity of the old tar pits.

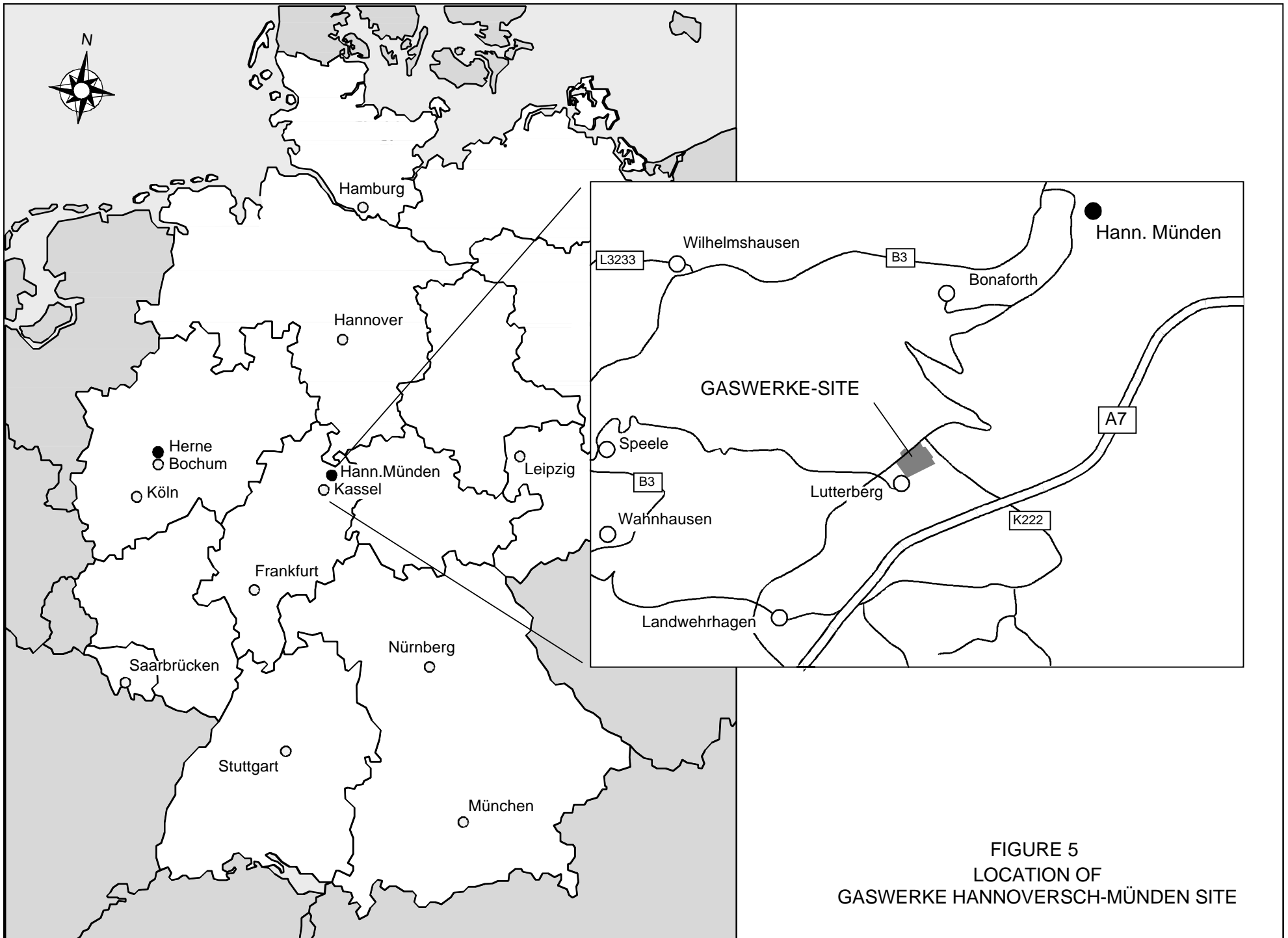


FIGURE 5
 LOCATION OF
 GASWERKE HANNOVERSCH-MÜNDEN SITE

Because of the similar history in the eastern portion of the site, the City of Hannoversch Münden and the County of Göttingen decided in 1993 to initiate remediation for the entire site. The Municipal Water and Power Supply Department of the city is funding the remediation project as the responsible party.

2.1.1.1 Site Contamination

A comprehensive site characterization effort was completed and indicated extensive contamination of the building debris, subsurface soil, and groundwater. This section briefly discusses the subsurface soil contamination at the GHM site.

The highest concentrations of TRPH, PAHs, and BTEX were detected in samples of slag, ashes, and soil from the rims of the old tar pits. Site investigation data show that the soil consists mainly of a sandy silt that is slightly clayey. In some areas on the site, brick debris was found to be a substantial part of the soil.

[Table 5](#) shows general characterization data for critical parameters in soil that were treated in the Hochtief Umwelt thermal desorption process in Herne. [Table 6](#) lists analytical data of a test batch of soil from the GHM site treated in a trial run using the Hochtief Umwelt thermal desorption system. Other contaminants present in soil included phenols and cyanides with very wide concentration ranges.

2.1.1.2 Remediation Plan and Approach

During construction of the school building on the western portion of the site, contaminated soil was removed from additional areas of the site. In two smaller portions of the site, contamination was still present and was removed by the remedial action in October 1994. Soon after the old tar pits were discovered, liquids were removed from the pits, and the pits were covered again for safety reasons. The subsequent planning process

**TABLE 5. AVAILABLE SITE CHARACTERIZATION DATA
HOCHTIEF UMWELT THERMAL DESORPTION TECHNOLOGY
GHM SITE**

Parameter	Measured Value
TRPH	2,000 to 5,000 mg/kg
PAHs	>5,000 mg/kg
BTEX	100 to 300 mg/kg
Moisture Content	15 to 20 percent

Notes:

PAHs	Polynuclear aromatic hydrocarbons
TRPH	Total recoverable petroleum hydrocarbons
BTEX	Benzene, toluene, ethylbenzene, and xylenes
mg/kg	Milligram per kilogram

focused primarily on the evaluation of technology alternatives available for the treatment of contaminated solids. Site investigation data showed that severe contamination was present in the tar pit area; most of the soil in other portions of the site was only slightly contaminated. During the remedial action starting in mid-October 1994, approximately 3,800 mt of soil with lower contaminant concentrations were excavated. Various materials (for example, foundation debris, pavement debris, filling soil, loamy soil, and gravel) were separated. The excavated materials were stored in piles for characterization. After the level of contamination was assessed, the material was transported to either a thermal desorption facility (for soils contaminated at lower levels) or to the Hochtief Umwelt facility (for soils contaminated at higher levels). The portion of soil with higher contaminant concentrations excavated from the rims of the tar pits was about 1,500 mt. This portion was transported to Herne to be treated by the Hochtief Umwelt thermal desorption system.

Groundwater at the GHM site is contaminated with organic chemicals. Groundwater contamination was investigated in 1990 and the results of this investigation were used to design a conventional on-site pump-and-treat system using activated carbon. This system was operated during excavation activities.

TABLE 6. ANALYTICAL CHARACTERIZATION OF A TEST BATCH OF GHM SITE SOIL

Parameter	Pretreatment Contaminant Concentration (mg/kg)	Posttreatment Contaminant Concentration (mg/kg)
Petroleum Hydrocarbons	< 2,000	9
Naphthalene	2,030	0.01
Acenaphthene	179	< 0.01
Acenaphthylene	402	< 0.01
Fluorene	781	< 0.01
Phenanthrene	2,320	0.02
Anthracene	565	< 0.01
Fluoranthene	4,240	0.03
Pyrene	3,140	0.03
Benzo(a)anthracene	752	0.01
Chrysene	587	0.01
Benzo(b)fluoranthene	480	< 0.01
Benzo(k)fluoranthene	245	< 0.01
Benzo(a)pyrene	631	< 0.01
Indeno(1,2,3-cd)pyrene	185	< 0.01
Dibenzo(a,h)anthracene	282	< 0.01
Benzo(g,h,i)perylene	134	< 0.01
Total PAHs	17,000	0.11
BTEX	> 300	< 0.01
Extractable Organic Halides	< 0.01	< 0.01
Arsenic	5.56	6.2
Lead	142	132
Mercury	0.05	0.028
Cadmium	< 0.01	< 0.01
Chromium (total)	33.8	35.6
Cobalt	32.7	20.6
Copper	40.3	40.8
Nickel	97.3	247
Zinc	1,080	697
Cyanides (total)	3.3	0.39

Notes:

PAHs Polynuclear aromatic hydrocarbons
 BTEX Benzene, toluene, ethylbenzene, and xylenes
 mg/kg Milligram per kilogram

2.1.2 Demonstration Objectives and Approach

Demonstration objectives were selected to provide potential users of the Hochtief Umwelt thermal desorption system with the necessary technical information to assess the applicability of the treatment system to other contaminated sites. This bilateral SITE demonstration had three primary objectives and four secondary objectives. These demonstration objectives are summarized below:

Primary Objectives

P-1 Determine the removal efficiency of the Hochtief Umwelt thermal desorption system for the following critical compounds:

-TRPH	-Benzo(b)fluoranthene
-Naphthalene	-Benzo(k)fluoranthene
-Acenaphthene	-Benzo(a)pyrene
-Acenaphthylene	-Indeno(1,2,3,c,d)pyrene
-Fluorene	-Dibenzo(a,h)anthracene
-Phenanthrene	-Benzo(g,h,i)perylene
-Anthracene	-Benzene
-Fluoranthene	-Toluene
-Pyrene	-Ethylbenzene
-Benz (a)anthracene	-Xylene
-Chrysene	

P-2 Document the critical contaminant concentrations in the treated soil at a confidence level of 95 percent

P-3 Document critical compound concentrations in the stack emissions

The primary objectives were achieved by collecting representative samples of contaminated feed soil, treated soil, and stack gas during three Test Runs.

Secondary Objectives

S-1 Document the moisture content and the particle size distribution of the feed and treated soil in the thermal desorption process

S-2 Document key nonproprietary system operating parameters

S-3 Document remediation costs per metric ton of soil

S-4 Document stack emission characteristics for informational purposes only

The secondary project objectives and the associated noncritical measurement parameters required to achieve those objectives are listed in [Table 7](#).

**TABLE 7. NONCRITICAL MEASUREMENT PARAMETERS
HOCHTIEF UMWELT THERMAL DESORPTION TECHNOLOGY**

Secondary Objective	Measurement Parameter
Document the moisture content and the particle size distribution of feed soil and treated soil in the thermal desorption process	Moisture content and particle size distribution in feed and treated soil
Document key nonproprietary system operating parameters	System operating parameters: feed soil flow rate, stack gas flow rate, temperature of soil exiting the dryer, shell temperature of the thermal desorption unit, temperature of soil exiting the thermal desorption unit, temperature of the gas stream exiting the thermal desorption unit, temperature of soil exiting the cooler
Document remediation costs per metric ton of soil	Commercial treatment costs ¹
Document stack emission characteristics for informational purposes only	Total carbon, hydrochloric acid, carbon monoxide, sulfur dioxide, particulate matter, and temperature

Note:

¹ Commercial treatment costs were obtained from Hochtief Umwelt. Capital and operating costs were not assessed in detail because Hochtief Umwelt considers this information proprietary.

To meet demonstration objectives, data were collected and analyzed using the methods and procedures summarized in the following section.

2.2 DEMONSTRATION PROCEDURES

This section describes the methods and procedures used to collect and analyze samples for the bilateral SITE demonstration of the Hochtief Umwelt technology. The activities associated with the Hochtief Umwelt SITE demonstration included (1) demonstration design, (2) soil and stack gas collection and analysis, and (3) field and laboratory QA/QC. The methods used to collect and analyze samples were conducted in accordance with the procedures outlined in [Sections 2.2.1](#) and [2.2.2](#). Field and laboratory QA/QC procedures are described in [Section 2.2.3](#).

2.2.1 Demonstration Design

This section describes the demonstration design, sampling and analysis program, and sample collection frequency and locations. The purpose of the demonstration was to collect and analyze data of known and acceptable quality to achieve the objectives stated in [Section 2.1.2](#).

2.2.1.1 Sampling and Analysis Program

Specific sampling objectives for the demonstration of the Hochtief Umwelt thermal desorption technology are given below:

- Collect representative samples. Samples were collected in a manner and frequency to ensure that the samples were representative of the medium being sampled.
- Conduct appropriate and necessary physical and chemical characterizations of the representative samples. Samples were collected and analyzed for the necessary target compounds to achieve demonstration project objectives.
- Maintain proper chain-of-custody control of all samples, from collection to analysis.
- Follow QA and QC procedures appropriate for U.S. EPA ORD Category II projects.

The GHM site was excavated and soils with total PAH concentrations exceeding 5,000 mg/kg were transported to the Hochtief Umwelt facility for treatment. The operating conditions for the thermal desorption system demonstration were determined by Hochtief Umwelt based on professional judgment

and experience. Because Hochtief Umwelt considers certain aspects of the system design and operating data proprietary, it is not possible to describe details on optimum operating conditions in this document. Because the residence time of soil in the system is approximately 2 hours, demonstration sampling was started at least 3 hours after processing had begun.

During the Hochtief Umwelt demonstration, three 8-hour, full-scale Test Runs were conducted. Samples were collected from three sampling locations (S1, S2, and S3). Samples of untreated and treated soil were collected at 30-minute intervals. Soil samples collected from sampling locations S1 and S2 included composite samples for PAH and TRPH analysis and discrete samples collected for BTEX analysis. However, discrete soil samples were collected for BTEX analysis during the first grab sampling event in each hourly composite instead of being collected during the second grab sampling event as specified in the QAPP. This allowed the samples for BTEX analysis to be placed in the container immediately after the first grab sampling event, minimizing the possibility that contaminant concentration would be diminished due to volatilization in the sampling buckets. A duplicate discrete sample for BTEX analysis was also collected each hour in case any need arose in the laboratory to reanalyze a sample. In this way, the duplicate sample could be used instead of reanalyzing material from the first sample jar, which might show diminished contaminant concentrations due to volatilization. This approach also required an addition to the sample numbering system to account for samples requiring multiple containers.

On February 22, 1995, the sampling team arrived at the facility and inspected the stack sampling port. The port was found to be too small to accept the sampling probe. After further inspection, a suitable port was identified at floor level in the small shack built to protect the sampling area from the elements. To obtain access to this port for the stack sampling equipment, portions of the shack were temporarily removed. Modifications included removal of three side wall panels, lifting up half of the plywood floor, and cutting several of the cross supports for the floor. The mechanical subcontractor at the facility could not undertake such extensive work without a written work order from the facility operations manager. Therefore, the modifications to the shack were delayed until the morning of February 23, when this work order could be obtained. The work was completed on the morning of February 23.

During the night of February 22, a problem developed in the stack gas treatment system, requiring facility shutdown. The problem was in the spray dryer unit of the flue gas treatment system. The spray nozzle geometry had been incorrectly set up so that the duct exiting the unit had become plugged with salts. The

blockage in the duct was cleared and new spray nozzles were installed on February 23. Facility operations were restarted during the night shift of February 23.

The first two test runs were conducted on February 24, with Test Run 1 beginning at 8:00 a.m. Soil sampling equipment was not decontaminated between these two runs because sampling was continuous. Sampling equipment was decontaminated on February 25 and equipment and field blanks were collected before sampling began for Test Run 3.

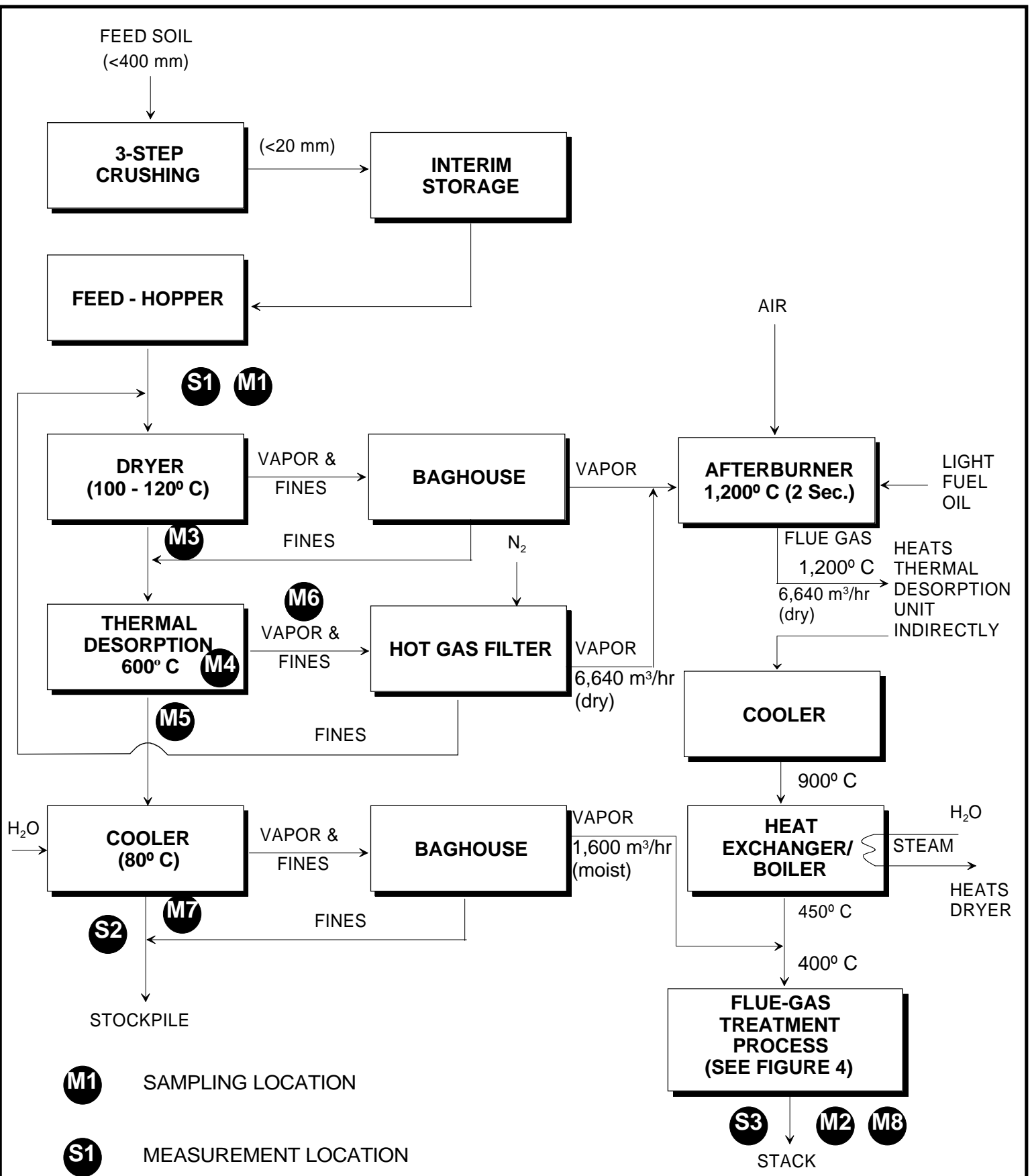
2.2.1.2 Sampling and Measurement Locations

Sampling locations were selected based on the configuration of the treatment system and project objectives; analytical parameters were selected based on the contaminants to be treated and project objectives. Sampling collection and measurement locations during the demonstration are shown on [Figure 6](#).

Samples were collected from three sampling locations and measurements were taken at eight measurement points in the treatment system to achieve the project objectives established in [Section 2.1.2](#). Specific sampling and measurement procedures are described in [Section 2.2.2](#). Sampling and measurement activities were conducted over three 8-hour test runs, as described above. Grab and composite sampling techniques were employed throughout the demonstration. [Figure 6](#) shows sampling locations for solids and gases.

These sampling locations are:

- Sampling Location S1: Contaminated feed soil. Contaminated soil was introduced into the shredder and fed into the 2-cm screen. The soil was then transported by conveyor belt to the interim storage pile, and then brought to the feed hopper of the thermal desorption unit by front-end loaders. Contaminated feed soil was then transported to the dryer by conveyor belt. Samples of the contaminated soil were collected from the conveyor belt that moves prepared soil into the dryer.
- Sampling Location S2: Treated soil. Samples were collected from the conveyor belt that transports treated soil from the cooler to the stockpile.



Note: Temperatures and flow rates shown in this figure are typical operating conditions only. See Section 2.3.1 for a discussion of operating conditions during the demonstration.

FIGURE 6
SAMPLING AND MEASUREMENT LOCATIONS

- Sampling Location S3: Stack gas. Samples were collected from sampling ports located on the exhaust stack.
- Measurement Location M1: Contaminated feed soil. Flow rate of the contaminated feed soil was determined by measuring the mass of the contaminated soil located on the conveyor belt from the feed hopper to the dryer using the belt scale located on the conveyor belt and documenting the duration of each test run.
- Measurement Location M2: Stack gas. Flow rate in the exhaust stack was measured using a continuous emission monitor.
- Measurement Location M3: Temperature of the soil exiting the dryer. The temperature was monitored continuously by Hochtief Umwelt using a temperature probe (thermocouple) that extends into the soil stream exiting the dryer.
- Measurement Location M4: Shell temperature of the thermal desorption unit. The temperature was monitored continuously by Hochtief Umwelt using eight temperature probes (thermocouples) along the length of the unit. A temperature probe was located on each of the eight sections of the thermal desorption unit.
- Measurement Location M5: Temperature of the soil exiting the thermal desorption unit. The temperature was monitored continuously by Hochtief Umwelt using a temperature probe (thermocouple) that extends into the soil stream.
- Measurement Location M6: Temperature of the gas stream exiting the thermal desorption unit. The temperature was monitored continuously by Hochtief Umwelt using a temperature probe (thermocouple) that extends into the gas stream.
- Measurement Location M7: Temperature of the soil exiting the cooler. The temperature was monitored continuously by Hochtief Umwelt using a temperature probe (thermocouple) that extends into the soil stream exiting the cooler.
- Measurement Location M8: Characteristics of stack emissions. Total organic carbon, hydrochloric acid, carbon monoxide, sulfur dioxide, particulate matter, and temperature levels were measured by Hochtief Umwelt.

2.2.2 Sampling and Analytical Methods

This section describes procedures for collecting representative samples at each sampling location and analyzing collected samples. Samples were collected at three locations. These locations include two soil sampling points and one stack gas sampling point, as described in the previous section. System operating parameters were monitored continuously by Hochtief Umwelt. Sampling began after Hochtief Umwelt judged that the system was operating at a steady state.

2.2.2.1 Soil Samples

Contaminated feed soil and treated soil are transported by dedicated conveyor belts in the Hochtief Umwelt facility. Samples collected were obtained from conveyor belts. Grab samples were obtained from the conveyor belt position closest to the process (just before the drying unit and after the cooler unit).

Discrete grab soil samples were collected from the conveyor belts at sampling locations S1 and S2 using an aluminum or stainless-steel scoop at the frequency described in [Section 2.2.1.1](#). The soil was immediately transferred to an appropriate precleaned sample container for BTEX analysis. All discrete samples collected for BTEX analysis were collected with minimal headspace. Grab samples were also collected and immediately transferred to an appropriate precleaned compositing container for use in the composite samples collected. Composite soil samples were collected at sampling locations S1 and S2 for analysis of PAHs, TRPH, moisture content, and particle size distribution. Any soil that was not needed for samples was returned to the conveyor belt from which it was collected. [Table 8](#) lists the analytical procedures used for samples collected during the demonstration.

2.2.2.2 Stack Gas Samples

Stack gas samples were collected from sampling ports located in the exhaust stack. Three stack gas samples were collected for BTEX analysis during each of three 8-hour Test Runs on February 24 and 25, 1995. Additionally, one stack gas sample was collected for PAH analysis during each Test Run. Stack gas samples were collected according to standard U.S. EPA stack sampling methods as published in 40 Code of Federal Regulations Part 60 (Standards of Performance for New Stationary Sources, Appendix A, Reference Methods) and the EPA SW-846 methods manual (EPA, 1996). Traverse point locations were determined based on the criteria in the sampling method. Stack gas samples for PAH analysis were collected using EPA Method 0010. Volatile organic residuals were analyzed using the volatile organic sampling train (VOST) as described in EPA Method 0030.

Stack emission characterization data, including total organic carbon, carbon monoxide, sulfur dioxide, particulate matter, and temperature, were routinely collected by Hochtief Umwelt. The stack

TABLE 8. ANALYTICAL METHODS

Matrix	Parameter	Method	Reference
Soil	BTEX	8260	SW-846 ¹
	TRPH	3540/418.1	SW-846 ¹ / MCAWW ²
	PAHs	3540/8270A	SW-846 ¹
	Percent Moisture	D2216	ASTM
	PSD	SOP	Institut Fresenius
Air	BTEX	0030	SW-846 ¹
	PAHs	MM5	SW-846 ¹

Notes:

ASTM	American Society for Testing and Materials
BTEX	Benzene, toluene, ethylbenzene, and xylenes
MM5	Modified Method 5
PAH	Polynuclear aromatic hydrocarbons
PSD	Particle size distribution
SOP	Standard operating procedures
TRPH	Total recoverable petroleum hydrocarbons
¹	EPA 1996
²	EPA 1983

characterization data were collected using a continuous emissions monitor (CEM) operated by Hochtief Umwelt. The CEM was operated in accordance with Hochtief Umwelt's standard operating procedures for the CEM system and included weekly calibration checks.

2.2.3 Quality Assurance and Quality Control Program

Quality control checks were an integral part of the Hochtief Umwelt bilateral SITE demonstration to ensure that the QA objectives were met. These checks and procedures focused on the collection of representative samples absent of external contamination and on the generation of comparable data. The QC checks and procedures conducted during the demonstration were of two kinds: (1) checks controlling field activities, such as sample collection and shipping, and (2) checks controlling laboratory activities, such as extraction and analysis. The results of the field and laboratory QC checks are summarized in Section 2.3.3.

2.2.3.1 Field Quality Control Checks

As a check on the quality of field activities including sample collection, shipment, and handling, three types of field QC checks (field blanks, trip blanks, and equipment blanks) were collected. In general, these QC checks assess the potential for contamination of samples in the field and ensure that the degree to which the analytical data represent site conditions is known and documented. Field QC results are reported in [Section 2.3.3](#).

2.2.3.2 Laboratory Quality Control Checks

Laboratory QC checks are designed to assess the precision and accuracy of the analysis, to demonstrate the absence of interferences and contamination from glassware and reagents, and to ensure the comparability of data. Laboratory-based QC checks consisted of method blanks, matrix spikes/matrix spike duplicates, surrogate spikes, blank spikes/blank spike duplicates, and other checks specified in the analytical methods. The laboratory also conducted initial calibrations and continuing calibration checks according to the specified analytical methods. The results of the laboratory internal QC checks for critical parameters are summarized in [Section 2.3.3](#).

2.2.3.3 Field and Laboratory Audits

An independent laboratory audit was conducted at the Institut Fresenius laboratory facility in Hessen, Germany on February 13 and 14, 1995 by Maxwell/S-Cubed, the NRMRL QA support contractor. Observations and recommendations were made regarding the analysis of PAHs, BTEX, TRPH, and percent moisture at the laboratory. During the audit, no serious concerns were identified; rather, suggestions for laboratory and project management communication were noted. On February 24 and 25 (during demonstration activities), an independent field audit of the stack sampling portion of the demonstration was conducted. The audit concluded that the major aspects of sampling and recovery were such that the results obtained from stack sampling activities will be of adequate quality to document the critical compound concentrations in the stack emissions.

2.3 DEMONSTRATION RESULTS AND CONCLUSIONS

This section presents the operating conditions, results and associated discussion, and conclusions of the bilateral SITE demonstration of the Hochtief Umwelt thermal desorption technology.

2.3.1 Operating Conditions

This section summarizes the configuration of the Hochtief Umwelt system, operating parameters, and system maintenance during the SITE demonstration. During this bilateral SITE demonstration, the Hochtief Umwelt system was operated at conditions determined by the developer. To document the Hochtief Umwelt system's operating conditions, soil and air were periodically monitored and sampled. The system operated for 16 hours in two test runs on February 24, 1995 and for 8 hours on February 25, 1995. Thus, the demonstration consisted of three 8-hour test runs.

2.3.1.1 Treatment System Configuration

The Hochtief Umwelt treatment system includes mechanical preparation, thermal desorption, and flue gas treatment processes. Mechanical preparation includes a three-step crushing and sieving process. The thermal desorption process includes a feed hopper, dryer unit, thermal desorption unit, cooler unit, afterburner, and filters. The flue gas treatment process includes a spray dryer, a sequence of gas scrubbers, and optional air stream adsorber and activated carbon bed. For this demonstration, the optional units were not used. The configuration of the Hochtief Umwelt treatment system components is shown in [Figure 3](#).

2.3.1.2 Operating Parameters

The developer monitored the Hochtief Umwelt thermal desorption system throughout the demonstration. System operating parameters monitored included stack gas flow, temperature of the soil exiting the dryer, thermal desorption unit, and cooler, of the thermal desorption unit, and of the gas stream exiting the thermal desorption unit, and stack gas emission characteristics. A discussion of the nonproprietary operating parameters measured during the demonstration is presented in [Section 2.3.2.2](#).

2.3.2 Results and Discussion

This section presents the results of the bilateral SITE demonstration of the Hochtief Umwelt thermal desorption technology at Herne, Germany. The results are presented by and interpreted in relation to project objectives. The specific primary and secondary objectives are shown at the beginning of each section in italics, followed by a discussion of the objective-specific results. The data used to evaluate the primary objectives are presented in [Tables 9 and 10](#). Data quality discussions and conclusions based on these results are presented in [Sections 2.3.3 and 2.3.4](#).

2.3.2.1 Primary Objectives

Primary objectives were considered critical for the evaluation of the Hochtief Umwelt thermal desorption system and are discussed below.

Primary Objective P-1

Determine the removal efficiency of the Hochtief Umwelt thermal desorption system for the following critical compounds:

-TRPH	-Benzo(b)fluoranthene
-Naphthalene	-Benzo(k)fluoranthene
-Acenaphthene	-Benzo(a)pyrene
-Acenaphthylene	-Indeno(1,2,3-cd)pyrene
-Fluorene	-Dibenzo(a,h)anthracene
-Phenanthrene	-Benzo(g,h,i)perylene
-Anthracene	-Benzene
-Fluoranthene	-Toluene
-Pyrene	-Ethylbenzene
-Benzo(a)anthracene	-Xylenes
-Chrysene	

To determine the removal efficiencies of the system, samples of soil entering and exiting the system were collected during the three test runs. The removal efficiency was calculated for each contaminant based on contaminant concentrations in the feed and treated soil (the treated soil exiting from the cooler). For this objective, the difference between the contaminant concentrations in the contaminated feed soil and

**TABLE 9. CRITICAL COMPOUND CONCENTRATIONS IN FEED SOIL
HOCHTIEF UMWELT THERMAL DESORPTION TECHNOLOGY
GHM SITE
(Sampling Location S1)**

Parameter	Test Run 1		Test Run 2		Test Run 3	
	Average Contaminant Concentration (mg/kg)	Average Moisture Content (%)	Average Contaminant Concentration (mg/kg)	Average Moisture Content (%)	Average Contaminant Concentration (mg/kg)	Average Moisture Content (%)
TRPH	2050	17.7	1550	17.4	954	18.8
Naphthalene	2240		2470		2080	
Acenaphthene ¹	61		84		62	
Acenaphthylene ¹	442		476		407	
Fluorene ¹	291		349		302	
Phenanthrene	1350		1520		1310	
Anthracene	349		411		339	
Fluoranthene ¹	1050		1160		997	
Pyrene ¹	871		954		825	
Benz(a)anthracene	100		95		181	
Chrysene	191		245		223	
Benzo(b)fluoranthene	347		569		293	
Benzo(k)fluoranthene	32		123		87	
Benzo(a)pyrene	278		391		236	
Indeno(1,2,3-cd)pyrene	175		204		121	
Dibenzo(a,h)anthracene	90		195		48	
Benzo(g,h,i)perylene	191		229		124	
Total PAHs	8060	9480	7640			

**TABLE 9. CRITICAL COMPOUND CONCENTRATIONS IN FEED SOIL (Continued)
HOCHTIEF UMWELT THERMAL DESORPTION TECHNOLOGY
GHM SITE
(Sampling Location S1)**

Parameter	Test Run 1		Test Run 2		Test Run 3	
	Average Contaminant Concentration (mg/kg)	Average Moisture Content (%)	Average Contaminant Concentration (mg/kg)	Average Moisture Content (%)	Average Contaminant Concentration (mg/kg)	Average Moisture Content (%)
Benzene	28.8	17.7	19.8	17.4	47.1	18.8
Toluene	26.8		20.8			
Ethylbenzene	1.40		0.95			
Xylene (m + p)	26.7		11.5			
Xylene (o)	9.60		3.76			
Total BTEX	93.3		56.8			

Notes:

mg/kg Milligrams per kilogram

m + p Meta and para

o Ortho

TRPH Total recoverable petroleum hydrocarbons

PAH Polynuclear aromatic hydrocarbon

BTEX Benzene, toluene, ethylbenzene, and xylenes

¹ Denoted PAHs were not recovered within QC limits in some MS/MSD analyses of treated soil samples. A potential bias exists; results are therefore estimates. See Section 2.3.3 for a discussion.

**TABLE 10. CRITICAL COMPOUND CONCENTRATIONS IN TREATED SOIL
HOCHTIEF UMWELT THERMAL DESORPTION TECHNOLOGY
GHM SITE
(Sampling Location S2)**

Parameter	Test Run 1				Test Run 2				Test Run 3			
	Average Concentration (mg/kg)	Average Moisture Content (%)	Moisture Content Correction Factor	Average Normalized Concentration (mg/kg) ¹	Average Concentration (mg/kg)	Average Moisture Content (%)	Moisture Content Correction Factor	Average Normalized Concentration (mg/kg) ¹	Average Concentration (mg/kg)	Average Moisture Content (%)	Moisture Content Correction Factor	Average Normalized Concentration (mg/kg) ¹
TRPH	16.9	8.00	0.89	15.0	16.0	8.28	0.90	14.4	17.1	8.14	0.88	15.0
Naphthalene	1.40			1.24	1.30			1.17	1.20			1.06
Acenaphthene ²	< 0.30			< 0.30	< 0.30			< 0.30	< 0.30			< 0.30
Acenaphthylene ²	0.10			0.09	0.10			0.09	< 0.30			< 0.30
Fluorene ²	0.10			0.09	0.10			0.09	0.10			0.09
Phenanthrene	5.80			5.16	6.20			5.58	5.90			5.19
Anthracene	0.90			0.80	1.80			1.62	1.00			0.88
Fluoranthene ²	7.60			6.76	7.20			6.48	7.20			6.34
Pyrene ²	4.60			4.09	4.80			4.32	4.90			4.31
Benzo(a)anthracene	1.00			0.89	1.00			0.90	1.00			0.88
Chrysene	1.50			1.34	1.60			1.44	1.50			1.32
Benzo(b)fluoranthene	2.30			2.05	2.60			2.34	2.40			2.11
Benzo(k)fluoranthene	0.60			0.53	0.40			0.36	0.40			0.35
Benzo(a)pyrene	0.60			0.53	0.50			0.45	0.60			0.53
Indeno(1,2,3-cd)pyrene	0.20			0.18	0.10			0.09	0.10			0.09
Dibenzo(a,h)anthracene	0.10			0.09	< 0.50			< 0.50	< 0.50			< 0.50
Benzo(g,h,i)perylene	0.30			0.27	0.20			0.18	0.20			0.18
Total PAHs	27.1	24.1	27.9	25.1	26.5	23.3						

TABLE 10. CRITICAL COMPOUND CONCENTRATIONS IN TREATED SOIL (Continued)
HOCHTIEF UMWELT THERMAL DESORPTION TECHNOLOGY
GHM SITE
(Sampling Location S2)

Parameter	Test Run 1				Test Run 2				Test Run 3			
	Average Concentration (mg/kg)	Average Moisture Content (%)	Moisture Content Correction Factor	Average Normalized Concentration (mg/kg) ¹	Average Concentration (mg/kg)	Average Moisture Content (%)	Moisture Content Correction Factor	Average Normalized Concentration (mg/kg) ¹	Average Concentration (mg/kg)	Average Moisture Content (%)	Moisture Content Correction Factor	Average Normalized Concentration (mg/kg) ¹
Benzene	0.50	8.00	0.89	0.44	0.34	8.28	0.90	0.31	0.39	8.14	0.88	0.35
Toluene	0.56			0.50	0.30			0.27	0.29			0.26
Ethylbenzene	0.22			0.20	< 0.10			< 0.10	< 0.10			< 0.10
Xylene (m + p)	0.20			0.18	< 0.10			< 0.10	< 0.10			< 0.10
Xylene (o)	< 0.10			< 0.10	< 0.10			< 0.10	< 0.10			< 0.10
Total BTEX	1.58			1.42	0.94			0.82	0.98			0.91

Notes:

mg/kg Milligrams per kilogram

m + p Meta and para

o Ortho

TRPH Total recoverable petroleum hydrocarbons

PAH Polynuclear aromatic hydrocarbons

BTEX Benzene, toluene, ethylbenzene, and xylenes

¹ Contaminant concentrations normalized to moisture content of feed soil.

² Denoted PAHs were not recovered within QC limits in some MS/MSD analyses of treated soil samples. A potential bias exists; results are therefore estimates. See Section 2.3.3 for a discussion.

the treated soil is considered the critical parameter. The appropriate number of samples and the sample collection methods were discussed in [Section 2.2](#).

The contaminant removal efficiencies were calculated for each run using the following equations:

$$\%R = \frac{C_u - C_{tn}}{C_u} \times 100\%$$

where

%R	=	Contaminant reduction efficiency (%)
C_u	=	Arithmetic mean untreated soil contaminant concentration (mg/kg)
C_{tn}	=	Arithmetic mean treated soil contaminant concentration normalized to the arithmetic mean moisture content of the contaminated feed soil (mg/kg)

$$C_{t,norm} = (C_t) (Z)$$

where:

$C_{t,norm}$	=	Contaminant concentration in treated soil normalized to the arithmetic mean of feed soil moisture content (mg/kg)
C_t	=	Contaminant concentration in treated soil (mg/kg)
Z	=	Normalization factor

The normalization factor was calculated by using the following equation:

$$Z = \frac{1 - M_u}{1 - M_t}$$

where:

Z	=	Normalization factor
M_u	=	Arithmetic mean of moisture content of untreated soil (grams per gram [g/g])
M_t	=	Arithmetic mean of moisture content of treated soil (g/g)

For the calculation of the mean, sample concentrations below the method detection limits were assigned the concentration value of the detection limit. Given the equations above, the contaminant removal efficiencies for TRPH were 99.3 percent, 99.1 percent, and 98.4 percent for the three test runs. Removal efficiency for total PAH for all three test runs was 99.7 percent. Removal efficiency for BTEX was 98.5 percent, 98.6

percent, and 99.4 percent for the three test runs. The results for each test run are presented in [Table 11](#). Based on overall average contaminant concentrations, the overall average removal efficiencies were 99.0 percent for TRPH, 99.7 percent for total PAH, and 99.0 percent for BTEX. Overall average removal efficiencies are presented in [Table 12](#).

The results of this demonstration indicate that the Hochtief Umwelt technology can reduce TRPH, PAH, and BTEX concentrations in sandy soil from an average of 1,520 mg/kg to an average of 14.8 mg/kg for TRPH, from an average of 8,380 mg/kg to an average of 24.2 mg/kg for PAH, and from an average of 103 mg/kg to an average of less than 1.01 mg/kg for BTEX.

Primary Objective P-2

Document the critical contaminant concentrations in the treated soil at a confidence level of 95 percent.

Achievement of this objective was determined by collecting samples of the treated soil that was discharged from the system and analyzing the samples for TRPH, PAH, and BTEX. The 95 percent upper confidence limit (UCL) for contaminants in treated soil was calculated using the contaminant concentration data presented in [Table 10](#) and the following equation:

$$UCL_{t,95\%} = x + \frac{ts}{\sqrt{n}}$$

where:

- x = Treated soil arithmetic mean contaminant concentration normalized to the feed soil moisture content (see equation above)
- t = Student's t-test statistic value at the 95 percent confidence level
- s = Sample standard deviation
- n = Sample size (number of measurements)

For the calculation of the mean and standard deviation, sample concentrations below the method detection limits were assigned the concentration value of the detection limit. The 95 percent UCLs for TRPH, PAH, and BTEX in the treated soils are presented in [Table 13](#). These results indicate that the Hochtief Umwelt technology: (1) reduced TRPH concentrations in soil to between 16.1 and 17.8 mg/kg

**TABLE 11. CRITICAL COMPOUND REMOVAL EFFICIENCY ACHIEVED PER TEST RUN
HOCHTIEF UMWELT THERMAL DESORPTION TECHNOLOGY
GHM SITE**

Parameter	Test Run 1			Test Run 2			Test Run 3		
	Average Concentration in Untreated Soil (mg/kg)	Average Concentration in Treated Soil (mg/kg) ¹	Average Contaminant Removal Efficiency (%)	Average Concentration in Untreated Soil (mg/kg)	Average Concentration in Treated Soil (mg/kg) ¹	Average Contaminant Removal Efficiency (%)	Average Concentration in Untreated Soil (mg/kg)	Average Concentration in Treated Soil (mg/kg) ¹	Average Contaminant Removal Efficiency (%)
TRPH	2050	15.0	99.3	1,550	14.4	99.1	954	15.0	98.4
Naphthalene	2240	1.24	99.9	2,470	1.17	>99.9	2,080	1.06	99.9
Acenaphthene ²	61	<0.30	99.5	84	<0.30	99.6	62	<0.30	99.5
Acenaphthylene ²	442	0.09	>99.9	476	0.09	>99.9	407	<0.30	99.9
Fluorene ²	291	0.09	>99.9	349	0.09	>99.9	302	0.09	>99.9
Phenanthrene	1350	5.16	99.6	1,520	5.58	99.6	1,310	5.19	99.6
Anthracene	349	0.80	99.8	411	1.62	99.6	339	0.88	99.7
Fluoranthene ²	1050	6.76	99.4	1,160	6.48	99.4	997	6.34	99.4
Pyrene ²	871	4.09	99.5	954	4.32	99.5	825	4.31	99.5
Benzo(a)anthracene	100	0.89	99.1	95	0.90	99.0	181	0.88	99.5
Chrysene	191	1.34	99.3	245	1.44	99.4	223	1.32	99.4
Benzo(b)fluoranthene	347	2.05	99.4	569	2.34	99.6	293	2.11	99.3
Benzo(k)fluoranthene	32	0.53	98.3	123	0.36	99.7	87	0.35	99.6
Benzo(a)pyrene	278	0.53	99.8	391	0.45	99.9	236	0.53	99.8
Indeno(1,2,3-cd)pyrene	175	0.18	99.9	204	0.09	>99.9	121	0.09	99.9
Dibenzo(a,h)anthracene	90	0.09	99.9	195	<0.50	99.7	48	<0.50	99.0
Benzo(g,h,i)perylene)	191	0.27	99.9	229	0.18	99.9	124	0.18	99.9
Total PAHs	8,060	24.1	99.7	9,480	25.1	99.7	7,640	23.3	99.7

TABLE 11. CRITICAL COMPOUND REMOVAL EFFICIENCY ACHIEVED PER TEST RUN (Continued)
HOCHTIEF UMWELT THERMAL DESORPTION TECHNOLOGY
GHM SITE

Parameter	Test Run 1			Test Run 2			Test Run 3		
	Average Concentration in Untreated Soil (mg/kg)	Average Concentration in Treated Soil (mg/kg) ¹	Average Contaminant Removal Efficiency (%)	Average Concentration in Untreated Soil (mg/kg)	Average Concentration in Treated Soil (mg/kg) ¹	Average Contaminant Removal Efficiency (%)	Average Concentration in Untreated Soil (mg/kg)	Average Concentration in Treated Soil (mg/kg) ¹	Average Contaminant Removal Efficiency (%)
Benzene	28.8	0.44	98.5	19.8	0.31	98.4	47.1	0.35	99.3
Toluene	26.8	0.50	98.1	20.8	0.21	98.7	55.4	0.26	99.5
Ethylbenzene	1.40	0.20	85.7	0.95	<0.10	89.5	2.99	<0.10	96.7
Xylene (m + p)	26.7	0.18	99.3	11.5	<0.10	99.1	40.5	<0.10	99.8
Xylene (o)	9.6	<0.10	99.0	3.76	<0.10	97.3	14.3	<0.10	99.3
Total BTEX	93.3	1.42	98.5	56.8	0.82	98.6	160	0.91	99.4

Notes:

mg/kg Milligrams per kilogram

m + p Meta and para

o Ortho

TRPH Total recoverable petroleum hydrocarbons

PAH Polynuclear aromatic hydrocarbon

BTEX Benzene, toluene, ethylbenzene, and xylenes

¹ Average contaminant concentration in treated soil is normalized to the moisture content of the untreated soil

² Denoted PAHs were not recovered within QC limits in some MS/MSD analyses of treated soil samples. A potential bias exists; results are therefore estimates. See Section 2.3.3 for a discussion.

**TABLE 12. OVERALL AVERAGE CRITICAL COMPOUND REMOVAL EFFICIENCIES
HOCHTIEF UMWELT THERMAL DESORPTION TECHNOLOGY
GHM SITE**

Parameter	Overall Average Concentration in Untreated Soil (mg/kg)	Overall Average Concentration in Treated Soil (mg/kg)¹	Removal Efficiency (%)
TRPH	1,520	14.8	99.0
Naphthalene	2,260	1.16	99.9
Acenaphthene ²	69.0	< 0.30	99.6
Acenaphthylene ²	442	0.16	> 99.9
Fluorene ²	314	0.09	> 99.9
Phenanthrene	1,390	5.31	99.6
Anthracene	366	1.10	99.7
Fluoranthene ²	1,070	6.53	99.4
Pyrene ²	883	4.24	99.5
Benzo(a)anthracene	125	0.89	99.3
Chrysene	220	1.37	99.4
Benzo(b)fluoranthene	403	2.17	99.5
Benzo(k)fluoranthene	80.7	0.41	99.4
Benzo(a)pyrene	302	0.50	99.8
Indeno(1,2,3-cd)pyrene	167	0.12	99.9
Dibenzo(a,h)anthracene	111	0.36	99.7
Benzo(g,h,i)perylene	181	0.21	99.9
Total PAHs	8,380	24.9	99.7
Benzene	31.9	0.37	98.8
Toluene	34.3	0.32	99.0
Ethylbenzene	1.78	0.13	94.4
Xylene (m + p)	26.2	0.13	99.6
Xylene (o)	9.22	< 0.10	98.9
Total BTEX	103	1.05	99.0

Notes:

mg/kg Milligram per kilogram
o Ortho
BTEX Benzene, toluene, ethylbenzene, and xylenes
¹ Average contaminant concentration in treated soil is normalized to the moisture content of the untreated soil.
² Denoted PAHs were not recovered within QC limits in some MS/MSD analyses of treated soil samples. A potential bias exists; results are therefore estimates. See Section 2.3.3 for a discussion.

m + p Meta and para
PAH Polynuclear aromatic hydrocarbon
TRPH Total recoverable petroleum hydrocarbons

**TABLE 13. 95 PERCENT UPPER CONFIDENCE LIMIT OF
CRITICAL COMPOUND CONCENTRATIONS IN TREATED SOIL (mg/kg)
HOCHTIEF UMWELT THERMAL DESORPTION TECHNOLOGY
GHM SITE**

Parameter	Test Run 1	Test Run 2	Test Run 3
TRPH	16.1	17.5	16.8
Naphthalene	1.48	1.50	1.33
Acenaphthene ¹	NC	NC	NC
Acenaphthylene ¹	0.09	0.09	NC
Fluorene ¹	0.09	0.17	0.09
Phenanthrene	6.79	7.70	6.89
Anthracene	1.86	3.41	1.24
Fluoranthene ¹	9.12	8.84	9.11
Pyrene ¹	5.64	5.95	6.01
Benzo(a)anthracene	1.38	1.23	1.15
Chrysene	1.91	2.01	1.86
Benzo(b)fluoranthene	2.87	3.24	3.54
Benzo(k)fluoranthene	0.86	0.52	0.62
Benzo(a)pyrene	0.86	0.69	0.98
Indeno(1,2,3-cd)pyrene	0.34	0.09	0.18
Dibenzo(a,h)anthracene	0.17	NC	NC
Benzo(g,h,i)perylene	0.51	0.26	0.27
Total PAHs	34.0	35.7	33.3
Benzene	0.64	0.38	0.50
Toluene	0.79	0.33	0.36
Ethylbenzene	0.36	0.10	0.10
Xylene (m + p)	0.28	0.10	0.10
Xylene (o)	0.10	0.10	0.10
Total BTEX	2.17	1.01	1.16

Notes:

mg/kg	Milligram per kilogram	PAH	Polynuclear aromatic hydrocarbon
m + p	Meta and para	BTEX	Benzene, toluene, ethylbenzene, and xylene
o	Ortho	TRPH	Total recoverable petroleum hydrocarbons
NC	Not Calculated		
¹	Denoted PAHs were not recovered within QC limits in some MS/MSD analyses of treated soil samples. A potential bias exists; results are therefore estimates. See Section 2.3.3 for a discussion.		

at the 95 percent UCL; (2) reduced total PAH concentrations in soil to between 33.3 and 35.7 mg/kg at the 95 percent UCL; and (3) reduced BTEX concentrations in soil to between 1.01 mg/kg and 2.17 mg/kg at the 95 percent UCL.

Primary Objective P-3

Document critical compound concentrations in the stack emissions.

This objective was achieved by collecting and analyzing stack gas samples for PAHs and BTEX. Stack gas samples were not analyzed for TRPH. The results indicate that concentrations in stack emissions ranged from 78.4 to 240 micrograms per dry standard cubic meter ($\mu\text{g}/\text{dscm}$) for total PAH and from 181 to 350 $\mu\text{g}/\text{dscm}$ for BTEX. It should be noted that meta- and para-xylene and toluene concentrations are potentially biased high based on field or equipment blank contamination, as discussed in more detail in [Section 2.3.3](#). However, these potential biases are negligible compared to the BTEX concentrations.

The average PAH and BTEX concentrations for each test run are summarized in [Table 14](#). The concentration and the amount of released stack gas was also monitored continuously by Hochtief Umwelt during routine operation of the system.

2.3.2.2 Secondary Objectives

Secondary objectives provide additional information that is useful, but not critical, for the evaluation of the Hochtief Umwelt technology. Four secondary objectives were selected for the bilateral SITE demonstration of the Hochtief Umwelt system. The secondary project objectives and the associated noncritical measurement parameters required to achieve those objectives are presented in [Table 7](#).

**TABLE 14. CRITICAL COMPOUND CONCENTRATIONS IN STACK GAS
HOCHTIEF UMWELT THERMAL DESORPTION TECHNOLOGY
GHM SITE
(Sampling Location S3)**

Parameter	Test Run 1	Test Run 2	Test Run 3
	Average Contaminant Concentration ($\mu\text{g/dscm}$)	Average Contaminant Concentration ($\mu\text{g/dscm}$)	Average Contaminant Concentration ($\mu\text{g/dscm}$)
Naphthalene	128	100	51.1
Acenaphthene	< 4.00	< 4.00	< 4.00
Acenaphthylene	< 4.00	< 4.00	< 4.00
Fluorene	< 4.00	< 4.00	< 4.00
Phenanthrene	32.7	19.7	11.1
Anthracene	30.7	18.3	10.6
Fluoranthene	24.5	13.2	5.60
Pyrene	15.7	8.50	< 4.00
Benzo(a)anthracene	< 4.00	5.10	< 4.00
Chrysene	8.60	6.90	< 4.00
Benzo(b)fluoranthene	< 4.00	< 4.00	< 4.00
Benzo(k)fluoranthene	< 4.00	< 4.00	< 4.00
Benzo(a)pyrene	< 4.00	< 4.00	< 4.00
Indeno(1,2,3-cd)pyrene	< 4.00	< 4.00	< 4.00
Dibenzo(a,h)anthracene	< 4.00	< 4.00	< 4.00
Benzo(g,h,i)perylene	< 4.00	< 4.00	< 4.00
Total PAHs	240	172	78.4
Benzene	224	214	147
Toluene ¹	87.3	104	23.2
Ethylbenzene	7.37	8.33	2.13
Xylene (m + p) ¹	18.1	17.1	6.37
Xylene (o)	6.00	6.37	2.30
Total BTEX	343	350	181

Notes:

$\mu\text{g/dscm}$

Micrograms per dry standard cubic meter

PAH

Polynuclear aromatic hydrocarbons

BTEX

Benzene, toluene, ethylbenzene, and xylenes

¹

Denotes compounds detected in one or more field blanks. Results are therefore potentially biased high. See Section 2.3.3 for a discussion.

Secondary Objective S-1

Document the moisture content and the particle size distribution of the feed and treated soil in the thermal desorption process.

This objective was achieved by collecting soil samples from the contaminated feed soil and treated soil and analyzing the samples for moisture content and particle size distribution (PSD). The sample results indicate that the moisture content of the contaminated feed soil ranged from 17.4 percent to 18.8 percent by weight. The moisture content of the treated soil ranged from 8.0 percent to 8.28 percent by weight. The particle size distribution results indicate that the soil is a silty sand. The moisture content and particle size distribution results of contaminated and treated soil are summarized in [Table 15](#).

**TABLE 15. MOISTURE CONTENT AND PARTICLE SIZE DISTRIBUTION OF SOIL
HOCHTIEF UMWELT THERMAL DESORPTION TECHNOLOGY
GHM SITE**

Run Number	Analytical Parameter	Soil Type ¹	
		Contaminated Feed Soil (Sampling Location S1)	Treated Soil (Sampling Location S2)
1	Particle Size Distribution	Sand 52.5/36.7/10.9 ²	Sand 55.8/36.5/7.7 ²
	Percent Moisture	17.7	8.00
2	Particle Size Distribution	Sand 63.6/29.5/6.9 ²	Sand 62.1/30.2/7.8 ²
	Percent Moisture	17.4	8.28
3	Particle Size Distribution	Sand 61.6/31.9/6.5 ²	Sand 60.6/31.2/8.2 ²
	Percent Moisture	18.8	8.14

Notes:

¹ Based on particle size distribution according to an Institut Fresenius standard operating procedure
² % sand/ % silt/ % clay

Secondary Objective S-2

Document key nonproprietary system operating parameters.

The following nonproprietary system operating parameter data were collected during the demonstration: (1) flow rate of feed soil, (2) flow rate of stack gas, (3) temperature of soil exiting the dryer, (4) shell temperature of the thermal desorption unit, (5) temperature of soil exiting the thermal desorption unit (6) temperature of the gas stream exiting the thermal desorption unit, and (7) temperature of soil exiting the cooler. [Table 16](#) summarizes the range of average system flow rates and temperatures during the three runs of the demonstration.

**TABLE 16. SYSTEM OPERATING PARAMETERS
HOCHTIEF UMWELT THERMAL DESORPTION TECHNOLOGY
GHM SITE**

Measurement Location	Units	Range	Average
M1 Flow Rate of Feed Soil	mt/h	6.5	6.5
M2 Flow Rate of Stack Gas	nm ³ /h	19,700 to 19,900	19,800
M3 Temperature of Soil Exiting The Dryer	°C	125 to 131	128
M4 Shell Temperature of the Thermal Desorption Unit	°C	737 to 742	740
M5 Temperature of Soil Exiting The Thermal Desorption Unit	°C	488 to 535	511
M6 Temperature of Gas Stream Exiting Thermal Desorption Unit	°C	593 to 605	598
M7 Temperature of the Soil Exiting the Cooler	°C	66 to 78	70.3

Notes:

mt/h Metric tonnes per hour
nm³/h Normal cubic meter per hour

Secondary Objective S-3

Document remediation costs per metric tonne of soil.

For the application of the Hochtief Umwelt thermal desorption system and the Herne site, the commercial treatment cost per metric ton was 430 Deutsche Mark (DM) (\$286, assuming a 1.5 DM to \$1 U.S. exchange rate). This is the commercial treatment cost provided by Hochtief Umwelt.

Secondary Objective S-4

Document stack emission characteristics for informational purposes only.

Stack emission characterization data, including total carbon, hydrochloric acid, carbon monoxide, sulfur dioxide, particulate matter, and temperature, were routinely collected by Hochtief Umwelt at Measurement Location 8 and documented for information purposes. The concentration of the total organic carbon in the stack emissions averaged 5.70 milligram per cubic meter (mg/m³); hydrochloric acid was not detected in the gas stream; carbon monoxide concentrations averaged 13.6 mg/m³; sulfur dioxide concentrations averaged less than 1.10 mg/m³; particulate matter concentrations averaged 1.03 mg/m³; and temperature averaged 72.7 °C. Table 17 summarizes the stack emission characterization data collected during the demonstration.

TABLE 17. STACK EMISSION CHARACTERIZATION DATA AT MEASUREMENT LOCATION M8 HOCHTIEF UMWELT THERMAL DESORPTION TECHNOLOGY GHM SITE

Parameter	Units	Test Run			Mean
		1	2	3	
Total Organic Carbon	mg/m ³	6.00	6.00	5.10	5.70
Hydrochloric Acid	mg/m ³	<1.00	<1.00	<1.00	<1.00
Carbon Monoxide	mg/m ³	11.5	14.3	15.0	13.6
Sulfur Dioxide	mg/m ³	1.3	<1.00	<1.00	<1.10
Particulate Matter	mg/m ³	1.00	1.00	1.10	1.03
Temperature	°C	72.0	73.0	73.0	72.7

Notes:

mg/m³ Milligram per cubic meter

2.3.3 Data Quality

This section summarizes and assesses all quality control sample results for soil and stack gas samples collected and analyzed during the Hochtief Umwelt Bilateral SITE demonstration. The purpose of this data quality assessment was to identify any limitations of the data presented in this report, or qualifications of the conclusions based on known information on data quality.

2.3.3.1 Soil Samples

The primary QC samples processed in relation to soil samples included field, equipment, and trip blanks, as well as matrix spike/matrix spike duplicates (MS/MSD).

The results for various blank samples associated with soil sampling are identified in [Table 18](#) as relating to Sampling Location S1 and S2. Since the capture of volatile organic compounds (VOCs) from ambient air was the primary contamination concern at the site, field blanks consisting of purified water were exposed to ambient air at the sampling location for untreated soil (S1) and were subsequently analyzed for BTEX only. No BTEX analytes above the detection limit of 1.0 micrograms per liter ($\mu\text{g/L}$) were detected in any of the three field blank samples taken at Sampling Location S1 or the trip blank. One equipment blank was collected during Test Run 3 by rinsing decontaminated soil sampling equipment with purified water; results indicated some contamination with TRPH, xylene, and traces of several PAHs. However, contamination levels in the equipment blank were minimal compared to even treated soil concentration levels. Therefore, this result does not appear to have any significant impact on data quality for the soil samples. Overall, it does not appear that field contamination of soil samples was a significant issue.

One MS/MSD analysis was conducted in association with each of the three runs on a treated soil sample to assess the precision and accuracy of both the TRPH and the PAH results in the soil matrix. [Table 19](#) lists the results of these three MS/MSD analyses. TRPH recoveries and relative percent differences (RPDs) were consistently within the pre-established QC limits, as shown in [Table 19](#). Thus, the precision and accuracy of the TRPH data are acceptable and there are no limitations on the TRPH data based on the results of the MS/MSD analyses. BTEX recoveries were also consistently within the

TABLE 18. QC RESULTS OF FIELD BLANK, TRIP BLANK, AND EQUIPMENT BLANK ANALYSES

Test Run	Sampling Location	Unit	Blank Type	Contaminant Concentration																					
				TRPHs	Naphthalene	Acenaphthene	Acenaphthylene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benzo(a)anthracene	Chrysene	Benzo(b)fluoranthene	Benzo(k)fluoranthene	Benzo(a)pyrene	Indeno(1,2,3,c,d)pyrene	Dibenzo(a,h)anthracene	Benzo(g,h,i)perylene	Benzene	Toluene	Ethylbenzene	Xylene (m + p)	Xylene (o)
1	S1	µg/L	Field Blank	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<1.00	<1.00	<1.00	<1.00	<1.00
		µg/L	Trip Blank	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<1.00	<1.00	<1.00	<1.00
	S3	µg/dscm	Field Blank	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<5.00	10.2*	<5.00	10.8*	<5.00
2	S1	µg/L	Field Blank	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<1.00	<1.00	<1.00	<1.00	<1.00
3	S1	µg/L	Field Blank	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<1.00	<1.00	<1.00	<1.00	<1.00
		µg/dscm		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<5.00	<5.00	<5.00	<5.00
	µg	NA		5.06	0.02J	<4.00	0.43J	1.23J	0.16J	0.39J	0.26J	0.23J	0.07J	0.17J	0.19J	<4.00	0.34J	0.48J	0.35J	NA	NA	NA	NA	NA	NA
	S1	µg/L	Trip Blank	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<1.00	<1.00	<1.00	<1.00	<1.00
	S1	µg/L	Equipment Blank	80	0.10J	<0.50	0.08J	0.06J	0.06J	0.03J	0.05J	0.04J	0.05J	0.06J	0.07J	0.08J	<0.50	0.23J	0.40J	0.27J	<1.00	<1.00	<1.00	1.32*	<1.00
	S2	µg/L		11	0.07J	<0.50	0.04J	0.03J	0.05J	0.02J	0.02J	0.02J	0.01J	<0.50	0.05J	0.06J	<0.50	0.08J	0.19J	0.16J	<1.00	<1.00	<1.00	1.41*	<1.00
	S3**	µg/dscm		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<5.00	10.9*	<5.00	7.30*
µg		NA		5.06	0.02J	<4.00	0.43J	1.23J	0.16J	0.39J	0.26J	0.23J	0.07J	0.17J	0.19J	<4.00	0.34J	0.48J	0.35J	NA	NA	NA	NA	NA	NA

Notes:

- NA Not applicable
- TRPH Total recoverable petroleum hydrocarbons
- µg/L Microgram per liter
- µg/dscm Microgram per dry standard cubic meter
- * Outside QC limit
- ** Field blank also served as equipment blank for PAH analysis
- J Compound detected below the method detection limit

**TABLE 19. QC RESULTS FOR MATRIX SPIKE AND MATRIX SPIKE DUPLICATE ANALYSIS IN TREATED SOIL
HOCHTIEF UMWELT THERMAL DESORPTION TECHNOLOGY
GHM SITE**

Parameter	Matrix Spike 1			Matrix Spike 2			Matrix Spike 3			QC Limits (%R)	QC RPD (percent)
	Matrix Spike (%R)	Matrix Spike Duplicate (%R)	RPD (%)	Matrix Spike (%R)	Matrix Spike Duplicate (%R)	RPD (%)	Matrix Spike (%R)	Matrix Spike Duplicate (%R)	RPD (%)		
TRPH	100	94.4	5.85	65.0	70.8	8.55	89.6	87.8	2.06	50 - 150	< 30
Naphthalene	33.2	23.9	26.11	33.6	NA	NA	NA	NA	NA	21 - 133	< 30
Acenaphthene	36.2*	24.1*	17.9	48.4	NA	NA	NA	NA	NA	47 - 145	< 30
Acenaphthylene	29.6*	30.3*	20.4	45.8	NA	NA	NA	NA	NA	33 - 145	< 30
Fluorene	42.2*	45.0*	6.11	55.3*	NA	NA	NA	NA	NA	59 - 121	< 30
Phenanthrene	91.3	112	14.8	89.0	NA	NA	NA	NA	NA	54 - 120	< 30
Anthracene	56.2	65.1	12.9	71.1	NA	NA	NA	NA	NA	27 - 133	< 30
Fluoranthene	113	139*	15.8	109	NA	NA	NA	NA	NA	26 - 137	< 30
Pyrene	94.1	99.2	3.93	119*	NA	NA	NA	NA	NA	52 - 115	< 30
Benzo(a)anthracene	84.6	72.2	15.0	102	NA	NA	NA	NA	NA	33 - 143	< 30
Chrysene	76.4	73.7	3.56	86.0	NA	NA	NA	NA	NA	17 - 168	< 30
Benzo(b)fluoranthene	133	147	9.39	120	NA	NA	NA	NA	NA	24 - 159	< 30
Benzo(k)fluoranthene	101	112	10.7	113	NA	NA	NA	NA	NA	11 - 162	< 30
Benzo(a)pyrene	79.7	86.7	7.83	99.7	NA	NA	NA	NA	NA	17 - 163	< 30
Indeno(1,2,3-cd)pyrene	38.4	45.8	17.2	67.1	NA	NA	NA	NA	NA	D - 171	< 30

TABLE 19. QC RESULTS FOR MATRIX SPIKE AND MATRIX SPIKE DUPLICATE ANALYSES IN SOIL (Continued)

Parameter	Matrix Spike 1			Matrix Spike 2			Matrix Spike 3			QC Limits (%R)	QC RPD (percent)
	Matrix Spike (%R)	Matrix Spike Duplicate (%R)	RPD (percent)	Matrix Spike (%R)	Matrix Spike Duplicate (%R)	RPD (percent)	Matrix Spike (%R)	Matrix Spike Duplicate (%R)	RPD (percent)		
Dibenzo(a,h)anthracene	23.3	29.2	22.1	66.4	NA	NA	NA	NA	NA	D - 227	< 30
Benzo(g,h,i)perylene	36.2	43.0	16.5	68.6	NA	NA	NA	NA	NA	D - 219	< 30
Benzene	100	108	NA**	105	104	NA**	NA	NA	NA	39 -150	< 30
Toluene	106	105	NA**	108	100	NA**	NA	NA	NA	46 -148	< 30
Ethylbenzene	99.5	107	NA**	106	102	NA**	NA	NA	NA	36 -143	< 30
Xylene (m + p)	119	126	NA**	101	102	NA**	NA	NA	NA	32 -160	< 30
Xylene (o)	99.9	109	NA**	108	103	NA**	NA	NA	NA	32 -160	< 30

Notes:

- %R Percent recovery
- D Detected (result greater than zero)
- m + p Meta and para
- o Ortho
- NA Not analyzed
- RPD Relative percent difference
- * Outside QC limits
- ** Relative percent difference could not be determined because the laboratory did not use the same spike concentrations for the matrix spike and the matrix spike duplicate

pre-established QC limits, as shown in [Table 19](#). Unfortunately, the RPD could not be determined for BTEX matrix spikes because the laboratory did not use the same spike concentrations for the matrix spike and matrix spike duplicate. However, blank spike/blank spike duplicate (BS/BSD) BTEX data met all QA objectives for percent recovery and RPD (see [Table 20](#)). This finding, together with the fact that the MS/MSD duplicate results were generally similar despite the lack of identical spiking levels, indicates that overall method precision was acceptable.

The MS/MSD results for the PAH data indicated a number of apparent problems, as shown in [Table 19](#). First, due to laboratory errors, an MS/MSD sample was not processed in association with one run, and only a single MS analysis was completed in association with another run. Thus, only one complete pair of MS/MSD results was obtained (Matrix Spike 1). Furthermore, the available MS/MSD results showed varying recoveries for different PAH analytes; 9 out of the 48 results were found to be outside pre-established QC limits. Because there was no consistent bias (that is, consistently high or consistently low recoveries) to the MS/MSD data, it is difficult to assess the causes of the somewhat erratic recoveries, other than it appears to have been a laboratory problem. Review of the laboratory data and backup information did not reveal the problem. As a result, the data relating to selected PAH results in soil samples has been flagged as potentially subject to either a high or low bias.

2.3.3.2 Stack Gas Samples

The primary QC samples processed in relation to stack gas samples included field, equipment, and trip blanks, as well as MS/MSD.

The results for various blank samples associated with stack gas sampling are identified in [Table 18](#) as relating to Sampling Location S3. The field blanks consisted of sampling trains exposed to ambient air at Sampling Location S3. Results indicated some contamination with PAHs, but not at sufficient concentrations to significantly affect the results of stack gas sampling. There was also contamination of the field blank with toluene and meta-/para-xylene, as shown in [Table 18](#). If actual samples of the stack gas were similarly contaminated, the results for toluene and meta-/para-xylene would be biased high, and the bias for meta-/para-xylene could be particularly significant given the similarity of the observed blank contamination levels and actual sample results (see [Table 14](#)). However, the overwhelming contribution

**TABLE 20. QC RESULTS OF BLANK SPIKE AND BLANK SPIKE DUPLICATE ANALYSES FOR TRPH AND VOCs IN SOIL
HOCHTIEF UMWELT THERMAL DESORPTION TECHNOLOGY
GHM SITE**

Parameter	Blank Spike 1			Blank Spike 2			Blank Spike 3			Objective	
	Blank Spike Recovery (%R)	Blank Spike Duplicate Recovery (%R)	Relative Percent Difference (%)	Blank Spike Recovery (%R)	Blank Spike Duplicate Recovery (%R)	Relative Percent Difference (%)	Blank Spike Recovery (%R)	Blank Spike Duplicate Recovery (%R)	Relative Percent Difference (%)	QA Recovery (%R)	QA RPD (%)
TRPH	96.2	NA	NA	132	NA	NA	70.6	NA	NA	50 - 150	< 30
Benzene	100	98.9	2.16	90.9	97.5	6.90	94.3	98.8	4.66	39 - 150	< 30
Toluene	97.9	97.2	0.69	92.1	102	9.50	90.3	99.1	9.10	46 -148	< 30
Ethylbenzene	102	94.8	6.76	93.1	102	9.14	95.8	98.3	2.52	36 - 143	< 30
Xylene (m + p)	102	92.5	9.40	92.5	98.7	6.38	93.7	99.3	5.73	32 -160	< 30
Xylene (o)	103	95.3	7.97	94.9	103	8.59	94.1	99.6	5.61	32 - 160	< 30

Notes:

- %R Percent recovery
- RPD Relative percent difference
- QA Quality assurance
- D Detected (result greater than zero)
- m + p meta and para
- o Ortho
- NA Not analyzed

of benzene to the BTEX concentration (see [Table 12](#)) makes this QC issue not particularly significant with respect to the BTEX results. Thus, while the toluene and xylene data are qualified, there is no affect on the overall conclusions regarding BTEX removal efficiencies.

A BS/BSD sample was used to assess the precision and accuracy of the method for PAH analysis in stack gas. The results, shown in [Table 21](#), indicate that the pre-established QC limits for recovery of spiked compounds were met in all cases. However, the RPD was outside these QC limits for seven out of the 16 individual PAHs, indicating that method precision was less than desired. However, the noncompliant RPDs were reasonably close to the QC limit of 30 percent. Given that the semivolatile

organic compound (SVOC) stack gas sampling results were not used to calculate destruction and removal efficiencies or to compare to specific regulatory thresholds, it is believed that the somewhat lower than desired precision in the stack gas results does not seriously impair the overall quality of the data or the conclusions of this report.

2.3.4 Conclusions

This demonstration was limited to an evaluation of the technology's ability to remove TRPH, PAH, and BTEX from soil. Based on the Hochtief Umwelt bilateral SITE demonstration, specific conclusions for each primary and secondary objective are summarized below:

- The average removal efficiencies achieved were 99.0 percent for TRPH, 99.7 percent for PAHs, and 99.0 percent for BTEX.
- The 95 percent UCL of concentrations in treated soil for Test Run 1 was 16.1 mg/kg for TRPH, 34.0 mg/kg for PAHs, and 2.17 mg/kg for BTEX. The 95 percent upper confidence limit of concentrations in treated soil for Test Run 2 was 17.5 mg/kg for TRPH, 35.7 mg/kg for PAHs, and 1.01 mg/kg for BTEX. The 95 percent upper confidence limit of concentrations in treated soil for Test Run 3 was 16.8 mg/kg for TRPH, 33.3 mg/kg for PAHs, and 1.16 mg/kg BTEX.

**TABLE 21. QC RESULTS FOR BLANK SPIKE AND BLANK SPIKE DUPLICATE ANALYSES OF PAHs IN STACK GAS
HOCHTIEF UMWELT THERMAL DESORPTION TECHNOLOGY
GHM SITE**

Parameter	Matrix Spike 1			QC Limits (%R)	QC RPD (%)
	Matrix Spike (%R)	Matrix Spike Duplicate (%R)	RPD (%)		
Naphthalene	47.7	75.0	40.9*	21 - 133	< 30
Acenaphthene	63.6	92.3	36.7*	47 - 145	< 30
Acenaphthylene	62.0	84.3	30.3*	33 - 145	< 30
Fluorene	71.9	104.3	36.6*	59 - 121	< 30
Phenanthrene	67.3	94.3	32.8*	54 - 120	< 30
Anthracene	69.2	92.6	28.8	27 - 133	< 30
Fluoranthene	60.9	85.7	32.8*	26 - 137	< 30
Pyrene	60.1	84.1	32.3*	52 - 115	< 30
Benzo(a)anthracene	78.4	96.7	20.7	33 - 143	< 30
Chrysene	79.6	98.5	20.9	17 - 168	< 30
Benzo(b)fluoranthene	72.1	97.1	29.3	24 - 159	< 30
Benzo(k)fluoranthene	66.5	88.1	27.8	11 - 162	< 30
Benzo(a)pyrene	78.8	102	25.3	17 - 163	< 30
Indeno(1,2,3-cd)pyrene	102	133	26.0	D - 171	< 30
Dibenzo(a,h)anthracene	94.3	120	23.7	D - 227	< 30
Benzo(g,h,i)perylene	100	124	20.9	D - 219	< 30

* **Bold** indicates result is outside QC limits (see discussion in Section 2.3.3)

Note:

%R	Percent recovery
QC	Quality control
RPD	Relative percent difference
D	Detected (result greater than zero)

Soil PAH results were compromised by some noncompliant recoveries in the MS/MSD analyses, indicating that a potential high or low bias may exist for some individual PAH analytes. As a result, the soil PAH results described above should be considered estimates.

- PAH concentrations in stack emissions ranged from 92.6 to 224 $\mu\text{g}/\text{dscm}$ and BTEX concentrations ranged from 181 to 350 $\mu\text{g}/\text{dscm}$. The specific average contaminant concentrations for each test run are presented in [Section 2.3.2.1](#).
- The moisture content of the contaminated feed soil ranged from 17.4 to 18.8 percent by weight and the moisture content of the treated soil ranged from 8.0 to 8.28 percent by weight. Soils treated during the demonstration were identified as silty sand.
- The average feed soil flow rate for each test run was 6.5 mt/h. The stack gas flow rate ranged from 19,700 to 19,900 nm^3/h and averaged 19,800 nm^3/h during the demonstration. The temperature of soil exiting the dryer unit ranged from 125 to 131°C and averaged 128°C during the demonstration. The temperature of the thermal desorption unit ranged from 737 to 742°C and averaged 740°C during the demonstration. The temperature of the soil exiting the thermal desorption unit ranged from 488 to 535°C and averaged 511°C during the demonstration. The temperature of the gas stream exiting the thermal desorption unit ranged from 593 to 605°C and averaged 598°C. The temperature of soil exiting the cooling unit ranged from 66 to 78°C and averaged 70.3°C.
- The concentration of total carbon in stack emissions ranged from 2.5 to 13.5 mg/m^3 and averaged 7.70 mg/m^3 ; hydrochloric acid was not detected on any of the samples; carbon monoxide concentrations ranged from 1 to 24 mg/m^3 and averaged 13.6 mg/m^3 ; sulfur dioxide concentrations ranged from less than 1.00 to 5 mg/m^3 and averaged 1.1 mg/m^3 ; particulate matter concentrations ranged from less than 1.00 to 2 mg/m^3 and averaged 1.03 mg/m^3 .
- The commercial cost, provided by Hochtief Umwelt, for application of the Hochtief technology at the Herne site was 430 DM per metric ton (\$286 per metric ton assuming a 1.5 DM to \$1 U.S. exchange rate).

3.0 ECONOMIC ANALYSIS

This section presents cost estimates for using the Hochtief Umwelt technology to treat soil contaminated with TRPH, PAH, and BTEX. Cost estimates presented in this section are based on data provided by Hochtief Umwelt GmbH. Capital and operating costs were not assessed in detail because Hochtief Umwelt considers this information proprietary.

For the application of the Hochtief Umwelt thermal desorption system at the Herne site, the cost per metric ton was 430 DM (\$286, assuming a 1.5 DM to \$1 U.S. exchange rate), as provided by Hochtief Umwelt. This cost estimate incorporates only the treatment cost at the facility and does not include transportation costs to convey the soil to the facility.

Although soil treatment costs were not independently estimated, the following cost categories (Evans 1990) should be considered when evaluating the potential cost of treating soil using the Hochtief Umwelt technology:

- Site preparation
- Permitting and regulatory requirements
- Capital equipment
- Startup
- Labor
- Consumables and supplies
- Utilities
- Effluent treatment and disposal
- Residuals and waste shipping and handling
- Analytical services
- Maintenance and modifications
- Demobilization

4.0 TECHNOLOGY APPLICATIONS ANALYSIS

This section evaluates the general applicability of the Hochtief Umwelt technology to contaminated waste sites. Information presented in this section is intended to assist decision makers in screening specific technologies for a particular cleanup situation. This section presents the advantages, disadvantages, and limitations of the technology and discusses factors that have a major impact on the performance and cost of the technology. The analysis is based both on the demonstration results and on the available information from other applications of the technology.

4.1 FEASIBILITY STUDY EVALUATION CRITERIA

This section assesses the Hochtief Umwelt technology against the nine evaluation criteria used for conducting detailed analysis of remedial alternatives in feasibility studies under CERCLA (EPA 1988).

4.1.1 Overall Protection of Human Health and the Environment

The Hochtief Umwelt technology provides both short-term and long-term protection to human health and the environment by reducing the concentrations of TRPH, PAH, and BTEX in soil. Furthermore, the soil vapor extract is processed through an afterburner and flue gas treatment train to minimize organic emissions in the stack gas. If required, organic air emissions are further minimized by passing the stack gas through carbon adsorption units prior to discharge to the atmosphere.

4.1.2 Compliance with ARARs

Although general and specific applicable or relevant and appropriate requirements (ARARs) were not specifically identified for the Hochtief Umwelt technology, compliance with chemical-, location-, and action-specific ARARs should be assessed on a site-specific basis. While location- and action-specific ARARs generally can be met, compliance with chemical-specific ARARs depends on the efficiency of the Hochtief Umwelt system to remove contaminants from the soil and on the site-specific cleanup level.

4.1.3 Long-Term Effectiveness and Permanence

The Hochtief Umwelt system permanently reduces levels of TRPH, PAH, and BTEX in soil using a continuous thermal desorption process. Potential long-term risks to treatment system workers, the community, and the environment from emissions of treated gas and discharge of treated soil are mitigated by ensuring that established standards are met.

4.1.4 Reduction of Toxicity, Mobility, or Volume Through Treatment

As discussed previously, the Hochtief Umwelt thermal desorption technology permanently removes TRPH, PAH, and BTEX. As such, the toxicity, mobility, and volume of contaminants are also significantly reduced.

4.1.5 Short-Term Effectiveness

The permanent removal of TRPH, PAH, and BTEX from soils is achieved relatively quickly, providing for short-term as well as long-term effectiveness. Potential short-term risks focus on air emissions and include potential exposures of workers, the community, and the environment to various toxins in air emissions from the process. However, in the Hochtief process, soil vapors from the thermal desorption of soils are sent through an afterburner and extensive flue gas treatment system, which minimize the ultimate emission of toxins in the stack gas.

4.1.6 Implementability

Implementation of the Hochtief Umwelt system involves (1) site preparation, (2) facility construction, and (3) operation, monitoring, and maintenance. Minimal adverse impacts to the community, workers, or the environment are anticipated during site preparation and system installation.

Site preparation and access requirements for the technology can be significant. The site must be accessible to large trucks. The Hochtief Umwelt thermal desorption system is a large fixed treatment facility with three major components. Construction of the facility requires several months. Supplemental structures are also required to house, integrate, and control all the components. Operation and maintenance of the facility require technical and engineering personnel around the clock. Contaminated soils must be excavated and

transported to the facility. Depending on the distance from the contaminated site to the facility, transportation efforts can be significant.

4.1.7 Cost

For the application of the Hochtief Umwelt technology at the Herne site, the commercial treatment cost per metric ton of soil is 430 DM (\$286, assuming a 1.5 DM to \$1 U.S. exchange rate). These costs were provided by Hochtief Umwelt.

4.1.8 State Acceptance

State acceptance is anticipated because the Hochtief Umwelt system uses well-documented and widely accepted processes to remove TRPH, PAH, and BTEX from soil and to treat stack gas emissions. If remediation is conducted as part of RCRA corrective actions, state regulatory agencies will require that permits be obtained before implementing the system. For example, a permit to operate the treatment system, an air emissions permit, and a permit to store contaminated soil for greater than 90 days if these items are considered hazardous wastes may be required.

4.1.9 Community Acceptance

The system's size and space requirements, as well as the principle of operation, may raise concern in nearby communities. However, proper management and operational controls should ensure that the surrounding community is subjected to only minimal short-term risks. Furthermore, the capability of this process to provide permanent removal of soil contaminants through *in situ* techniques makes this technology likely to be accepted by the public.

4.2 APPLICABLE WASTES

The Hochtief Umwelt technology demonstrated at Herne, Germany, was designed to remove TRPH, PAH, and BTEX from soil. The developer claims that the technology can also remove other contaminants, such as dioxins and furans, PCBs, and other halogenated hydrocarbons as well as volatile heavy metals (for example, mercury).

4.3 LIMITATIONS OF THE TECHNOLOGY

The developer claims that there are no concentration limits on the contaminated media that can be treated by the system. However, high concentrations of contaminants may require more than one pass through the system to achieve remediation goals.

5.0 HOCHTIEF UMWELT TECHNOLOGY STATUS

According to Hochtief Umwelt, the thermal desorption technology can be used for remediation of contaminated soils, especially those contaminated with volatile organic compounds and semivolatile organic compounds. The Hochtief Umwelt system has been used to treat soil from multiple sites in Europe. All treatment has been conducted at a single fixed facility in Herne, Germany. There are currently no commercially operating systems in the U.S.

6.0 REFERENCES

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