

NORDAC SOIL WASHING SYSTEM

**NORDDEUTSCHES ALTLASTEN-SANIERUNGS-CENTRUM GmbH & COMPANY KG
FACILITY**

HAMBURG, GERMANY

EPA - BMBF BILATERAL SITE DEMONSTRATION

INNOVATIVE TECHNOLOGY EVALUATION REPORT

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NOTICE

The information in this document has been prepared for the U.S. Environmental Protection Agency's (EPA) Superfund Innovative Technology Evaluation (SITE) program by PRC Environmental Management, Inc. under Contract No. 68-C5-0037. This document has been prepared in accordance with a bilateral agreement between EPA and the Federal Republic of German Ministry for Research and Technology (BMBF). This document has been subjected to EPA's peer and administrative reviews, and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use.

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 (ORD). 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 Nordac soil washing technology developed by Norddeutsches Altlasten-Sanierungs-Centrum GmbH & Co. KG (Nordac), Hamburg, Germany. The demonstration was conducted at the Nordac facility located in Hamburg, Germany. The Nordac technology demonstration evaluated the treatment of soils from a site used by the chemical industry for the production of artificial resins and plastics, located in Germany. Soils from the site are contaminated with high levels of volatile organic compounds (VOCs), specifically benzene, toluene, ethylbenzene, and xylene (BTEX). This Innovative Technology Evaluation Report (ITER) provides an interpretation of the data collected during the Nordac SITE 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 EPA's Center for Environmental Research Information, 26 Martin Luther King Drive, Cincinnati, Ohio 45268, (513) 569-7562. Requests should include the EPA document number found on the report's cover. When the limited supply is exhausted, additional copies can be purchased from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia 22161, (703) 487-4600. Reference copies will be available at EPA libraries in the Hazardous Waste Collection.

E. 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
bgs	Below Ground Surface
BMBF	Federal Republic of German Ministry for Research and Technology
BTEX	Benzene, toluene, ethylbenzene, and xylenes
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERI	Center for Environmental Research Information
CLU-IN	Clean-up Information
DM	Deutsche Mark
EPA	United States Environmental Protection Agency
g/g	Grams per gram
ITER	Innovative Technology Evaluation Report
m	Meter
m-xylene	Meta-xylene
mg/kg	Milligrams per kilogram
mg/L	Milligrams per liter
mL	Milliliter
mm	Millimeter
mt	Metric tons
mt/hr	Metric tons per hour
Nordac	Norddeutsches Altlasten-Sanierungs-Centrum GmbH & Co. KG
NPL	National Priorities List
NRMRL	National Risk Management Research Laboratory
o-xylene	Ortho-xylene
ORD	U.S. EPA Office of Research and Development
OSWER	Office of Solid Waste and Emergency Response
p-xylene	Para-xylene
PCB	Polychlorinated Biphenyls
PRC	PRC Environmental Management, Inc.
QA/QC	Quality assurance and quality control
QAPP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act
RPD	Relative percent difference
SARA	Superfund Amendments and Reauthorization Act (of 1986)
SITE	Superfund Innovative Technology Evaluation

ACRONYMS AND ABBREVIATIONS (CONTINUED)

SVOC	Semivolatile Organic Compounds
TCLP	Toxicity Characteristic Leaching Procedure
$\mu\text{g/L}$	Micrograms per liter
μm	Micron
UCL	Upper confidence limit
VISITT	Vendor Information System for Innovative Treatment Technologies
VOC	Volatile Organic Compound

**CONVERSION TABLE
(Metric to English Units)**

<u>To Convert</u>	<u>Into</u>	<u>Multiply By</u>
Centimeters	Feet	3.28×10^{-2}
Centimeters	Inches	0.39
Cubic meters	Cubic feet	35
Cubic meters	Gallons	264
Cubic meters	Cubic yards	1.31
Degrees Celsius	Degrees Fahrenheit	add 17.8 and multiply by 1.80
Hectopascals	Atmosphere	9.86×10^{-4}
Kilograms per square meter	Pounds per square inch, absolute	1.42×10^{-3}
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 Nordac soil washing 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 Nordac technology was demonstrated on May 20 and 21, 1996 at the Nordac facility in Hamburg, Germany. Soil contaminated with volatile organic compounds (VOCs), specifically benzene, toluene, ethylbenzene, and xylene (BTEX), was used for the demonstration.

The Nordac Soil Washing Technology

The Nordac soil washing technology was developed by Norddeutsches Altlasten-Sanierungs-Centrum GmbH & Co. KG (Nordac), Hamburg, Germany. The Nordac system is a full-scale commercial treatment technology developed to remove contaminants, including VOCs, from soil and reduce the volume of soil that will require additional treatment to meet applicable cleanup requirements. Through a multistep treatment approach, the system washes VOCs from soil and separates out fine-grained soil from coarser-grained soil. The treatment system is fully automated and can process 320 metric tons of soil per day.

Waste Applicability

The Nordac technology demonstrated in Hamburg, Germany, effectively reduced toluene, ethylbenzene, and xylene concentrations in sandy soils. The developer claims that in addition to VOCs, the technology can also remove some other VOCs, semivolatile organic compounds (SVOCs), petroleum hydrocarbons, polychlorinated biphenyls (PCBs), and selected metals from soil.

Demonstration Objectives and Approach

This bilateral SITE demonstration of the Nordac technology was designed with three primary and three secondary objectives. The objectives were chosen to provide potential users of the technology with the information necessary to assess the applicability of the Nordac 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 for individual VOCs that are detected in the untreated soil at greater than the minimum concentration of 25 mg/kg.
- P-2 Determine the concentration of individual VOCs in the treated soil at the 95 percent confidence level.
- P-3 Determine the mass fraction of total feed soil discharged as process residuals requiring further treatment or disposal because residuals are a hazardous waste according to the Toxicity Characteristic Leaching Procedure (TCLP).

Secondary Objectives:

- S-1 Document the particle size distribution of the feed soil.
- S-2 Document the average feed soil processing rate on a mass per hour basis over the duration of three 6-hour test runs.
- S-3 Document commercial treatment costs of the process provided by Nordac.

Demonstration Conclusions

Based on the Nordac bilateral SITE demonstration, specific conclusions for each primary and secondary objective are summarized below. (Note: Benzene is not included in these conclusions because benzene levels in the untreated soil were less than 25 mg/kg and, therefore, is not considered a critical contaminant for this demonstration.)

- The average removal efficiencies achieved were 98.3 percent for toluene, 97.3 percent for ethylbenzene, 97.5 percent for meta- (m-) and para- (p-) xylene, and 95.6 percent for ortho- (o-) xylene. Removal efficiencies ranged from 94.4 to 99.4 percent.
- The 95 percent upper confidence limit of concentrations in treated soil is presented in [Table ES-1](#).

**TABLE ES-1
95 PERCENT UPPER CONFIDENCE LIMIT IN TREATED SOIL**

Contaminant	Test Run		
	1 (mg/kg)	2 (mg/kg)	3 (mg/kg)
Toluene	0.88	3.90	0.28
Ethylbenzene	10.7	34.0	2.87
m- & p-xylene	37.6	114.0	13.7
o-xylene	17.8	30.9	9.66

mg/kg Milligrams per kilogram
m- & p- Meta and para
o ortho

- TCLP-leachable VOCs could not be determined for this demonstration, but BTEX concentrations in the sediment filter cake are greater than the TCLP level, indicating that if 100 percent of the BTEX leached out, the sediment filter cake would be characterized as hazardous waste. Sediment filter cake represents 21 percent of the total mass of soil treated by the Nordac system.
- The feed soil was characterized to be sand for all 3 test runs. The specific particle size distribution is presented in [Section 2.3](#) of the ITER.
- During the demonstration, the Nordac system processed soil at rates ranging from 14.6 mt/hr to 19.6 metric tons per hour (mt/hr).
- The commercial cost for application of the Nordac technology at the Hamburg site is 150 to 200 DM per metric ton (\$100 to \$133 per metric ton assuming a 1.5 DM to one U.S. dollar exchange rate).

Technology Applicability

The Nordac technology was evaluated to identify its advantages, disadvantages, and limitations. The evaluation was based on the nine criteria used for decision making in the Superfund feasibility study process. This demonstration was limited to an evaluation of the technology's ability to remove BTEX from soil.

Overall Protection of Human Health and the Environment

The Nordac technology provides both short-term and long-term protection to human health and the environment by reducing the concentrations of VOCs in soils. VOCs are removed by high pressure spraying. Treated process water is fed back into the system or discharged to the municipal sewer system. Exposure from air emissions is minimized through the removal of contaminants from the system's air process stream using carbon adsorption units before discharge to the atmosphere.

Compliance with ARARs

Although general and specific applicable or relevant and appropriate requirements (ARARs) were not identified for the Nordac technology, compliance with chemical-, location-, and action-specific ARARs should be determined 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 Nordac system to remove contaminants from the soil and the site-specific cleanup level.

Long-Term Effectiveness and Permanence

The Nordac system permanently reduces BTEX in the soil through high-pressure spraying, and separates out fine-grained materials from coarser-grained materials. Potential long-term risks to treatment system workers, the community, and the environment from emissions of treated gas and discharge of treated water are mitigated by ensuring that established standards are met.

Reduction of Toxicity, Mobility, or Volume Through Treatment

As discussed previously, the Nordac soil washing technology permanently removes BTEX. As such, the toxicity, mobility, and volume of contaminants are also significantly reduced.

Short-Term Effectiveness

The permanent removal of BTEX from soils is achieved relatively quickly, providing for short-term as well as long-term effectiveness. Potential short-term risks presented during system operation to workers, the

community, and the environment include air emissions. Exposure from fugitive air emissions during operation, monitoring, and maintenance are minimized through the removal of contaminants in the system's air process stream using carbon adsorption units before discharge.

Implementability

The Nordac soil washing system is a large fixed treatment facility with many 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 Nordac technology at the Hamburg site, the commercial treatment cost per metric ton is 150 to 200 DM (\$100 to \$133, assuming a 1.5 DM to one U.S. dollar exchange rate). This cost includes treatment of the soil at the facility and disposal of treated soil and residuals.

State Acceptance

State acceptance is anticipated because the Nordac system uses widely accepted processes to remove contaminants from soil and to treat process water and air 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, such as a permit to operate the treatment system, an air emissions permit, and a permit to store contaminated soil for greater than 90 days if soil is considered hazardous wastes.

Community Acceptance

The system's size and space requirements may raise concern in nearby communities. However, proper management and operational controls coupled with minimal short-term risks to the community and the

permanent removal of contaminants through ex situ processes make this technology likely to be accepted by the public.

1.0 INTRODUCTION

This report documents the findings of an evaluation of the Nordac soil washing technology developed by Norddeutsches Altlasten-Sanierungs-Centrum GmbH & Co. KG (Nordac), Hamburg, 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 Nordac technology demonstration was conducted on May 20 and 21, 1996 at the Nordac facility in Hamburg, Germany (see [Figure 1](#)). The demonstration evaluated the technology's effectiveness in remediating soil contaminated with volatile organic compounds (VOCs), specifically toluene, ethylbenzene, and xylene. The soil was from a site used by the chemical industry for the production of artificial resins and plastics. Soil and process water was sampled by Arbeitgemeinschaft (ArGe) focon-Probiotec with assistance from PRC Environmental Management, Inc. (PRC). System operating parameters were monitored by Nordac. All samples were analyzed by Institut Fresenius. All demonstration activities were conducted in accordance with the August 1995 quality assurance project plan (QAPP) (PRC 1995). ArGe focon-Probiotec, Nordac, and Institut Fresenius contributed extensively to the development of this document.

This report provides information from the bilateral SITE demonstration of the Nordac technology that is useful for remedial managers, environmental consultants, and other potential technology users in implementing the technology at contaminated sites. [Section 1.0](#) presents an overview of the SITE program and the bilateral agreement, describes the Nordac technology, and lists key contacts. [Section 2.0](#) presents information relevant to the technology's effectiveness, including the contaminated soil 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 an assessment of the technology related to the 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.

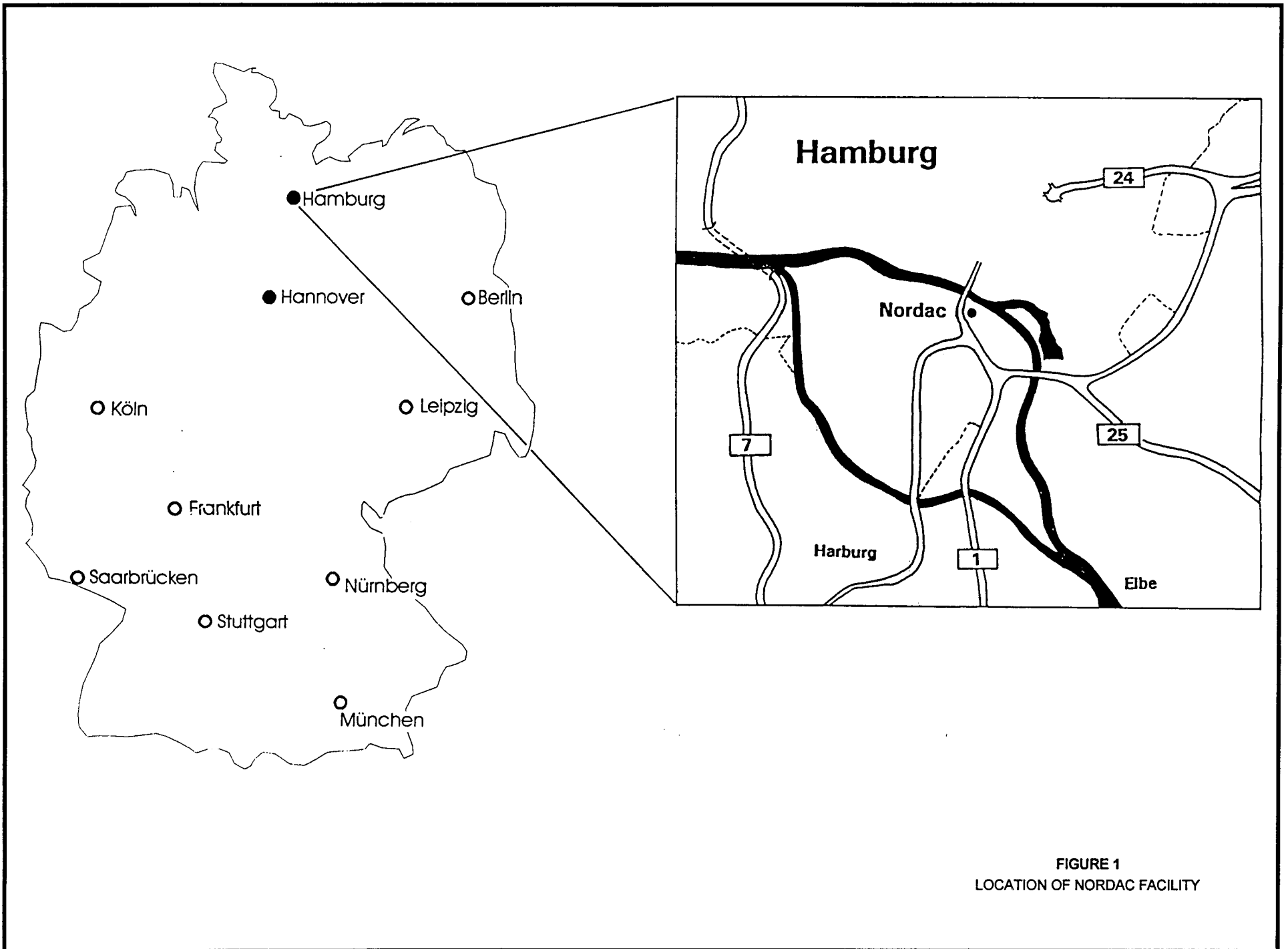


FIGURE 1
LOCATION OF NORDAC FACILITY

1.1 SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION PROGRAM

This section provides background information about the EPA SITE program. Additional information about the SITE program, the Nordac technology, and the 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/quality control (QA/QC) procedures must be 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 and cleaning up at 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).

However, 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, where possible, remove impediments to development and commercial use of innovative technologies
- 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 Nordac 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 their native country
- Facilitate international technology exchange

Technologies in the U.S. and in Germany will be evaluated under the bilateral agreement. Individual or, in some cases, multiple remediation technologies will be demonstrated at each site. Technology evaluations occurring in the U.S. correspond to SITE demonstrations; those occurring in Germany correspond to full-scale site remediation 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. partners to develop an EPA Category II QAPP. An EPA Category II QAPP titled "Quality Assurance Project Plan for the Nordac Soil Washing System Demonstration in Hamburg, Germany" dated August 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](#).

Germany

USA

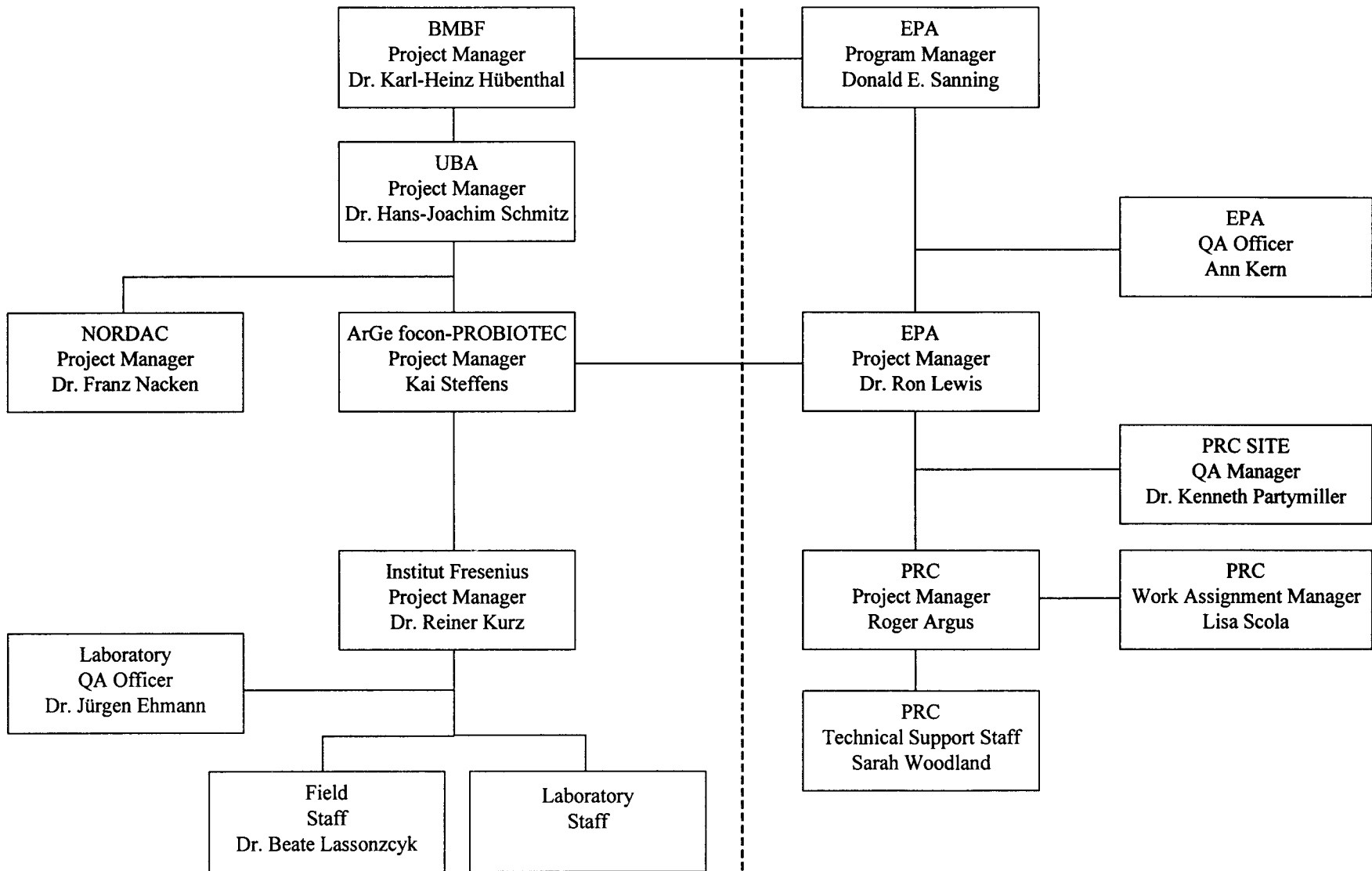


FIGURE 2
BILATERAL PROJECT ORGANIZATION

1.3 NORDAC TECHNOLOGY DESCRIPTION

This section describes the process equipment and system operations of the Nordac soil treatment facility. The information provided in this section is limited due to Nordac's proprietary claims on much of the process design and system operating data. For example, detailed descriptions of system components are not available as Nordac considers this information proprietary. 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

The Nordac soil washing technology was developed to remove contaminants from soil and to reduce the volume of soil that will require additional treatment to meet applicable cleanup requirements. The Nordac system is a full-scale commercial treatment technology that incorporates the multistep treatment approach illustrated in [Figure 3](#). The Nordac soil washing system is operated to wash contaminants from soil and to separate out fine-grained soil (identified as sediment filter cake in [Figure 3](#)) from coarser-grained soil (diameter greater than 25 microns). The fine-grained soil, which has a higher surface area-to-volume ratio and a correspondingly higher concentration of contaminants, is recovered and subsequently incinerated in a fluidized bed combustor, treated in a bioremediation system, or landfilled, depending on contaminant levels. Contaminant levels in the coarser-grained soils should be sufficiently reduced using the soil washing system to allow use of the soil as admixture for road construction work. In addition to the fine-grained soil stream, the Nordac soil washing system generates process wastewater, air emissions, and lightweight solid residuals that are treated or disposed of by conventional methods.

The Nordac soil washing treatment system is fully automated and can process 320 metric tons of soil per day. Before initiating the soil washing process, soils are pretreated by crushing and mixing with water to form a slurry. The feed soil is initially separated by size, and materials with a diameter greater than 50 millimeters (mm) are mechanically crushed. The soil is then transported to a homogenization unit, where it is mixed with recycled process water using a plough blade mixer to create a pumpable slurry.

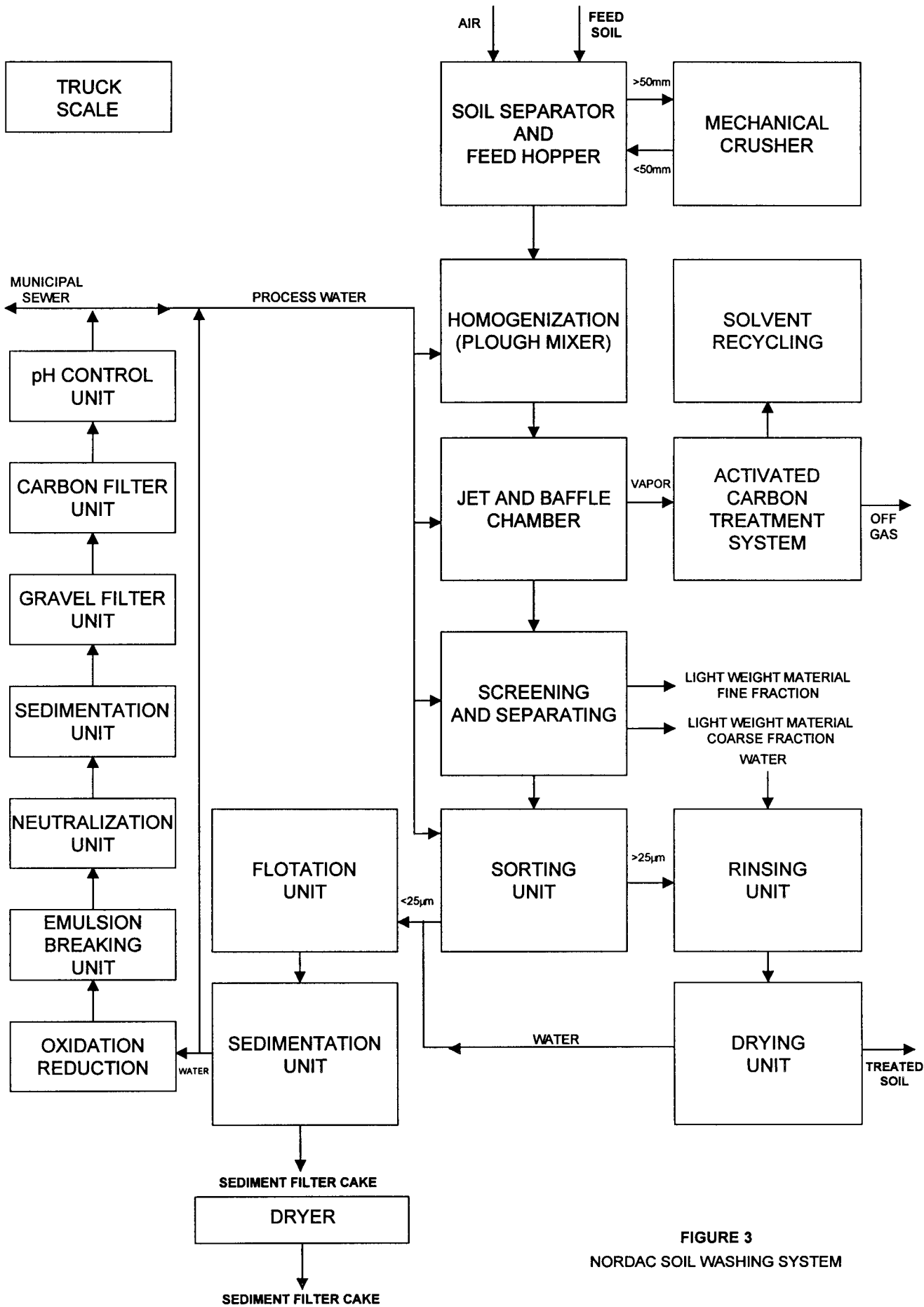


FIGURE 3
NORDAC SOIL WASHING SYSTEM

The slurry is transported to a water jet and baffle chamber, where it undergoes high pressure spraying with recycled process water. In the water jet and baffle chamber, the slurry passes through a series of high pressure water jets that blast the slurry into a steel wall. This impact breaks up the soil particles and exposes contaminants adhered to the soil. The water jets are configured in a circular array, producing a cone-shaped spray. The soil particles are drawn through the focal point of the water jet, which facilitates removal of contaminants adhering to the soil particles. Additionally, the water jet produces a partial vacuum that draws in a large volume of air. The resulting stripping effect releases volatile compounds from the soil into the process air.

After contaminants are stripped in the jet and baffle chamber, the water/soil slurry is separated into three fractions (lightweight solids, coarse grain solids, and fine grain solids/water slurry) using a multistep separating process. In the initial step, the lightweight fraction, including organic material such as wood and coal particles, is separated into coarse and fine material subfractions and removed using a jig method. During this separation step, recycled process water is used to float and separate these materials. Both subfractions of lightweight material are subsequently disposed of off-site as hazardous waste or treated further, if warranted. The second separation step removes coarse grain particles greater than 25 microns (μm) in diameter from the slurry using a spiral separator. The spiral separator also uses recycled process water to assist in separating and rinsing the coarse material. The coarse particles are then transferred to a rinsing and drying unit where clean water is used to remove any remaining fine soil particles or residual process water. The coarse grain particles are then dried using a filter press and stockpiled for reuse.

The remaining slurry consists of process water and fine grain particles less than 25 μm in diameter. This slurry is separated using a flotation/sedimentation system to remove the remaining particulate material. This system has the capacity to process 170 cubic meters of slurry per hour. Removal of fine grain particles and suspended substances is facilitated by the use of flocculating agents in the sedimentation unit. A concentrated sedimentation filter cake is discharged from the sedimentation unit. Contaminants that can be removed in the flotation unit, such as mineral oils and coal particles, are also concentrated in the sediment filter cake. The sediment filter cake is disposed of by incineration or is treated by bioremediation, depending on the residual concentrations of contaminants.

The majority (90 to 95 percent) of the remaining process water is recycled into the separating units described above. The concentration of contaminants in the recycled water is maintained below a

proprietary limit by adding treated water as necessary. The portion of the process water that is not recycled is treated in a wastewater treatment system that incorporates a series of chemical and physical processes. These processes include an oxidation/reduction unit, an emulsion breaking unit, a neutralization unit, a sedimentation unit, a gravel filter unit, an activated carbon adsorption unit, and a pH control unit. A portion of the treated water is subsequently fed back to the system; the remainder is discharged into the municipal sewage system.

Process air emissions are treated before release to meet pertinent regulatory limits. The process air treatment unit consists of a granular activated carbon adsorption system with a capacity of 8,000 cubic meters per hour. The contaminants captured by the carbon adsorption system are recovered and recycled during the carbon regeneration process. The performance of the process air treatment unit was not evaluated as part of this demonstration, so a detailed description of this unit is not provided.

1.3.2 System Operation

The excavated material, including waste and contaminated soil, was transported by trucks to the Nordac facility in Hamburg, Germany. The soils used for this demonstration contained high concentrations of toluene, ethylbenzene, and xylenes. Benzene concentrations were below 25 mg/kg, and therefore benzene is not considered a critical contaminant in this demonstration. Average toluene concentrations for each test run ranged from 28 to 55 milligrams per kilogram (mg/kg), average ethylbenzene concentrations ranged from 160 to 340 mg/kg, average meta- (m-) and para- (p-) xylene concentrations ranged from 730 to 1,160 mg/kg, and ortho- (o-) xylene concentrations ranged from 210 to 300 mg/kg.

During the demonstration, soil was processed at rates ranging from 10.2 to 13.7 metric tons per hour. For this demonstration the processing rate was limited by the capacity of the flotation and sedimentation units to accept fine-grained material. When those units are at capacity, then the contaminated soil feeding into the system must be stopped temporarily. Likewise, when the storage bin at the system exit is full, soil feeding into the system must be stopped temporarily. The Nordac system is fully automated to allow for 24-hour operation. For this demonstration, the soil washing system operated 6 to 12 hours per day or more.

1.4 KEY CONTACTS

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

Nordac Soil Washing Technology

Franz Nacken
Nordac
Oberwerder Damm 1-5
20539 Hamburg
(040) 789178-0

EPA-BMBF Bilateral Technology Evaluation Program

Donald Sanning
Bilateral Program Manager
U.S. Environmental Protection Agency
Office of Research and Development
26 West Martin Luther King Drive
Cincinnati, Ohio 45268
513-569-7875

Dr. Ronald Lewis
Technical Project Manager
U.S. Environmental Protection Agency
Office of Research and Development
26 West Martin Luther King Drive
Cincinnati, Ohio 45268
513-569-7856

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 data base provides summarized information on innovative treatment technologies.
- The Vendor Information System for Innovative Treatment Technologies (VISITT) (Hotline: 800-245-4505) data base 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 NORDAC TECHNOLOGY EFFECTIVENESS

This section documents the background, field and analytical procedures, results, and conclusions used to assess the ability of the Nordac technology to remove BTEX from contaminated soil. This assessment is based on data collected during the Nordac bilateral SITE demonstration.

2.1 BACKGROUND

The bilateral SITE demonstration of the Nordac technology was conducted at the Nordac facility in Hamburg, Germany ([Figure 1](#)). Contaminated soil for the demonstration was excavated from a site used by the chemical industry for the production of artificial resins and plastics, located in Germany. The site background is described in the following section. An overview of the demonstration objectives and approach is presented in [Section 2.1.2](#)

2.1.1 Site Background

The feed soil used for this demonstration was excavated from a site contaminated by elevated levels of BTEX. The name and location of the site are considered confidential. The site was and is used by the chemical industry for the production of artificial resins and plastics. The area from which the contaminated soil was excavated was used as a dump site for production-specific waste including debris. Therefore, the soil was contaminated with high levels of BTEX.

The site was first characterized using soil vapor analysis, and then soil excavation. The excavated material showed total petroleum hydrocarbon contamination at 390 mg/kg and total BTEX contamination at 480 mg/kg. Based on the results of the soil vapor analysis, higher BTEX concentrations were expected. Subsequently, boring samples were collected and analyzed. These samples showed higher BTEX concentrations. For example, one such sample showed a total BTEX concentration of 1,240 mg/kg.

At the contaminated site, groundwater is usually at 2.6 to 2.9 meters (m) below ground surface (bgs). For soil excavation, the groundwater table was lowered to 3.5 m bgs to obtain sufficient contaminated soil.

The contaminated soil was determined to be primarily sand with a moisture content of 10 to 15 percent.

2.1.2 Demonstration Objectives and Approach

Demonstration objectives were selected to provide potential users of the Nordac technology with the necessary technical information to assess the applicability of the treatment system to other contaminated sites. This bilateral SITE demonstration selected three primary objectives and three secondary objectives to evaluate the Nordac technology. These demonstration objectives are summarized below:

Primary Objectives:

- P-1 Determine the removal efficiency for individual VOCs that are detected in the untreated soil at greater than the minimum concentration of 25 mg/kg.
- P-2 Determine the concentration of individual VOCs in the treated soil at the 95 percent confidence level.
- P-3 Determine the mass fraction of total feed soil discharged as process residuals requiring further treatment or disposal because it is a hazardous waste according to the Toxicity Characteristic Leaching Procedure (TCLP).

The primary objectives were achieved by collecting representative samples of contaminated feed soil, treated soil, and sediment filter cake during three test runs. The primary objectives and the associated critical measurement parameters required to achieve those objectives are listed in [Table 1](#).

Secondary Objectives:

- S-1 Document to particle size distribution of the feed soil.
- S-2 Document the average feed soil processing rate on a mass per hour basis over the duration of three 6-hour test runs.
- S-3 Document commercial treatment costs of the process as provided by Nordac.

TABLE 1. CRITICAL MEASUREMENT PARAMETERS

Primary Objective	Measurement Parameters
Determine the removal efficiency for individual VOCs that are detected in the untreated soil at greater than the minimum concentration of 25 mg/kg	<ol style="list-style-type: none"> 1) Concentrations of critical VOCs (considered critical if >25 mg/kg in feed soil) in untreated and treated soil 2) Moisture content in the untreated and treated soil
Determine the concentration of individual VOCs in the treated soil at the 95 percent confidence level	<ol style="list-style-type: none"> 1) Concentrations of critical VOCs (as determined in P1) in treated soil
Determine the mass fraction of total feed soil discharged as process residuals requiring further treatment or disposal because it is a hazardous waste according to the TCLP.	<ol style="list-style-type: none"> 1) Masses of untreated soil, treated soil, sediment filter cake, and light weight fraction 2) TCLP leachate concentrations in sediment filter cake 3) Moisture content of sediment filter cake

The secondary project objectives and the associated noncritical measurement parameters required to achieve those objectives are listed in [Table 2](#).

TABLE 2. NONCRITICAL MEASUREMENT PARAMETERS

Secondary Objective	Measurement Parameter
Document the particle size distribution of the feed soil	Particle size distribution in the feed soil
Document average feed soil processing rate on a mass per hour basis over the duration of three 6-hour test runs	Mass per hour of feed soil
Document commercial treatment costs of the process as provided by Nordac.	Commercial treatment costs ^a

^a Commercial treatment costs will be obtained from Nordac. Capital and operating costs will not be assessed in detail since Nordac 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 Nordac technology. The activities associated with the Nordac SITE demonstration included (1) demonstration design, (2) soil and process water 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 Nordac soil washing 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.

Sampling locations were selected based on the configuration of the treatment system and project objectives; analytical parameters were selected based on the contaminant to be treated and project objectives. Sampling collection and measurement locations during the demonstration are shown on [Figure 4](#). Samples were collected from five sampling locations and measurements were taken at three measurement points in the treatment system to achieve the project objectives established in [Section 2.1.2](#).

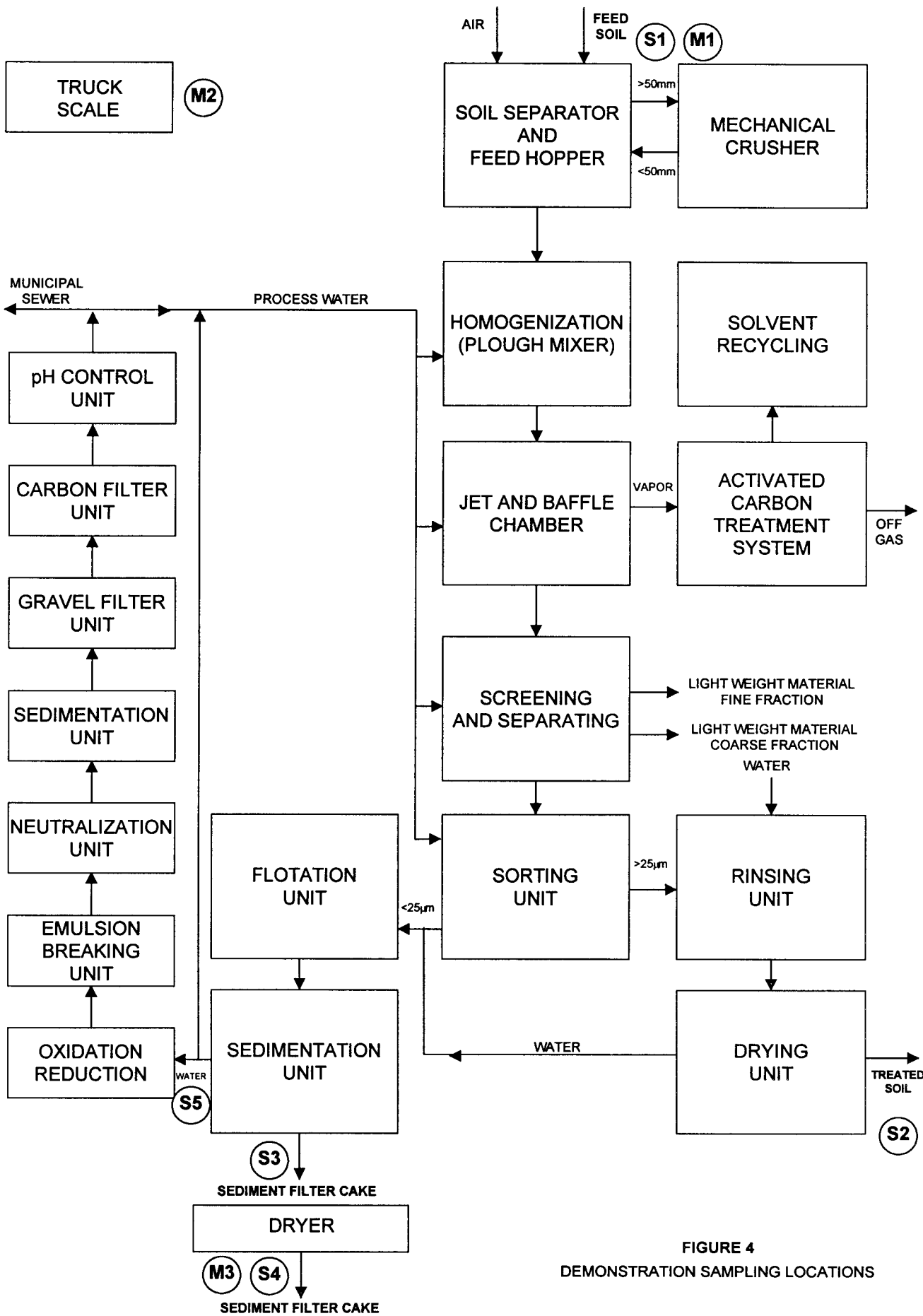


FIGURE 4
DEMONSTRATION SAMPLING LOCATIONS

Specific sampling and measurement procedures are described in [Section 2.2.2](#). These sampling and measurement locations are:

- *Sampling Location S1:* Contaminated feed soil. Contaminated soils were introduced into the feed hopper and fed into the homogenizing unit via a conveyor belt. Samples of the contaminated soil were collected from the conveyor belt.
- *Sampling Location S2:* Treated soil. Samples of treated soil were collected from the treated soil conveyor belt exiting the system.
- *Sampling Location S3:* Sediment filter cake (moist). Samples were collected from the sediment filter cake conveyor belt before it passed through the dryer.
- *Sampling Location S4:* Sediment filter cake (dry). Samples were collected from the sediment filter cake conveyor belt after passing through the dryer.
- *Sampling Location S5:* Process water. Samples were collected at the first sedimentation tank.
- *Measurement Location M1:* Contaminated feed soil. Feed soil mass processing rates were determined using a belt scale on the conveyor belt that transports soil into the processing system.
- *Measurement Location M2:* Treated soil and lightweight fraction. The mass of the treated soil and lightweight fraction was measured using a certified off-site truck scale when the material was transported from Nordac to the disposal site.
- *Measurement Location M3:* Sediment filter cake. The mass of the sediment filter was measured using a belt scale on the conveyor belt that transports the filter cake to the dryer.

2.2.1.2 Sampling and Measurement Activities

Sampling and measurement activities were conducted over three 6-hour test runs, as described above. Grab and composite sampling techniques were employed throughout the demonstration.

Samples of the untreated and treated soil were collected according to the methodology described in the QAPP (PRC 1995) at 30-minute intervals. Soil samples collected from sampling locations S1 and S2 included both the half-hourly grab samples for VOC analysis and composite samples for particle size distribution analysis. Grab samples from sampling locations S3, S4, and S5 were collected during the middle of each test run. Sampling locations S4 and S5 were two additional sample locations that were not mentioned in the QAPP. Sampling location S4 was added to collect additional sediment filter cake

samples after it had passed through a dryer, and sampling location S5 was added to collect process water samples from the system to assess contamination in the process water used in the system.

A total of 12 feed soil samples, 12 treated soil samples, and grab samples at the other sampling locations were collected as expected test run 1. Test run 2 began immediately after test run 1.

One hour and 45 minutes into the second test run, Nordac increased the water pressure in the jet and baffle chamber from 40 bar to 250 bar. Almost 1 hour later, Nordac stopped feeding contaminated soil into the processing units for approximately one-half hour because the flotation and sedimentation units were at their capacity and could not accept additional fine-grained material. Therefore, a feed soil sample was not collected at that time. When Nordac resumed feeding soil into the processing system, no treated soil sample was collected because no treated soil was exiting the system since soil had not been fed into the system for about one half hour. Nordac stopped feeding contaminated soil into the processing units for approximately one-half hour a second time because the flotation and sedimentation units were again at capacity and unable to handle all of the fine-grained material in the system. A feed soil sample was not collected at that time. Therefore, only 10 feed soil samples and 11 treated soil samples were collected during the second test run.

During the third test run, Nordac stopped feeding soil into the system because the storage bin at the exit was full. A treated soil sample was taken at that time, but no contaminated soil was available. One hour later, Nordac resumed feeding soil into the system. A contaminated soil sample was taken at that time, but no treated soil was available. All samples were taken over a period of 6½ hours, so that 12 feed soil samples and 12 treated soil samples were collected for the third test run.

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 five locations. These locations include four soil sampling points and one liquid sampling point, as described in the previous section. System operating

parameters were monitored continuously by Nordac. Sampling began after Nordac judged that the system was operating at a steady state.

2.2.2.1 Soil Samples

Contaminated feed soil, treated soil, and sediment filter cake are transported by dedicated conveyor belts in the Nordac facility. Samples collected were obtained from conveyor belts. Grab samples were obtained from the conveyor belt position closest to the process (for example, feed soil was sampled just before it entered the homogenization unit).

Grab soil samples were collected from the conveyor belts at sampling locations S1, S2, S3, and S4 using a disposable plastic scoop containing approximately 1 liter of soil at the frequency described in [Section 2.2.1.1](#). A 500 milliliter (mL) volume was immediately transferred to an appropriate precleaned sample container for VOC and moisture content analysis. The remaining soil was immediately transferred to an appropriate precleaned compositing container for use in the composite samples collected. Composite soil samples of 2,000 mL were collected at sampling locations S1, S2, and S3 for analysis of particle size distribution. Any soil that was not needed for samples was returned to the specific conveyor belt from which it was collected. [Table 3](#) lists the analytical procedures used for samples collected during the demonstration.

**TABLE 3. ANALYTICAL METHODS
NORDAC SOIL WASHING SYSTEM**

Matrix	Parameter	Method	Reference
Soil	Volatile Organic Compounds	EPA SW-846 8260A ⁽¹⁾	EPA 1994
	Percent Moisture	D2216	ASTM 1992
	Particle Size	Standard Operating Procedure	Institut Fresenius
Aqueous	Volatile Organic Compounds	EPA SW-846 8260A	EPA 1994

⁽¹⁾ Methanol extraction option was used for all samples

The particle size distribution was determined using an Institute Fresenius Standard Operating Procedure, which is based on the German Standard Method DIN 19 683 Parts 1 and 2. This method involves

sampling a soil suspension in a settling cylinder at timed intervals and determining the concentration of solids in suspension at each interval (PRC 1995).

2.2.2.2 Process Water Samples

Process water samples were collected at sampling location S5 (identified in [Section 2.2.1](#) and shown on [Figure 4](#)) directly into precleaned sample containers. Only one process water sample was preserved with hydrochloric acid. All data associated with unpreserved water samples have been flagged appropriately. A grab sample was collected midway through each test run. [Table 3](#) lists the analytical procedures used for samples collected during the demonstration.

2.2.3 Quality Assurance and Quality Control Program

Quality control checks and procedures were an integral part of the Nordac 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 quality control checks are summarized below and 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 representativeness of the samples, and ensure that the degree to which the analytical data represent actual site conditions is known and documented. The field QC results are reported in [Section 2.3.3](#).

2.2.3.2 Laboratory Quality Control Checks

Laboratory QC checks are designed to determine the precision and accuracy of the analyses, 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 performed 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

No project specific audits were conducted during this technology demonstration. However, general systems audits of Institut Fresenius have been conducted under other bilateral technology demonstrations.

2.3 DEMONSTRATION RESULTS AND CONCLUSIONS

This section presents the operating conditions, results and discussion, data quality, and conclusions of the bilateral SITE demonstration of the Nordac soil washing technology.

2.3.1 Operating Conditions

This section summarizes the configuration of the Nordac system and operating parameters during the SITE demonstration. During this bilateral SITE demonstration, the Nordac treatment system was operated at conditions determined by the developer. The system operated for 12 hours in two test runs on May 20, 1996 and for 6 hours on May 21, 1996 over the demonstration period. The demonstration consisted of three 6-hour test runs.

2.3.1.1 Treatment System Configuration

The Nordac treatment system includes a soil separator, mechanical crusher, homogenization unit, jet and baffle chamber, sorting/separating unit, rinsing/drying unit, flotation/sedimentation system, carbon

treatment system, and wastewater treatment system. The configuration of the Nordac treatment system components is shown in [Figure 3](#).

2.3.1.2 Operating Parameters

The developer monitored the Nordac soil treatment system throughout the demonstration. During the second test run, Nordac increased the water pressure in the jet and baffle chamber from 40 bar to 250 bar. Nordac considers system operating parameters proprietary and as such will not allow them to be measured, with the exception of the masses of the treated soil, untreated soil, and sediment filter cake. These masses are presented in [Section 2.3.2.1.3](#).

2.3.2 Results and Discussion

This section presents the results of the bilateral SITE demonstration of the Nordac technology at Hamburg, Germany. The results are presented by and have been evaluated in relation to project objectives. The specific primary and secondary objectives are shown at the top 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 4, 5, 6, and 7](#). Process water samples were taken for each test run to document VOC concentration in the process water. These data are presented in [Table 8](#). Data quality 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 Nordac treatment system. The results for each primary objective are discussed in the following subsections.

**TABLE 4. VOC CONCENTRATIONS IN FEED SOIL
NORDAC SOIL WASHING SYSTEM
(Sampling Location S1)**

Contaminant	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	<5	11.55	<5	12.17	<5	12.75
Toluene	54.6		52.5		28.4	
Ethylbenzene	339		313		169	
Xylene (m + p)	1160		1060		737	
Xylene (o)	292		280		213	

mg/kg Milligrams per kilogram

% Percent

m + p Meta and para

o Ortho

**TABLE 5. VOC CONCENTRATIONS IN TREATED SOIL
NORDAC SOIL WASHING SYSTEM
(Sampling Location S2)**

Contaminant	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	<0.05	12.80	1.01	<0.05	0.05	13.28	1.01	0.05	<0.05	13.50	1.01	<0.05
Toluene	0.57			0.58	1.49			1.51	0.18			0.18
Ethylbenzene	6.48			6.61	14.2			14.4	1.60			1.61
Xylene (m + p)	22.9			23.2	47.6			48.2	8.04			8.11
Xylene (o)	11.6			11.8	15.6			15.8	6.87			6.93

mg/kg Milligrams per kilogram

% Percent

m + p Meta and para

o Ortho

⁽¹⁾ Contaminant concentrations normalized to moisture content of feed soil.

**TABLE 6. VOC CONCENTRATIONS IN SEDIMENT FILTER CAKE BEFORE THE DRYER
NORDAC SOIL WASHING SYSTEM
(Sampling Location S3)**

Contaminant	Test Run 1				Test Run 2				Test Run 3			
	Contaminant Concentration (mg/kg)	Moisture Content (%)	Moisture Content Correction Factor	Normalized Contaminant Concentration (mg/kg) ⁽¹⁾	Contaminant Concentration (mg/kg)	Moisture Content (%)	Moisture Content Correction Factor	Normalized Contaminant Concentration (mg/kg) ⁽¹⁾	Contaminant Concentration (mg/kg)	Moisture Content (%)	Moisture Content Correction Factor	Normalized Contaminant Concentration (mg/kg) ⁽¹⁾
Benzene	5.5	51.5	1.82	10.0	<5	44.7	1.59	<7.94	<1	49.8	1.74	<1.74
Toluene	48.5			88.5	28.4			45.1	7.9			13.7
Ethylbenzene	610			1110	325			516	115			199
Xylene (m + p)	2050			3740	1100			1750	499			868
Xylene (o)	543			990	305			484	139			241

mg/kg Milligrams per kilogram

% Percent

m + p Meta and para

o Ortho

⁽¹⁾ Contaminant concentrations normalized to moisture content in feed soil.

**TABLE 7. VOC CONCENTRATIONS IN SEDIMENT FILTER CAKE AFTER THE DRYER
NORDAC SOIL WASHING SYSTEM
(Sampling Location S4)**

Contaminant	Test Run 1				Test Run 2				Test Run 3			
	Contaminant Concentration (mg/kg)	Moisture Content (%)	Moisture Content Correction Factor	Normalized Contaminant Concentration (mg/kg) ⁽¹⁾	Contaminant Concentration (mg/kg)	Moisture Content (%)	Moisture Content Correction Factor	Normalized Contaminant Concentration (mg/kg) ⁽¹⁾	Contaminant Concentration (mg/kg)	Moisture Content (%)	Moisture Content Correction Factor	Normalized Contaminant Concentration (mg/kg) ⁽¹⁾
Benzene	<5	48.5	1.72	<8.59	<5	34.5	1.34	6.7	1.5	54.3	1.91	2.86
Toluene	34.4			59.1	20.0			26.8	4.7			8.97
Ethylbenzene	390			669	217			291	66.5			127
Xylene (m + p)	1330			2290	727			975	379			723
Xylene (o)	351			603	200			268	103			197

mg/kg Milligrams per kilogram

% Percent

m + p Meta and para

o Ortho

⁽¹⁾ Contaminant concentrations normalized to moisture content in feed soil.

**TABLE 8. VOC CONCENTRATIONS IN PROCESS WATER
NORDAC SOIL WASHING SYSTEM
(Sampling Location S5)**

Contaminant	Test Run 1 ($\mu\text{g/L}$)⁽¹⁾	Test Run 2 ($\mu\text{g/L}$)⁽¹⁾	Test Run 3 ($\mu\text{g/L}$)	Average Overall Concentrations ($\mu\text{g/L}$)
Benzene	3	3	3	3
Toluene	431	382	139	317
Ethylbenzene	2650	1880	800	1780
Xylene (m + p)	9270	6310	3230	6270
Xylene (o)	2720	1980	930	1880

$\mu\text{g/L}$ Micrograms per Liter

m + p Meta and para

o Ortho

⁽¹⁾ Process water sample was not preserved with hydrochloric acid.

2.3.2.1.1

Primary Objective P-1

Determine the removal efficiency for individual VOCs that are detected in the untreated soil at greater than the minimum concentration of 25 mg/kg.

To determine removal efficiency, samples of soil entering and exiting the system were collected during the three test runs. Since toluene, ethylbenzene, and xylene concentrations in the untreated soil exceeded 25 mg/kg, they are considered the critical contaminants for this demonstration. However, data are also provided for benzene since the samples were analyzed for total BTEX. The removal efficiency was calculated based on BTEX concentrations in the feed and treated soil. For this objective, the difference between the BTEX concentrations in the contaminated feed soil and the treated soil is considered the critical parameter. Since contaminant concentrations depend on the mass of the sample that is analyzed, data were normalized to account for differences in moisture content. The appropriate number of samples and the sample collection methods were discussed in [Section 2.2](#).

The removal efficiencies were calculated for each run using the data presented in [Tables 4 and 5](#) and the following equations:

$$CRE_n = \frac{C_{u,n} - C_{t,n}}{C_{u,n}} \times 100\%$$

where:

CRE_n	=	Contaminant removal efficiency (%)
$C_{u,n}$	=	Arithmetic mean of untreated soil contaminant concentration for test run "n" (mg/kg)
$C_{t,n}$	=	Arithmetic mean of treated soil contaminant concentration for test run "n" normalized to the arithmetic mean moisture content of the contaminated feed soil for test run "n" (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:

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

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)

The overall contaminant removal efficiencies were 98.3 percent for toluene, 97.3 percent for ethylbenzene, 97.5 percent for xylene (m + p), and 95.6 percent for xylene (o). Benzene was not considered a critical contaminant. The results by test run are presented in [Table 9](#), and the overall average results are presented in [Table 10](#).

The results of this demonstration indicate that the Nordac technology can reduce BTEX concentrations in sandy soil from an average of 44.7 mg/kg to an average of 0.74 mg/kg for toluene; from an average of 272 mg/kg to an average of 7.34 mg/kg for ethylbenzene; from an average of 982 mg/kg to an average of 25.9 mg/kg for xylene (m + p); and from an average of 260 mg/kg to an average of 11.4 mg/kg for xylene (o). Benzene was not considered a critical contaminant.

**TABLE 9. VOC REMOVAL EFFICIENCY ACHIEVED PER TEST RUN
NORDAC SOIL WASHING SYSTEM**

Compounds	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	<5	<0.05	NC	<5	<0.05	NC	<5	<0.05	NC
Toluene	54.6	0.58	98.9	52.5	1.51	97.1	28.4	0.18	99.4
Ethylbenzene	339	6.61	98.1	313	14.4	95.4	170	1.61	99.1
Xylene (m + p)	1160	23.2	98.0	1060	48.2	95.5	737	8.11	98.9
Xylene (o)	292	11.8	96.0	280	15.8	94.4	213	6.93	96.7

mg/kg Milligrams per kilogram

% Percent

NC Not calculated since benzene concentrations were below the method detection limit for both untreated and treated samples

m + p Meta and para

o Ortho

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

**TABLE 10. OVERALL AVERAGE VOC REMOVAL EFFICIENCIES
NORDAC SOIL WASHING SYSTEM**

Compound	Overall Average Concentration in Untreated Soil (mg/kg)	Overall Average Concentration in Treated Soil (mg/kg)⁽¹⁾	Removal Efficiency (%)
Benzene	<5	<0.07	NC
Toluene	44.7	0.74	98.3
Ethylbenzene	272	7.34	97.3
Xylene (m + p)	982	25.9	97.5
Xylene (o)	260.1	11.4	95.6

mg/kg Milligram per kilogram

% Percent

NC Not calculated since benzene concentrations were below method detection limit

m + p Meta and para

o Ortho

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

**TABLE 11. 95 PERCENT UPPER CONFIDENCE LIMIT (UCL) OF
BTEX CONCENTRATIONS IN TREATED SOIL (mg/kg)
NORDAC SOIL WASHING SYSTEM**

Compound	Run Number		
	1	2	3
Benzene	NC	NC	NC
Toluene	0.88	3.90	0.28
Ethylbenzene	10.7	34.0	2.87
Xylene (m + p)	37.6	114	13.7
Xylene (o)	17.8	30.9	9.66

NC Not calculated since almost all benzene concentrations were below method detection limit in data set

2.3.2.1.2 Primary Objective P-2

Determine the concentration of VOCs in the treated soil at the 95 percent confidence level.

This objective was achieved by collecting samples of the treated soil that was discharged from the system and analyzing the samples for BTEX. The 95 percent upper confidence limit (UCL) for VOCs in the treated soil was calculated using the individual sample BTEX concentration data 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)

The 95 percent UCL was not calculated if a data set contained a significant number of concentrations below the method detection limit.

The 95 percent upper confidence limits for BTEX in the treated soils are presented in [Table 11](#). These results indicate that the Nordac technology (1) reduced toluene concentrations in soil to between 0.28 to 3.90 mg/kg at the 95 percent upper confidence level; (2) reduced ethylbenzene concentrations in soil to between 2.87 and 34.0 mg/kg at the 95 percent upper confidence level; (3) reduced m- and p-xylene concentrations in soil to between 13.7 and 114 mg/kg at the 95 percent upper confidence level; and (4) reduced o-xylene concentrations in soil to between 9.66 and 30.9 mg/kg at the 95 percent upper confidence level.

2.3.2.1.3 Primary Objective P-3

Determine the mass fraction of total feed soil discharged as process residuals requiring further treatment or disposal because it is a hazardous waste according to the TCLP.

To determine the TCLP leachate concentrations, samples from the sediment filter cake were collected and masses of the untreated soil, treated soil, lightweight fraction, and sediment filter cake were measured. However, TCLP-leachable VOCs were not determined because Institut Fresenius does not have the zero headspace extractor required to complete the TCLP method for VOCs. Instead, the samples were analyzed for total VOCs, and the results are presented in [Tables 6 and 7](#). The entire batch of untreated soil was measured to be 1,932 metric tons (mt) (1,700 mt dry weight). Other masses were measured to be 1,407 mt of treated soil (1,224 mt dry weight), 74 mt of the lightweight fraction (27 mt dry weight), and 401 mt of sediment filter cake (225 mt dry weight). BTEX concentrations in the sediment filter cake are greater than the TCLP level, indicating that if 100 percent of the BTEX leached out, the sediment filter cake would be characterized as hazardous waste. When all masses are converted to dry weight, sediment filter cake represents 15 percent of the total mass of soil fed to the Nordac system.

2.3.2.2 Secondary Objectives

Secondary objectives provide additional information that is useful, but not critical, for the evaluation of the Nordac technology. Three secondary objectives were selected for the bilateral SITE demonstration of the Nordac system. The secondary project objectives and the associated noncritical measurement parameters required to achieve those objectives were presented in [Table 2](#).

The results of each secondary objective are discussed in the following subsections.

2.3.2.2.1 Secondary Objective S-1

Document the particle size distribution of the feed soil.

The particle size distribution results are presented in [Table 12](#). Particle size distribution was also documented for samples taken from the treated soil (S2) and the sediment filter cake (S3).

**TABLE 12. PARTICLE SIZE DISTRIBUTION OF SOIL
NORDAC SOIL WASHING SYSTEM**

Run Number	Soil Type ^a		
	Contaminated Feed Soil (Sampling Location S1)	Treated Soil (Sampling Location S2)	Sediment Filter Cake (Sampling Location S3)
1	Sand 90.88/5.38/3.74 ^b	Sand 93.25/4.65/2.1	Sand 92.05/5.8/2.15
2	Sand 90.62/5.2/4.18	Sand 93.4/4.6/2.0	Sandy Loam 69.6/18.5/11.9
3	Sand 90.79/5.33/3.88	Loam 38.92/41.53/19.56	Sandy Loam 59.02/25.13/15.85

^a Based on particle size distribution according to an Institut Fresenius standard operating procedure

^b (% sand/ % silt/ % clay)

In test run 1, the treated soil and sediment filter cake had similar particle size distribution. In test run 2, the sediment filter cake was finer than the treated soil. In test run 3, the sediment filter cake was coarser than the treated soil.

2.3.2.2.2 Secondary Objective S-2

Document the average feed soil processing rate on a mass per hour basis over the duration of three 6-hour test runs.

During the demonstration, the processing rate of feed soil was monitored using a belt scale which is not certified and known to give biased results. Therefore, Nordac routinely determines a correction factor for each treated batch of soil. However, all soils and fractions are measured on a certified truck scale as it is transported to or from the facility. The correction factor for the feed soil belt scale was calculated using the following equation:

$$Y = \frac{M_t}{M_b}$$

where:

Y = Correction factor
M_t = Mass measured with truck scale (certified)
M_b = Mass measured with belt scale (not certified)

For the demonstration batch, the correction factor was calculated to be 1.43, since the sum of the truck scale readings for the untreated soil was 1,932 mt and the sum of the belt scale readings was 1,347 mt.

The feed soil processing rates were calculated using the following equation:

$$P_c = (Y)(P_b)$$

where:

P_c = Corrected processing rate
Y = Correction factor
P_b = Processing rate determined with the belt scale

The Nordac system processed feed soil at rates ranging from 14.6 metric tons per hour (mt/hr) to 19.6 mt/hr. During test runs 2 and 3, Nordac stopped feeding contaminated soil into the system because of system limitations. Therefore, no soil was recorded as being processed during those times. The overall average feed soil processing rate was 15.2 mt/hr. The average feed soil processing rates for the three test runs were 17.5 mt/hr, 14.4 mt/hr, and 15.0 mt/hr.

2.3.2.2.3 Secondary Objective S-3

Document commercial treatment costs of the process as provided by Nordac.

For the application of the Nordac technology at the Hamburg site, the commercial treatment cost per metric ton is 150 to 200 DM (\$100 to \$133, assuming a 1.5 DM to one U.S. dollar exchange rate). This cost includes treatment of the soil at the facility and disposal of treated soil and residuals.

2.3.3 Data Quality

This section summarizes the data quality for soil and process water samples collected and analyzed during the Nordac bilateral SITE demonstration. This data quality assessment was conducted to incorporate the

analytical data validation results and the field data quality QC results, evaluate the impact of all QC measures on the overall data quality, and remove all unusable values from the investigation data set. The results of this assessment were used to produce the known, defensible information employed to define the investigation findings and draw conclusions.

A validation review of the analytical data for soil and process water samples was conducted to ensure that all laboratory data generated and processed are scientifically valid, defensible, and comparable. Data were validated using both field QC samples and laboratory QC analyses. The field samples included equipment blanks, field blanks, and trip blanks. Laboratory samples included method blanks, initial and continuing calibration, matrix spike/matrix spike duplicate, and blank spike/blank spike duplicate. Results from these samples were used to assess data precision, accuracy, representativeness, comparability, and completeness. The results are presented in [Tables 13](#) and [14](#).

Several data quality outliers were noted for field QC samples (see [Table 13](#)). These outliers indicate that some residual contamination may have been present in the field that could have affected the field sample data. However, this trace contamination is insignificant compared to high untreated soil contaminant concentrations and may indicate that treated soil contaminant concentrations are even lower than analyzed.

Relative percent difference (RPD) could not be determined for 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 data met all QA objectives to show that data met precision objectives. Blank spike/blank spike duplicate percent recoveries ranged from 101 to 122 percent, and relative percent differences were less than 12 percent. Percent recovery was measured for both matrix spikes and blank spikes and indicates that QA objectives for accuracy were met (see [Tables 14](#) and [15](#)).

As mentioned in Section 2.2.1.1, only 10 untreated soil samples were collected out of 12 expected samples during test run 2, indicating completeness of only 83 percent for untreated soil samples collected during test run 2. However, data from test run 2 is still useable because overall completeness for untreated soil samples is 94% and data for test run 2 is not different from data for test runs 1 and 3 which had 100 percent completeness. All other completeness percentages were above the 90 percent goal. For data used to draw conclusions related to project objectives, all other data quality indicators met the QA objectives, indicating that general data quality was good and that the sample data are useable as reported.

**TABLE 13. QC RESULTS OF EQUIPMENT BLANK, FIELD BLANK, AND TRIP BLANK ANALYSES
NORDAC SOIL WASHING SYSTEM**

Test Run	Sampling Location	Blank Type	Contaminant Concentration ($\mu\text{g/L}$)				
			Benzene	Toluene	Ethylbenzene	Xylene (m + p)	Xylene (o)
1	S1	Field Blank	<1.0	<1.0	6.3	<1.0	15.1
	S2		<1.0	<1.0	<1.0	3.1	1.1
	S3		<1.0	4.0	17.2	53.3	17.7
	S5		<1.0	2.1	11.2	8.4	11.1
2	S1	Equipment Blank	<1.0	<1.0	<1.0	1.3	<1.0
	S2		<1.0	1.5	<1.0	1.7	<1.0
	S3		<1.0	<1.0	<1.0	5.4	2.3
3	S1	Field Blank	<1.0	3.7	17.6	62.9	21.5
	S2		<1.0	2.2	10.3	36.5	12.2
	S3		<1.0	<1.0	3.2	10.8	3.9
	S5		<1.0	1.7	7.4	26.1	9.0
Not Applicable	Not Applicable	Trip Blank	<1.0	<1.0	<1.0	<1.0	<1.0
			<1.0	<1.0	<1.0	<1.0	<1.0
			<1.0	<1.0	<1.0	<1.0	<1.0
			<1.0	<1.0	<1.0	<1.0	<1.0

$\mu\text{g/L}$ Micrograms per Liter

m + p Meta and para

o Ortho

Note: Samples were not preserved with hydrochloric acid.

**TABLE 14. QC RESULTS FOR MATRIX SPIKE RECOVERY
NORDAC SOIL WASHING SYSTEM**

Compound	Matrix Spike 1 (%R)	Matrix Spike 2 (%R)	Matrix Spike 3 (%R)	Matrix Spike 4 (%R)	Matrix Spike 5 (%R)	Matrix Spike 6 (%R)	Matrix Spike 7 (%R)	Matrix Spike 8 (%R)	QC Limits (%R)
Benzene	127	120	128	125	126	124	120	128	39-150
Toluene	114	109	116	118	118	110	114	121	46-148
Ethylbenzene	130	131	137	115	129	88.5	116	131	26-162
Xylene (m + p)	134	163	112	110	169	58.7	112	150	32-160
Xylene (o)	128	131	153	106	126	96.8	133	155	32-160
Matrix sample location	Treated (S2)	Treated (S2)	Untreated (S1)	Treated (S2)	Treated (S2)	Treated (S2)	Treated (S2)	Treated (S2)	Treated (S2)

%R Percent recovery
m + p Meta and para
o Ortho

2.3.4 Conclusions

This section presents the conclusions of the Nordac bilateral SITE demonstration at Hamburg, Germany. The soil processing rate ranged from 10.2 to 13.7 mt/hr. For the Nordac technology demonstration, three primary and three secondary objectives were selected. The conclusions for each objective are summarized below. (Note: Benzene is not included in these conclusions because benzene levels in the untreated soil were less than 25 mg/kg and, therefore, is not considered a critical contaminant for this demonstration.)

- The removal efficiencies achieved by the Nordac treatment system were 98.3 percent for toluene, 97.3 percent for ethylbenzene, 97.5 percent for m- and p-xylene, and 95.6 percent for o-xylene. Removal efficiencies ranged from 94.4 to 99.4 percent.
- The 95 percent upper confidence limit of BTEX concentrations in treated soil is presented in Table 15.

**TABLE 15
95 PERCENT UPPER CONFIDENCE LIMIT IN TREATED SOIL**

Contaminant	Test Run		
	1 (mg/kg)	2 (mg/kg)	3 (mg/kg)
Toluene	0.88	3.90	0.28
Ethylbenzene	10.7	34.0	2.87
m- & p-xylene	37.6	114.0	13.7
o-xylene	17.8	30.9	9.66

- TCLP-leachable VOCs could not be determined for this demonstration, but BTEX concentrations in the sediment filter cake are greater than the TCLP level, indicating that if 100 percent of the BTEX leached out, the sediment filter cake would be characterized as hazardous waste. Sediment filter cake represents 21 percent of the total mass of soil treated by the Nordac system.
- Average BTEX concentrations in the process water were 317 $\mu\text{g/L}$ of toluene, 1,780 $\mu\text{g/L}$ of ethylbenzene, 6,270 $\mu\text{g/L}$ of m- and p-xylene, and 1,880 $\mu\text{g/L}$ of o-xylene. Test runs 1 and 2 process water samples were not preserved with hydrochloric acid. Therefore, the most accurate data is taken from the process water sample from the third test run which was preserved with hydrochloric acid and was analyzed to contain BTEX concentrations of 139 $\mu\text{g/L}$ of toluene, 800 $\mu\text{g/L}$ of ethylbenzene, 3,230 $\mu\text{g/L}$ of m- and p-xylene, and 930 $\mu\text{g/L}$ of o-xylene, significantly less than overall average concentrations.
- The native moisture content of the contaminated soil ranged from 10.1 percent to 15.2 percent by weight. The moisture content of the treated soil exiting the soil washing process ranged from 11

percent to 15 percent by weight. The moisture content of the sediment filter cake before going through the dryer ranged from 44.7 to 51.5 percent by weight. The moisture content of the sediment filter cake after going through the dryer ranged from 34.5 to 54.3 percent by weight.

- The feed soil was characterized to be sand for all 3 test runs. Additionally, treated soil was determined to be sand for test runs 1 and 2, and loam for test run 3. Sediment filter cake was determined to be sand for test run 1 and sandy loam for test runs 2 and 3.
- During the demonstration, the Nordac system processed soil at rates ranging from 14.6 mt/hr to 19.6 mt/hr. The quantities of treated materials were 1,407 mt of treated soil, 74 mt of lightweight fraction, and 401 mt of sediment filter cake.
- The commercial cost for application of the Nordac technology at the Hamburg site is 150 to 200 DM per metric ton (\$100 to \$133 per metric ton assuming a 1.5 DM to one U.S. dollar exchange rate).

3.0 ECONOMIC ANALYSIS

This section presents cost estimates for using the Nordac technology to treat soil contaminated with BTEX. Cost estimates presented in this section are based on data provided by Norddeutsches Altlasten-Sanierungs-Centrum GmbH & Co. KG.

For the application of the Nordac technology at the Hamburg site, the commercial treatment cost per metric ton is 150 to 200 DM (\$100 to \$133, assuming a 1.5 DM to one U.S. dollar exchange rate). For this demonstration, costs per metric ton included treatment of the soil at the facility and disposal of treated soil and residuals. Transportation of the untreated soil to the facility was not included.

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 Nordac 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 Nordac 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 available information from other applications of the technology.

4.1 FEASIBILITY STUDY EVALUATION CRITERIA

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

4.1.1 Overall Protection of Human Health and the Environment

The Nordac technology provides both short-term and long-term protection of human health and the environment by reducing the concentrations of contaminants in soil. The Nordac technology removes BTEX from soil by washing the soil. (Removal efficiency is discussed in more detail in [Section 2.0](#)) Treated process water is fed back into the system or discharged to the municipal sewer system. Exposure to air emissions is minimized through the removal of contaminants from the system's air process stream using carbon adsorption units before 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 Nordac technology, compliance with chemical-, location-, and action-specific ARARs should be determined 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 Nordac system in removing contaminants from the soil and the site-specific cleanup level.

4.1.3 Long-Term Effectiveness and Permanence

The Nordac system permanently reduces BTEX levels in soils, and separates out fine-grained materials from coarser-grained materials. Potential long-term risks to the treatment system workers, the community,

and the environment from emissions of treated gas and discharge of treated water are mitigated by ensuring that established standards are met.

4.1.4 Reduction of Toxicity, Mobility, or Volume Through Treatment

As discussed in [Section 4.1.1](#) and [4.1.3](#), the Nordac soil washing technology offers permanent removal of BTEX. As such, the toxicity, mobility, and volume of contaminants are also significantly reduced.

4.1.5 Short-Term Effectiveness

The permanent removal of BTEX from soils is achieved relatively quickly, providing for short-term effectiveness, as well as long-term effectiveness discussed in [Section 4.1.3](#). Potential short-term risks presented during system operation to workers, the community, and the environment include air emissions. Exposure from fugitive air emissions during operation, monitoring, and maintenance are minimized through the removal of contaminants in the system's air process stream using carbon adsorption units before discharge.

4.1.6 Implementability

The Nordac soil washing system is a large fixed treatment facility with many components ([Figure 3](#)). 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 Nordac technology at the Hamburg, Germany site, the commercial treatment cost per metric ton is 150 to 200 DM (\$100 to \$133, assuming a 1.5 DM to one U.S. dollar exchange rate). This cost includes treatment of the soil at the facility and disposal of the treated soil and residuals.

4.1.8 State Acceptance

State acceptance is anticipated because the Nordac system uses widely accepted processes to remove contaminants from soil and to treat the process water and air 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, such as 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.

4.1.9 Community Acceptance

The system's size and space requirements may raise concern in nearby communities. However, proper management and operational controls coupled with minimal short-term risks to the community and the permanent removal of contaminants through ex situ processes make this technology likely to be accepted by the public.

4.2 APPLICABLE WASTES

The Nordac technology demonstrated at Hamburg, Germany, was designed to remove BTEX from soil. The developer claims that the technology can also remove other contaminants, such as other VOCs, semivolatile organic compounds (SVOCs), petroleum hydrocarbons, polychlorinated biphenyls (PCBs), and selected metals from soil. However, the technology's applicability to contaminants other than toluene, ethylbenzene, and xylene was not examined as part of this demonstration.

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 NORDAC TECHNOLOGY STATUS

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

6.0 REFERENCES

American Society for Testing and Materials (ASTM). 1990. Water Content of Soil/Rock/Soil-Aggregate Mixtures, D2216.

Evans, G. 1990. "Estimating Innovative Technology Costs for the SITE Program." Journal of Air and Waste Management Assessment. Volume 40, Number 7. July.

PRC Environmental Management, Inc. (PRC) 1995 Quality Assurance Project Plan for the Nordac Soil Washing System Demonstration in Hamburg, Germany. August.

U.S. Environmental Protection Agency (EPA). 1987. Test Methods for Evaluating Solid Waste, Volumes IA-IC: Laboratory Manual, Physical/Chemical Methods; and Volume II: Field Manual, Physical/Chemical Methods, SW-846, Third Edition, (revision 0), Office of Solid Waste and Emergency Response, Washington, D.C.

EPA. 1988. "Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA." EPA/540/G-89/004. October.