

**ENTSORGUNGSBETRIEBE DUISBURG/
ZÜBLIN KNV CATALYTIC OXIDATION SYSTEM**

DUISBURG-NEUMUEHL SITE

DUISBURG, GERMANY

EPA - BMBF BILATERAL SITE DEMONSTRATION

INNOVATIVE TECHNOLOGY EVALUATION REPORT

Prepared for:

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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 (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, conducted under the SITE program, evaluated the Züblin KNV catalytic oxidation system developed by Züblin Umwelttechnik GmbH, Stuttgart, Germany. This evaluation was conducted at the Entsorgungsbetriebe Duisburg soil gas and groundwater treatment facility located at Usedomstrasse 17 in Duisburg-Neumuehl, State of Nordrhein-Westfalen, Germany. The facility was built on the site of a former coal-gasification plant. This evaluation focused only on the innovative part of the treatment facility - the Züblin KNV catalytic oxidation system. More specifically, the evaluation focused on the catalytic oxidation system's effectiveness in treating soil gas and stripping air (from the air stripper used for groundwater treatment) contaminated with high levels of benzene, toluene, ethylbenzene, and xylenes. This Innovative Technology Evaluation Report (ITER) provides an interpretation of the data collected during the evaluation and discusses the potential applicability of the technology to other contaminated sites.

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E. Timothy Oppelt, Director
National Risk Management Research Laboratory

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ACRONYMS AND ABBREVIATIONS

AC	Activated carbon
ARARs	Applicable or relevant and appropriate requirements
ArGe	Arbeitsgemeinschaft
BMBF	Federal Republic of Germany Ministry for Research and Technology
BTEX	Total of benzene, toluene, ethylbenzene, and xylenes
°C	Degrees Celsius
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
DM	Deutsche Mark
EPA	United States Environmental Protection Agency
°F	Degrees Fahrenheit
g/m ³	Grams per cubic meter
GC/MS	Gas chromatography/mass spectroscopy
HDPE	High density polyethylene
ITER	Innovative Technology Evaluation Report
LNAPL	Light nonaqueous phase liquid
m	Meter
m ³	Cubic meter
m ³ /hr	Cubic meters per hour
MDL	Method detection limit
mg/L	Milligrams per liter
mg/m ³	Milligrams per cubic meter
mg/Nm ³	Milligrams per normal cubic meter
mL	Milliliter
mm	Millimeter
NIOSH	National Institute for Occupational Safety and Health
Nm ³	Normal cubic meter
NPL	National Priorities List
NRMRL	National Risk Management Research Laboratory
ORD	U.S. EPA Office of Research and Development
PAH	Polynuclear aromatic hydrocarbons
PL	Public law
PRC	PRC Environmental Management, Inc.
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
SARA	Superfund Amendments and Reauthorization Act (of 1986)
SITE	Superfund Innovative Technology Evaluation
µg/L	Micrograms per liter
µg/Nm ³	Microgram per normal cubic meter
µm	Micron
UCL	Upper confidence limit
VOCs	Volatile organic compounds

**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) presents the findings of the Züblin KNV catalytic oxidation technology evaluation 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 technology was demonstrated on June 13, August 6, and August 13, 1996, at the Entsorgungsbetriebe Duisburg soil gas and groundwater treatment facility located at Usedomstrasse 17 in Duisburg-Neumuehl, State of Nordrhein-Westfalen, Germany. The technology evaluation focused only on the effectiveness of the Züblin KNV catalytic oxidation system in treating soil gas and stripping air (from the air stripper used to treat contaminated groundwater at the treatment facility) contaminated with high levels of benzene, toluene, ethylbenzene, and xylenes (BTEX).

The Züblin KNV Catalytic Oxidation Technology

The Züblin KNV catalytic oxidation system was developed by Züblin Umwelttechnik GmbH, Stuttgart, Germany. It is used as an afterburner to thermally oxidize gaseous organic contaminants at a temperature exceeding 400 degrees Celsius (°C) (752 degrees Fahrenheit (°F)). According to the developer, oxidation byproducts are carbon dioxide and water/steam. The maximum throughput capacity of the Züblin KNV catalytic oxidation system is 5,000 normal cubic meters of gas per hour (Nm³/hr), and is the biggest catalytic oxidation system applied in hazardous waste site remediation in Germany. The system's heat exchanger uses hot treated gas to preheat cold untreated gas. Treated offgas must meet established emission standards before being discharged into the atmosphere. Stack gas contaminant concentrations are monitored automatically at 30-minute intervals by a gas chromatography/mass spectroscopy (GC/MS) instrument. This data was not used to evaluate this technology. The system is fully automated to allow for 24-hour operation. The system is checked and maintained by one person once a week.

Waste Applicability

In this technology evaluation, the Züblin KNV catalytic oxidation system significantly reduced BTEX concentrations in contaminated soil gas and stripping air. BTEX concentrations were consistently reduced from the 700 to 1,000 milligrams per Nm³ (mg/Nm³) range to below the detection level of 0.5 mg/Nm³. Although the reduction in concentrations of other organic contaminants was not measured during this

evaluation, past operating information provided by the developer indicates that total organic carbon may also be significantly reduced by the Züblin KNV catalytic oxidation system.

Evaluation Objectives and Approach

Two primary and two secondary objectives were selected for this technology evaluation. The objectives were chosen to provide potential technology users with information necessary to assess the applicability of the technology to other contaminated sites. The objectives were:

Primary Objectives

- P-1 Determine the removal efficiencies of the Züblin KNV catalytic oxidation system for gas contaminated with BTEX.
- P-2 Document BTEX concentrations in the treated gas at a confidence level of 95 percent.

Secondary Objectives

- S-1 Document key nonproprietary system operating parameters (stack gas flow rates and reactor temperatures).
- S-2 Document remediation cost per year of operation.

Evaluation Conclusions

Specific conclusions for each primary and secondary objective are summarized below:

- The overall average removal efficiency was greater than 99.9 percent for benzene, greater than 99.8 percent for toluene, greater than 94.7 percent for ethylbenzene, greater than 99.8 percent for m- and p-xylenes, and greater than 98.6 percent for o-xylene. The calculation of a higher removal efficiency for ethylbenzene was hindered by low concentrations in the untreated gas (overall average of 9.4 mg/Nm³) relative to the 0.5 mg/Nm³ detection level. Information provided by the developer on the operation of the treatment system prior to the technology evaluation indicated that total BTEX concentrations had been reduced from an inlet concentration range of 3,000 to 4,000 mg/Nm³ below 1 mg/Nm³, which corresponds to greater than 99 percent removal efficiency.
- Exact values for the 95 percent upper confidence level of BTEX concentrations in treated gas were not calculated because BTEX concentrations were consistently below the 0.5 mg/Nm³ detection level.

- The stack gas flow rates ranged from 2,500 cubic meters per hour (m³/hr) to 3,300 m³/hr (at actual temperature and pressure). Reactor temperatures ranged from 520 °C to 580 °C (968 °F to 1076 °F).
- Based on information provided by Züblin, the capital cost is 3,200,000 Deutsche Mark (DM) (US\$1,888,000 at 1.00 DM to US\$0.59); annual operating cost, including supplemental fuel, is 425,000 DM (US\$250,750); and the annualized remediation cost (operating cost plus 10-year amortized equipment cost) is 745,000 DM (US\$439,550). These costs are applicable specifically to the treatment system evaluated at the rated capacity of 5,000 normal cubic meters per hour (Nm³/hr) in operation for 10 years.

Technology Applicability

The Züblin KNV catalytic oxidation 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.

Overall Protection of Human Health and the Environment

The Züblin KNV catalytic oxidation technology provides both short-term and long-term protection of human health and the environment by significantly reducing the concentrations of volatile organic compounds (VOCs) in contaminated gaseous streams. VOCs are permanently destroyed through thermal oxidation. Contaminated gas is treated to meet air emission standards and is discharged to the atmosphere.

Compliance with ARARs

Although general and specific applicable or relevant and appropriate requirements (ARARs) were not identified for the Züblin KNV catalytic oxidation technology, compliance with chemical-, location-, and action-specific ARARs should be determined on a site-specific basis. Although location- and action-specific ARARs generally can be met, compliance with chemical-specific ARARs depends on the efficiency of the treatment system in removing contaminants and on the site-specific cleanup level.

Long-Term Effectiveness and Permanence

The Züblin KNV catalytic oxidation system permanently removes VOCs from gaseous streams through destruction by thermal oxidation. This permanent destruction ensures long-term effectiveness. The high

removal efficiency of the treatment system was documented in this technology evaluation and also in information on past operations of the treatment system.

Potential long-term risks to the treatment system workers, the community, and the environment from emissions of treated gas are mitigated by ensuring that emissions standards are met.

Reduction of Toxicity, Mobility, or Volume Through Treatment

As discussed previously, the Züblin KNV catalytic oxidation technology offers permanent thermal destruction of VOCs. As such, the toxicity, mobility, and volume of contaminants are also significantly reduced.

Short-Term Effectiveness

The permanent thermal destruction of VOCs in gaseous streams is achieved almost instantaneously, providing for short-term, as well as long-term effectiveness. Although the residence time for the reactor was not provided by the developer, it is assumed that the residence time, as is typical in other thermal oxidation systems, is relatively short based on the treatment system's high design flow rate (5,000 Nm³/hr).

Potential short-term risks to the treatment system workers, the community, and the environment from emissions of treated gas are mitigated by ensuring that emission standards are met, and also by the treatment system's fail-safe controls, which will shut down the system should malfunctions occur.

Implementability

The Züblin KNV catalytic oxidation system is an integral part of the stationary Entsorgungsbetriebe Duisburg soil gas and groundwater treatment facility. Because the treatment facility is a fixed facility incorporating several processes, 5 months were required from installation to operation (June to November 1994). In addition to the treatment systems, supplemental structures were required to house, integrate, and control them. Operation and maintenance of the treatment facility require technical and engineering personnel. In applying the Züblin KNV catalytic oxidation system to a specific site, implementation can range from simple if the system is to be used only to treat offgas from an existing

treatment system (such as a soil vapor extraction system), to complex if the system is part of a large treatment facility with several treatment process (as in the case of this technology evaluation).

Cost

The annualized remediation cost of 745,000 DM (US\$439,550) is applicable specifically to the treatment system evaluated at the rated capacity of 5,000 Nm³/hr in operation for 10 years.

State Acceptance

State acceptance is anticipated because the Züblin KNV catalytic oxidation system is based on thermal oxidation, a proven means of achieving high destruction efficiency of organic contaminants, and is considered in many cases the best available control technology. If remediation is part of Resource Conservation and Recovery Act (RCRA) corrective actions, state regulatory agencies will require that permits, such as treatment permits and air emission permits, be obtained prior to installation and operation.

Community Acceptance

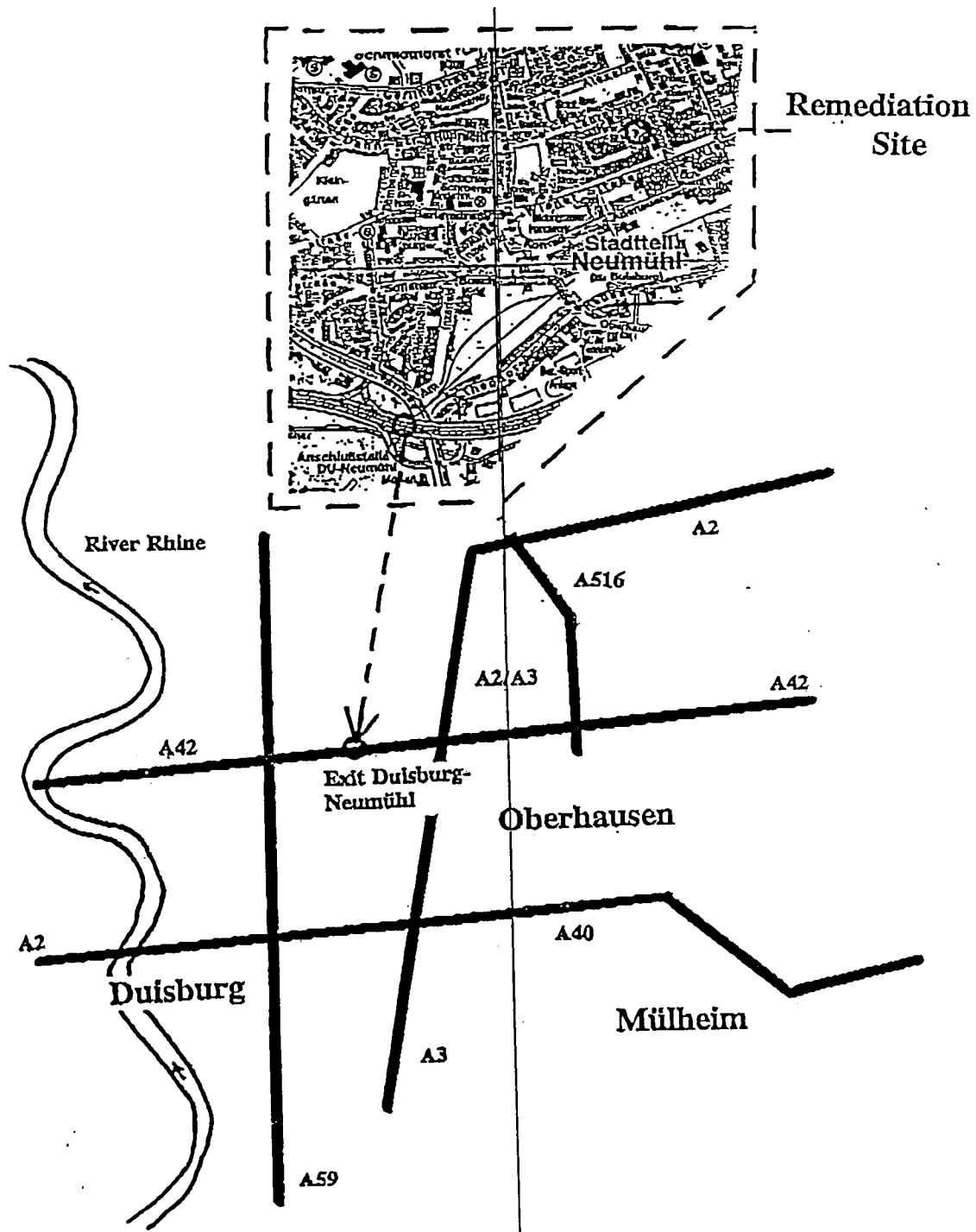
Because the Züblin KNV catalytic oxidation system is based on thermal oxidation, nearby communities may be concerned about potential risks associated with byproducts of thermal oxidation. However, the high removal efficiencies documented through this technology evaluation and past operational history; the short-term and long-term effectiveness achieved through permanent destruction of VOCs; and proper management and operational control of the treatment system should alleviate public concerns.

SECTION 1.0

INTRODUCTION

This Innovative Technology Evaluation Report (ITER) has been prepared by PRC Environmental Management, Inc. (PRC) for the U.S. Environmental Protection Agency (EPA). It presents the findings of an innovative technology evaluation that was conducted under a bilateral agreement between the EPA Superfund Innovative Technology Evaluation (SITE) program and the Federal Republic of Germany Ministry for Research and Technology (BMBF). The technology demonstrated was the Entsorgungsbetriebe Duisburg/Züblin KNV catalytic oxidation system developed by Züblin Umwelttechnik GmbH, Stuttgart, Germany. It was demonstrated on June 13, August 6, and August 13, 1996, at the Entsorgungsbetriebe Duisburg soil gas and groundwater treatment facility located at Usedomstrasse 17 in Duisburg-Neumuehl, State of Nordrhein-Westfalen, Germany (Figure 1). The treatment facility was built on the site of a former coal-gasification plant. The technology evaluation focused only on the Züblin KNV catalytic oxidation system's effectiveness in treating soil gas and stripping air (from the air stripper used to treat contaminated groundwater at the treatment facility) contaminated with high levels of benzene, toluene, ethylbenzene, and xylenes (BTEX). All evaluation activities were conducted in accordance with the May 1996 Quality Assurance Project Plan (QAPP) (PRC 1996) that was written specifically for this evaluation. The Züblin KNV catalytic oxidation system was operated by Züblin Umwelttechnik GmbH. Samples were collected by Arbeitsgemeinschaft (ArGe) focon-Probiotec and Institut Fresenius with assistance from PRC. Analyses were performed by Institut Fresenius. ArGe focon-Probiotec, Züblin Umwelttechnik GmbH, and Institut Fresenius contributed extensively to the development of this ITER.

This ITER provides information from the bilateral SITE evaluation of the Züblin KNV catalytic oxidation system that is useful for remedial project 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 technology, and lists key contacts. [Section 2.0](#) presents information on the technology's effectiveness, including site background, evaluation objectives, evaluation procedures, and the results and conclusions of the evaluation. [Section 3.0](#) presents information on the costs associated with applying the technology. [Section 4.0](#) presents



ZUEBLIN KNV DEMONSTRATION
FIGURE 1 SITE LOCATION

information on 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, applicable wastes/contaminants, and limitations of the technology. Finally, [Section 5.0](#) presents the technology status.

1.1 SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION PROGRAM

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 to pay for handling emergencies at and for cleaning up uncontrolled hazardous waste sites; this fund has become known as the Superfund. Under CERCLA, EPA has proceeded to investigate these hazardous waste sites and establish national priorities for site remedies. The investigations are undertaken primarily 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).

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 a formal program to accelerate development, evaluation, and use of new or innovative technologies for site cleanups. This program, known as SITE, has four goals:

- Identify and, where possible, remove impediments to development and commercial use of alternative technologies.
- Establish an evaluation program 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 available alternative treatment remedies at uncontrolled hazardous waste sites.
- Structure a development program that nurtures emerging technologies.

Each year, EPA selects the best available innovative technologies for evaluation. These technologies are screened and selected based on: (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 evaluations and applicability to sites or problems needing remedy, and (4) the developer's capability for and approach to testing. The SITE evaluation program is administered by EPA's Office of Research and Development (ORD) at the National Risk Management Research Laboratory (NRMRL) in Cincinnati, Ohio.

SITE evaluations 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. For this technology evaluation of the Züblin KNV catalytic oxidation system, the site was selected cooperatively by EPA and BMBF. The EPA/BMBF bilateral agreement is discussed in [Section 1.2](#).

The main objectives of the SITE evaluation program and the bilateral agreement are to develop reliable performance and cost data on innovative alternative technologies. The SITE program emphasizes the collection of performance data of known quality. Therefore, the procedures used to collect and analyze samples are critical; approved quality assurance and quality control (QA/QC) procedures must be stringently applied throughout the evaluation.

SITE and bilateral evaluations provide detailed data on performance, cost effectiveness, and reliability so that potential users have sufficient information to make educated judgments about the applicability of the technology to a specific site and the comparability of the technology to other technology alternatives.

The demonstration and evaluation process yields the following conclusions about the technology from the assessment of sampling and analysis results and other available and verifiable information:

- Effectiveness of the technology in treating target contaminants
- Potential need for pre- and post-treatment processing of raw and treated materials
- Site-specific wastes and media to which the technology can be applied
- Any potential site-specific system operating problems and their possible solutions
- Approximate capital, operating, and maintenance costs

- Projected long-term operating and maintenance costs

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 toward developing and evaluating remedial technologies. The bilateral agreement has the following goals:

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

Technologies at 12 sites, six in the U.S. and six 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 evaluations; those occurring in Germany correspond to full-scale site remediation activities. In the case of the U.S. evaluations, evaluation 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 evaluations in Germany, the German partners will provide all required information to allow the U.S. partners to develop an EPA Category II quality assurance project plan (QAPP).

ArGe focon-Probiotec (a partnership of two German environmental consulting firms) was commissioned by the BMBF to compile summary reports on German technologies and sites, to evaluate U.S. evaluation plans, and to facilitate the bilateral agreement on behalf of the 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 shown in [Figure 2](#).

1.3 TECHNOLOGY DESCRIPTION

This section describes the process equipment and operations of the Entsorgungsbetriebe Duisburg soil gas and groundwater treatment facility. It should be noted that the information provided in this section is limited because of the developer's proprietary claims on process design and operating data. For example, detailed descriptions of some system components are not available as the developer considers this information proprietary. However, an effort has been made to present pertinent information to support the test approach and subsequent sampling and analysis methods that were used to achieve the project objectives.

Although the technology evaluation focused only on the innovative part of the treatment facility, the Züblin KNV catalytic oxidation system, this section also describes the soil gas and groundwater treatment facility in operation at the site. The entire remediation system was not evaluated because of the conventional nature of the groundwater treatment system and because of budgetary, logistical, and schedule limitations.

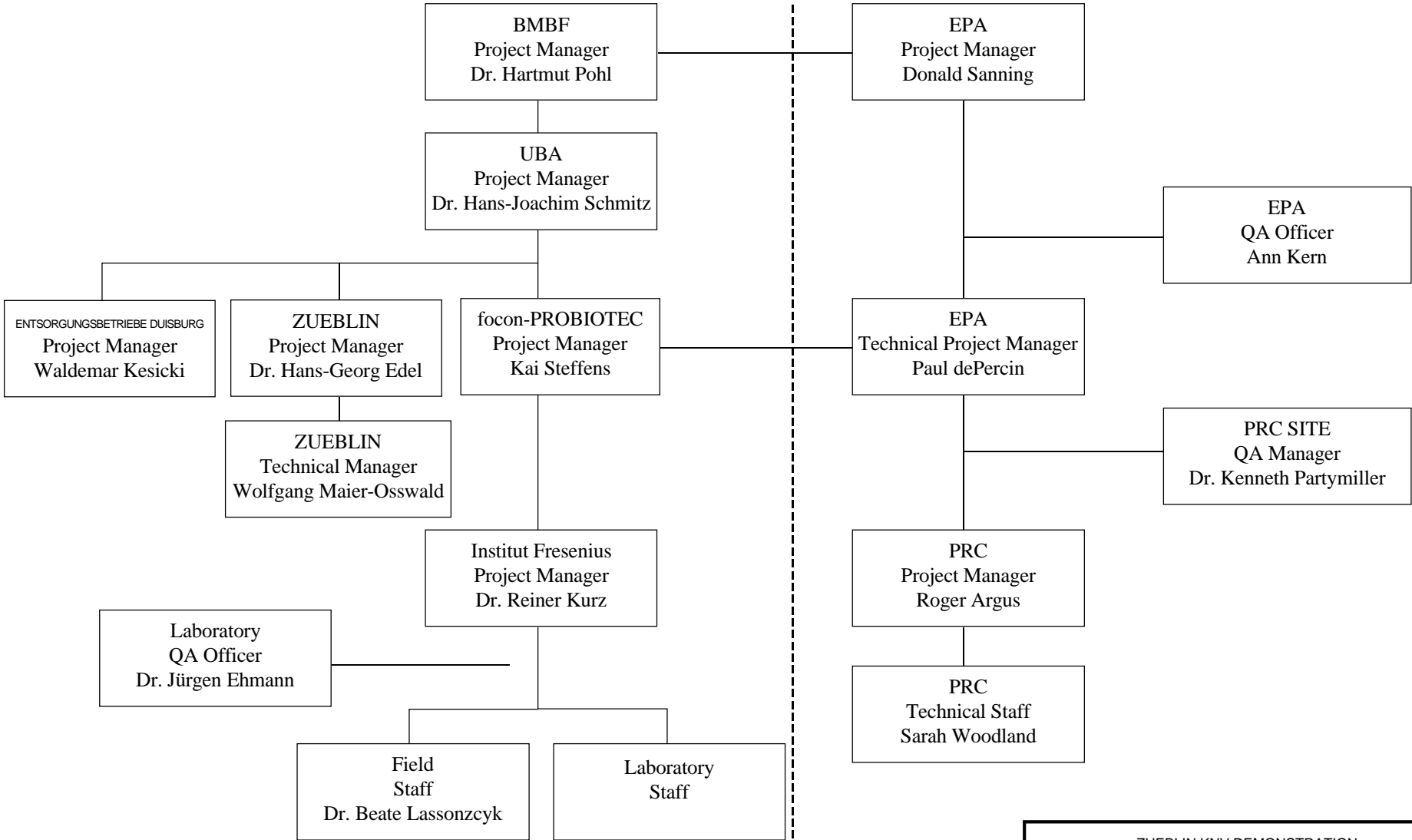
1.3.1 Process Equipment

The full-scale soil gas and groundwater treatment facility owned by Entsorgungsbetriebe Duisburg is a stationary plant located at Usedomstrasse 17 in Duisburg-Neumuehl, State of Nordrhein-Westfalen, Germany (Figure 1). This facility was designed by Züblin Umwelttechnik GmbH, Stuttgart, Germany, and uses conventional processes to treat groundwater. The offgases from the groundwater treatment system and the soil gas extraction system are treated using the Züblin KNV catalytic oxidation system. The facility incorporates the following processes:

- Soil gas and groundwater extraction
- Groundwater treatment (skimming, stripping, and biodegradation)
- Soil gas and stripping air treatment

Germany

USA



ZUEBLIN KNV DEMONSTRATION
FIGURE 2
PROJECT ORGANIZATION

The treatment process flow diagram is shown in [Figure 3](#). Typical untreated and treated contaminant concentrations in offgas and groundwater, based on operations prior to this technology evaluation, are shown in [Table 1](#).

1.3.1.1 Soil Gas and Groundwater Extraction

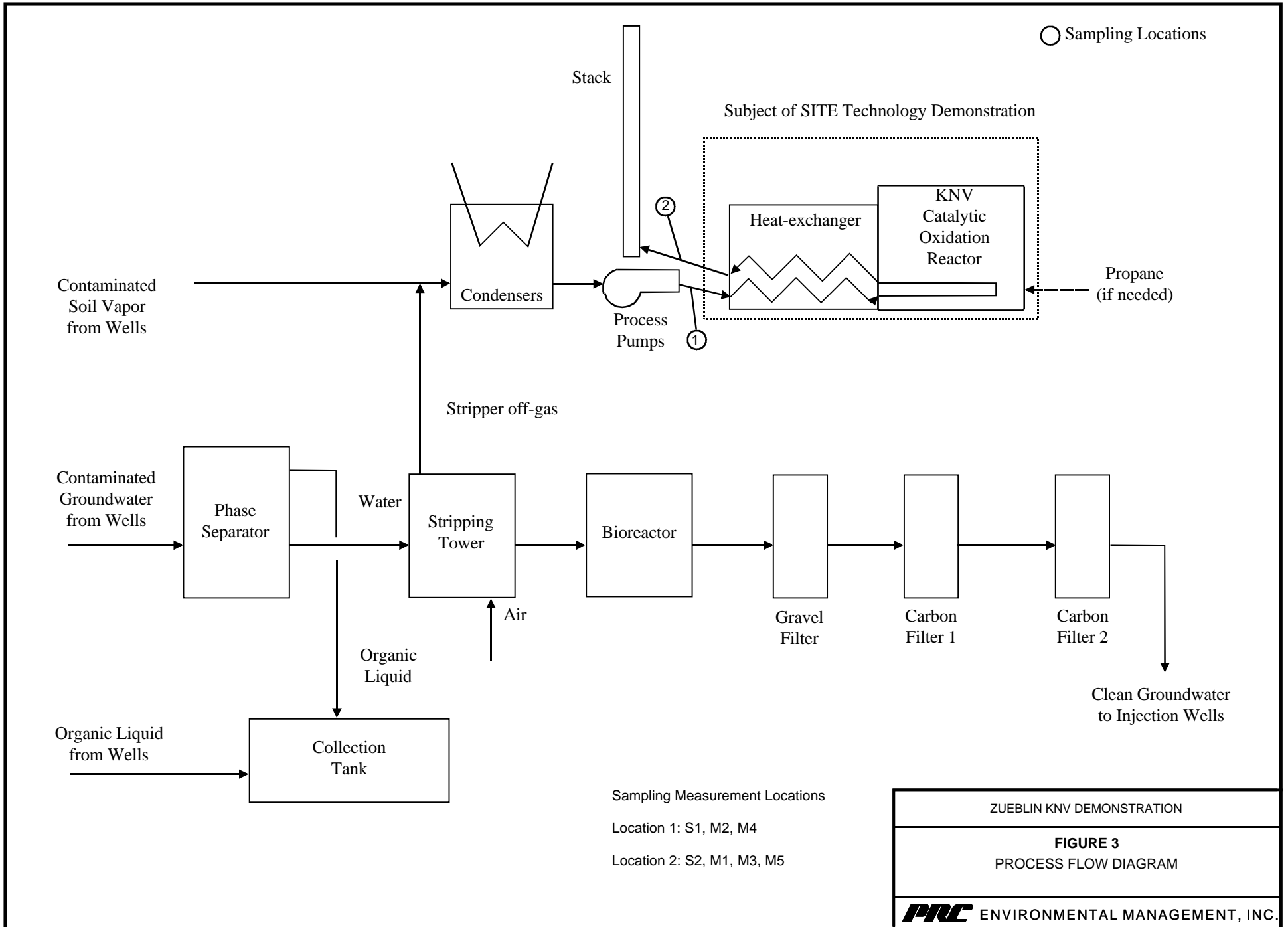
Soil gas and groundwater contaminated with high levels of volatile organic compounds (VOCs) are extracted from soil using 10 gas extraction wells and three groundwater extraction wells. The groundwater extraction wells have an inner diameter of 15.24 centimeters (cm) and are equipped with floating filters (developed by Züblin) for the removal of light nonaqueous phase liquids (LNAPL). LNAPLs are drawn from the wells and collected in an interim storage tank for subsequent disposal. Soil gas is extracted and fed directly to the Züblin KNV catalytic oxidation system.

1.3.1.2 Groundwater Treatment

This conventional process, shown in [Figure 3](#), involves removal of organic contaminants from the groundwater in four major process steps. The water treatment process is located in a 15- by 25-meter steel hall and consists of four primary units:

- Phase separator
- Stripping tower
- Bioreactor
- Filter/adsorption units

In the first step of the process, groundwater is fed to a phase separator (skimmer) unit to remove LNAPL floating on the water surface. The removed LNAPL is transferred to a collection tank. Next, the underflow water from the skimmer unit is sprayed into a conventional stripping tower to remove VOCs. The stripping tower is made of high density polyethylene (HDPE), has an inner diameter of 1.4 meters, and is 12 meters high. The throughput capacity is 30 cubic meters (m³) of water per hour. After it exits the stripping tower, water is fed to a bioreactor where semivolatile contaminants such as petroleum hydrocarbons and polynuclear aromatic hydrocarbons (PAHs) are biodegraded. The bioreactor is a floating bed reactor with a polymeric carrier aerated by ambient air.



ZUEBLIN KNV DEMONSTRATION

FIGURE 3
PROCESS FLOW DIAGRAM

TABLE 1		
TYPICAL CONTAMINANT CONCENTRATIONS IN TREATED AND UNTREATED GROUNDWATER AND GAS STREAMS (based on operations prior to the technology demonstration)		
Contaminant	Average Contaminant Concentration Levels	
	Untreated	Treated
Groundwater (throughput: 30 m ³ /hr)		
BTEX	750,000 µg/L	< 1 µg/L
TRPH	800,000 µg/L	< 1 µg/L
PAHs (16 compounds)	3,000 µg/L	< 1 µg/L
Gas (throughput: 5,000 Nm ³ /hr)		
BTEX	3,000 - 4,000 mg/Nm ³	< 1 mg/Nm ³
Total organic carbon	4,000 - 5,000 mg/Nm ³	< 5 mg/Nm ³
m ³ /hr	Cubic meters per hour	
BTEX	Total of benzene, toluene, ethylbenzene, and total xylenes	
µg/L	Micrograms per liter	
TRPH	Total recoverable petroleum hydrocarbons	
PAHs	Polynuclear aromatic hydrocarbons	
Nm ³ /hr	Normal cubic meters per hour (based on actual temperature and pressure conditions 273 Kelvin, 1.013 bar, dry)	
mg/Nm ³	Milligrams per normal cubic meter	

The offgases from the stripping tower and the bioreactor are fed to the Züblin KNV catalytic oxidation system. Bioreactor effluent water is passed through a gravel filter to remove fine particulates prior to activated carbon (AC) polishing. The treated water is then reinjected into the aquifer. Typical removal efficiencies of the different steps in the groundwater treatment system, based on operations prior to this technology evaluation, are shown in [Table 2](#).

1.3.1.3 Soil Gas and Stripping Air Treatment

The innovative part of the Entsorgungsbetriebe Duisburg soil gas and groundwater treatment facility is the Züblin KNV catalytic oxidation system, which is used as an afterburner to thermally oxidize gaseous organic contaminants at a temperature greater than 400 °C (752 °F). Oxidation products are carbon dioxide and water/steam. The maximum throughput capacity of the Züblin KNV catalytic oxidation system is 5,000 normal cubic meters (Nm³ - cubic meter at standard conditions: 273 K, 1.013 bar, dry) of gas per hour, and is the biggest catalytic oxidation system applied in hazardous waste site remediation in Germany. Züblin claims that the system can be operated autothermally (with no additional fueling) when the benzene concentration in the gas is 3 grams per cubic meter (g/m³) or higher. Züblin also claims that the system can be operated economically when the benzene concentration is higher than 1 g/m³.

Excess moisture in extracted soil gas and stripping air is removed by condensation. The condensers are equipped with sampling devices to monitor the benzene concentration. When the benzene concentration exceeds 25 percent of the lower explosive limit, the respective gas extraction line is automatically shut down.

Condensed water is fed to the water treatment train. A blower withdraws gas from the condensers and routes it through the "cold" side of a heat exchanger, through the catalytic bed in the reactor, and subsequently through the "warm" side of the heat exchanger. Through this process, hot treated gas is used to preheat the cold untreated feed gas. Treated offgases, which must meet the emissions standards shown in Table 3, are released to the atmosphere via a 30-meter-high stack. Contaminant concentrations in the stack gas are automatically monitored at 30-minute intervals by a gas chromatography/mass spectroscopy (GC/MS) system. This data was not used to evaluate this technology.

TABLE 2
TYPICAL REMOVAL EFFICIENCIES
OF DIFFERENT STEPS
IN THE GROUNDWATER TREATMENT SYSTEM
(based on operations prior to the technology demonstration)

Contaminant Concentration Levels in µg/L
Percentages of Contaminants Remaining

Compounds	Untreated Water		After Stripper and Bioreactor		After Activated Carbon Filter 1	
	Concentration (µg/L)	Percentage Remaining	Concentration (µg/L)	Percentage Remaining	Concentration (µg/L)	Percentage Remaining
TPH	7,330	100%	240	3.3%	< 0.1	< 0.001%
PAHs	5,220	100%	285	5.4%	< 0.1	< 0.001%
BTEX	86,500	100%	51	0.06%	< 5	< 0.006%

µg/L Micrograms per liter

TPH Total petroleum hydrocarbons

PAHs Polynuclear aromatic hydrocarbons

BTEX Total benzene, toluene, ethylbenzene, and total xylenes

TABLE 3
EMISSION STANDARDS FOR DISCHARGE
OF WASTEWATER AND OFFGASES IN DUISBURG-NEUMUEHL

Contaminant	Concentration
Treated Wastewater:	
Benzene	1 µg/L
Toluene	1 µg/L
Xylenes	2 µg/L
Sum of BTEX	5 µg/L
Sum of PAHs (excluding naphthalene)	5 µg/L
Sum of PAHs (including naphthalene)	10 µg/L
Hydrocarbons	5 mg/L
OffGas:	
Benzene	1 mg/Nm ³
Total organic carbon	5 mg/Nm ³
BTEX	Total of benzene, toluene, ethylbenzene, and xylenes
µg/L	Micrograms per liter
PAH	Polynuclear aromatic hydrocarbons
mg/L	Milligrams per liter
VOC	Volatile organic compounds
SVOC	Semivolatile organic compounds
mg/Nm ³	Milligrams per normal cubic meter (based on 273 K, 1013 bar, dry)

The physical characteristics of the Züblin KNV catalytic oxidation system are listed below:

Model:	HKNV-4500, LTG Stuttgart
Outer Diameter:	2.2 meters
Height:	3.5 meters
Material of Construction:	Stainless steel
Installed Power Supply:	25 kW
Burner:	Propane gas, 230 kilowatts (kW)
Catalytic Bed:	Precious metal on aluminum carrier

The design performance characteristics are:

Throughput Capacity:	5,000 Nm ³ /hr
Offgas Concentrations:	
Benzene:	< 1 mg/Nm ³
Total organic carbon:	< 5 mg/Nm ³

1.3.2 System Operation

The soil gas and groundwater treatment facility is fully automated to allow for 24-hour operation. During routine operation, no support personnel are necessary. The treatment facility is checked and maintained by one person once a week, during which time the automatic emission records are copied from the plant's data system to a diskette for reporting in the office of the operating company.

Fully automated emission monitors are located on the roofs of the buildings that surround the remediation site. If emission readings exceed threshold values, the treatment facility is shut down automatically and an alarm is reported to the operating company office in the city of Dortmund (about 80 kilometers away).

The treatment facility is equipped with automatic systems that allow safe shutdown of the plant in case of an electrical power blackout or other emergency. To allow for safe operation of the blowers, burners, and other process equipment, emergency supply systems for fuel and electrical power are on standby. Safe operation of the afterburner and continuous functioning of the control systems are guaranteed by redundant energy supply systems and control system design.

1.4 KEY CONTACTS

Additional information on the Züblin KNV catalytic oxidation system and the EPA/BMBF bilateral technology evaluation program can be obtained from the following sources:

- Züblin KNV Catalytic Oxidation System
Dr. Hans-Georg Edel and Mr. Wolfgang Maier-Osswald
Züblin Umwelttechnik GmbH
Albstadweg 1
D-70567 Stuttgart
(0711) 7883-249 and (0711) 7883-636
- EPA/BMBF Bilateral Technology Evaluation Program
Mr. Donald Sanning and Mr. Paul dePercin
U.S. Environmental Protection Agency
Office of Research and Development
26 W. Martin Luther King Drive
Cincinnati, Ohio 45268
(513) 569-7875 and (513) 569-7797

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 300 technologies submitted by nearly 200 developers, manufacturers, and suppliers of innovative treatment technology equipment and services.

- The OSWER 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.

SECTION 2.0

ZÜBLIN KNV CATALYTIC OXIDATION SYSTEM

This section documents the site background, evaluation objectives, evaluation procedures, and results and conclusions used to assess the effectiveness of the Züblin KNV catalytic oxidation system in treating soil gas and stripping air contaminated with BTEX from the Duisburg-Neumuehl site. This assessment is based on data collected during the evaluation conducted at the site.

2.1 SITE BACKGROUND

The benzene factory of a coking plant was operated at the Duisburg-Neumuehl site until 1961. These facilities were demolished in 1968 and the area was leveled for a new residential development. Soil and groundwater contaminated from operation of the benzene factory remained at the site. Typical values for soil gas and groundwater contamination are listed in [Table 1](#).

In 1972, a kindergarten and elementary school were built in the center of the site and residential apartment buildings were constructed in the surrounding area. In 1988, a remedial investigation of the school and kindergarten site was conducted. The school yard was determined to contain high levels of LNAPL. The total amount of LNAPL in soil beneath the school was estimated to be between 50 and 100 metric tons, and a 0.2 meter thick layer of LNAPL was detected on groundwater beneath the site. Ambient air was analyzed because a solvent smell was noted in the basement and the ground floor of the school and kindergarten building. Measurements showed high concentrations of organic contaminants in the air, leading to the partial closure the school building.

Extraction wells for groundwater and soil gas were installed in 1990 around the school and the kindergarten building and in the basement floor of the building. The district government (the responsible oversight authority) initiated a search for the party responsible for the cleanup; legal investigations and lawsuits followed. In 1993, the City of Duisburg decided to begin site remediation and carry the costs until a potentially responsible party can be identified. A request for proposals was issued, offers were evaluated, and in late 1993 the Züblin Umwelttechnik GmbH proposal was accepted. The remedial concept developed by Entsorgungsbetriebe Duisburg met the prerequisite to minimize risk to the surrounding residential area. Technical alternatives, such as adsorption of the contaminants to activated carbon, would have been

prohibitively expensive because of the high contaminant concentrations present in groundwater and soil gas. Furthermore, since the steel hall of the existing facility measures about 15 by 25 meters, an adsorption plant would have exceeded the available space.

The groundwater and soil gas treatment facility was installed in June 1994 in the yard of the elementary school, where the center of the contaminant plume is located. Operation of the facility started in November 1994. Approximately 8 metric tons of organic contaminants were removed by the facility between start-up and June 1995. The preliminary cleanup standard for groundwater was specified at 1 microgram of benzene per liter.

Because the facility is in a sensitive environment comprising the kindergarten, the elementary school, and housing, extensive emission monitoring is required. There are three automated gas chromatograph emission monitors on the roofs of the apartment buildings surrounding the site. BTEX readings are taken automatically at 15-minute intervals. The threshold value for the emissions was specified to be 1 milligram per normal cubic meter of ambient air (mg/Nm^3). Operations so far have shown that $0.5 \text{ mg}/\text{Nm}^3$ is not exceeded under routine operation and typical weather conditions. If the threshold value is exceeded in one of the emission monitors, the groundwater and soil gas treatment facility is automatically shut down.

Contaminant concentrations in the ambient air of the school building (basement and ground floor) dropped to background values after startup of the soil gas extraction system. The school and kindergarten were reopened, with ambient air in the building monitored at regular intervals.

2.2 EVALUATION OBJECTIVES

Two primary and two secondary objectives were selected for this technology evaluation. Primary objectives are considered critical for the technology evaluation. Secondary objectives provide additional information that is useful, but not critical. To obtain the data required to meet the specified project objectives, samples were collected and process measurements taken during each of the three evaluation days (June 13, August 6, and August 13, 1996). The sampling was scheduled by Institut Fresenius. The sampling and measurement locations are discussed in [Section 2.3](#). The primary objectives for this project are to:

1. Determine the removal efficiencies of the Züblin KNV catalytic oxidation system for gas contaminated with the following critical compounds (P-1):
 - Benzene
 - Toluene

- Ethylbenzene
- o-, m-, p-Xylenes

To determine the removal efficiencies of the system for these critical compounds, samples of gas entering and exiting the reactor of the Züblin KNV catalytic oxidation system were collected and analyzed. Untreated gas was sampled before entering the “cold” side of the heat exchanger. Treated gas was sampled after exiting the “warm” side of the heat exchanger (before entering the stack). Removal efficiencies were calculated as described in [Section 2.4](#) using the critical compound concentrations in the untreated and treated gas streams.

2. Document the critical contaminant concentrations in the treated gas at a confidence level of 95 percent (P-2).

To achieve this objective, samples of the treated gas (exiting the "warm" side of the heat-exchanger) were collected and analyzed. For this objective, the critical parameters are the concentrations in the treated air of the compounds listed above.

Temperature, pressure, and moisture content of the untreated gas and treated gas were also measured as critical parameters to support objectives P-1 and P-2.

The secondary objectives for this technology evaluation are to:

1. Document key, nonproprietary system operating parameters (S-1)

The stack gas flow rates and the reactor temperatures were measured in support of this objective.

2. Document remediation costs per year of operation (S-2)

Data in support of this objective were based on information provided by Züblin.

2.3 EVALUATION PROCEDURES

This section describes the sampling and analytical program and the quality assurance and quality control program.

2.3.1 Sampling and Analytical Program

Sampling objectives are necessary to produce well-documented data that are of known and reproducible quality and are defensible. Specific sampling objectives for this technology evaluation were:

- Collect representative samples. Samples were collected in a manner and frequency to ensure that they 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 evaluation project objectives.
- Maintain proper chain-of-custody control of all samples, from collection to analysis.
- Follow QA/QC procedures appropriate for EPA ORD Category II projects.

Two sampling locations and six measurement points were identified in the treatment system to achieve the project objectives established in [Section 2.2](#). Samples were collected and measurements taken for each of the three evaluation days. Grab sampling techniques were employed throughout the evaluation. [Figure 3](#) shows sampling and measurement locations for the gaseous streams. These sampling and measurement locations are:

- *Sampling Location S1: Untreated gas.* The contaminated gas was a combined stream of soil gas extracted from the wells and the stripper off gas. The sampling port in the contaminated gas duct was as far downstream of the Y joint as was possible and upstream of the "cold" side of the heat-exchanger.
- *Sampling Location S2: Treated gas exiting the "warm" side of the heat exchanger.* The sampling port is in the duct between the heat exchanger and the stack.
- *Measurement Point M1: Stack gas flow rate.* The air flow rate in the duct to the exhaust stack was measured using a certified propeller anemometer. The stack gas flow rate is identical to the feed gas flow rate.
- *Measurement Point M2: Feed gas temperature and pressure.* The temperature and pressure of the feed gas were measured using a digital thermometer and a pressure gauge.

- *Measurement Point M3: Stack gas temperature and pressure.* The temperature and pressure of the gas exiting the "warm" side of the heat exchanger were measured using a digital thermometer and a pressure gauge.
- *Measurement Point M4: Feed gas moisture content.* The moisture content of the feed gas was determined by EPA Method 4.
- *Measurement Point M5: Stack gas moisture content.* The moisture content of the stack gas was determined by EPA Method 4.
- *Measurement Point M6: Temperature of the KNV catalytic oxidation reactor.* The temperature was monitored continuously by Züblin using temperature probes (thermocouples) in the catalytic bed of the reactor.

Measurement points M2 and M4 were located at sampling location S1, and M1, M3, and M5 were located at sampling location S2.

The preliminary sample frequency (minimum number of samples) required is usually estimated using variability information for the parameters of interest. Considering cost, data quality, and anticipated gas homogeneity criteria, three discrete untreated gas samples and three discrete treated gas samples were collected for analysis of VOCs for each of the three evaluation days. [Table 4](#) lists the number of samples collected in the field at each location. The untreated and treated samples were taken within 30 minutes of each other.

System operating parameters were monitored continuously by Züblin. Sampling began after Entsorgungsbetriebe Duisburg/Züblin ensured the system was in normal operating conditions.

Gas samples were collected from sampling ports in the feed gas duct (port diameter: 2 millimeters) and the treated gas duct leading to the stack (port diameter: 25 millimeters). The feed gas duct has an inner diameter of about 250 millimeters and is located in near the heat exchanger. There was little space available for positioning of sampling equipment.

EPA Method 0030 was not used in this technology evaluation because of the sampling port space limitations, and the high contaminant concentrations expected in the untreated gas stream (BTEX in the 3,000 to 4,000 mg/Nm³ range based on operations prior to this evaluation; actual concentrations during the demonstration were determined to be in the 700 to 1,000 mg/Nm³ range). Furthermore, only one EPA Method 0030 sampling apparatus was available for use in Europe. Therefore, samples were

TABLE 4

SAMPLING AND ANALYTICAL PROGRAM

Sampling Location and Method	Analytical Parameter	Number of Samples			Total No. of Samples
		Field Samples	Field QC Samples ^b		
			Field Blanks	Trip Blanks	
Location S1 (untreated gas) Method: NIOSH 1501	VOCs ^a Method: SW-846	9	3 ^c	3	15
Location S2 (stack gas) Method: NIOSH 1501	VOCs Method: SW-846	9	0	0	9

a Critical volatile organic compounds: benzene, toluene, ethylbenzene, and xylenes
b Field QC samples were solid sorbent tubes
c One per sampling day

collected according to National Institute for Occupational Safety and Health (NIOSH) stack sampling method 1501, as specified in the NIOSH *Manual of Analytical Methods* (1984).

In NIOSH Method 1501, VOCs are removed from the sample gas by absorption into a coconut shell charcoal trap. A vacuum pump is used to withdraw the sample gas through the trap, and the gas volume passed over the trap is measured by a dry gas meter. The actual volume of gas withdrawn through the solid sorbent tube was 5 liters for the untreated gas at a flow rate less than 0.2 liter per minute, as required by the method. For the treated gas, the sampled volume was 20 liters at a flow rate less than 0.2 liter per minute. Institut Fresenius evaluated the latest gas analyses prior to the next round of sampling to confirm that the required sample volume had been collected in accordance with NIOSH Method 1501.

To avoid possible breakthrough of contaminants, two absorption tubes placed in series were used for the untreated gas. Only one tube was used for the treated gas. The glass tube containing the solid sorbent measured 70 millimeters long, with an inner diameter of 4 millimeters. It contained two sections of activated coconut shell charcoal (front = 100 mg, back = 50 mg) separated by a 2-millimeter urethane foam plug. A glass wool plug preceded the front section and a 3-millimeter urethane foam plug followed the back section. The tubes were provided by a commercial supplier.

The traps were checked for leaks before and after collection of each sample. Following the post-sampling leak checks, the traps were sealed with end caps and returned to their glass containers for storage and transport. The traps were maintained at 4 °C (39 °F) until they were analyzed.

Stack gas velocity and volumetric flow rate were measured using a certified propeller anemometer, because an S-type Pitot tube could not fit in the stack, and because the volumetric flow rate was too great for the available dry gas meters to measure the entire flow. The anemometer used to determine velocity was a new instrument. Calibrations were checked by the German Federal Calibration Agency before the demonstration and the meter itself was checked for proper function after the demonstration. Additionally, certified bubble flow meters, which were corrected for temperature and pressure, were used to check the flow meter calibration. The QA objective for this QC check was a maximum 10 percent bias from the certified value. The calibration checks were performed at the beginning and end of each sampling day.

The thermometer used to measure the feed and exit gas temperature was checked against a thermometer certified by the German Federal Calibration Agency. The moisture contents of the gas streams were determined according to EPA Method 4.

Temperature within the reactor of the Züblin KNV catalytic oxidation system is measured automatically by thermocouples on a continuous basis. A computer record is maintained of the temperature readings. A permanent record of the temperatures recorded was generated for each test run during the demonstration.

2.3.2 Quality Assurance And Quality Control Program

QC checks were an integral part of this evaluation in ensuring that QA objectives were met. These checks focused on the collection of representative samples absent of external contamination and on the generation of comparable data. QC checks consisted of field QC checks and laboratory QC checks.

As a check on the quality of field activities including sample collection, shipment, and handling, two types of field QC checks (field blanks and trip blanks) were used. For this technology evaluation, the field blanks also served as the equipment blanks. In general, these QC checks assessed the representativeness of the samples, and ensured that the degree to which the analytical data represented actual site conditions was known and documented. The field QC results are reported in [Section 2.4.2](#) and were all within acceptable limits.

Laboratory QC checks are designed to assess the precision and accuracy of the analyses, to demonstrate the absence of interference and contamination from glassware and reagents, and to ensure the comparability of data. Laboratory-based QC checks consisted of method blanks, laboratory method blanks, blank spikes, blank spike duplicates, and other checks specified in the analytical methods. The laboratory also completed initial calibrations and continuing calibrations checks according to specified analytical methods. The results of the laboratory internal QC checks were all within acceptable limits and are summarized in [Section 2.4.2](#).

2.4 EVALUATION RESULTS AND CONCLUSIONS

This section presents the results and discussion, data quality, and conclusions of the evaluation.

2.4.1 Results and Discussion

This section presents the sampling and analytical results of the evaluation. The results are presented by specific primary and secondary objectives. Data used to evaluate the objectives are summarized in [Tables 5A to 5F](#). Data quality and conclusions based on these results are discussed in [Sections 2.4.2 and 2.4.3](#). Except as noted, all primary and secondary objectives were achieved in accordance with the QAPP, and through the calculations discussed below.

2.4.1.1 Primary Objective P-1

Determine the removal efficiencies of the Züblin KNV catalytic oxidation system for gas contaminated with organic contaminants for the following critical compounds:

- Benzene
- Toluene
- Ethylbenzene
- o-, m-, and p-Xylenes

Removal efficiencies were calculated using the following equation:

$$\%R = \frac{C_U - C_T}{C_U} \times 100$$

where:

%R = Percent removal efficiency

C_U = Average contaminant concentration in untreated gas (mg/Nm³)

C_T = Average contaminant concentration in treated gas (mg/Nm³)

Daily average removal efficiencies for the critical compounds for each of the three evaluation days are presented in [Table 6A](#). The overall average removal efficiencies (overall average of the three daily

TABLE 5A

SUMMARY OF THE RESULTS OF THE UNTREATED GAS

DAY 1 (6/13/96), SAMPLE LOCATION S1

Sample Description	ZUB 1-1-1-1-S-1	ZUB 1-1-1-2-S-1	ZUB 1-1-1-3-S-1	Mean	Standard Deviation
Dry Gas Meter Correction Factor	0.979	0.979	0.979	--	--
Temperature	24.5 °C 76.1°F	25.9 °C 78.7 °F	25.9 °C 78.7 °F	--	--
Atmospheric Pressure (mbar)	1038	1036	1038	--	--
Volume (L)	5.0	5.5	5.0	--	--
Results (mg/m ³)					
Benzene	290	340	290	310	29
Toluene	200	230	190	210	21
Ethylbenzene	7.1	7.8	6.6	7.2	0.6
m- + p-Xylene	170	200	160	180	21
o-Xylene	34	39	32	35	4
Results Corrected to mg/Nm ³					
Benzene	300	350	290	310	32
Toluene	210	240	200	220	21
Ethylbenzene	7.2	7.9	6.7	7.3	0.6
m- + p-Xylene	170	200	160	180	21
o-Xylene	35	40	32	36	4
°C	Degrees Celsius				
°F	Degrees Fahrenheit				
mbar	Millibar				
NA	Not applicable				
L	Liter				
mg/m ³	Milligrams per actual cubic meter (based on actual temperature and pressure conditions)				
mg/Nm ³	Milligrams per normal cubic meter (based on 273 Kelvin and 1.013 bar, dry)				

TABLE 5B

SUMMARY OF THE RESULTS OF THE TREATED GAS

DAY 1 (6/13/96), SAMPLE LOCATION S2

Sample Description	ZUB 1-2-1-1-S	ZUB 1-2-1-2-S	ZUB 1-2-1-3-S	Mean	Standard Deviation
Dry Gas Meter Correction Factor	0.906	0.906	0.906	--	--
Temperature	28.1 °C 82.6 °F	21.5 °C 70.7 °F	22.8 °C 73.1 °F	--	--
Atmospheric Pressure (mbar)	1038	1036	1038	--	--
Volume (L)	20.0	20.0	20.0	--	--
Results (mg/m ³)					
Benzene	<0.5	<0.5	<0.5	<0.5	<0.5
Toluene	<0.5	<0.5	<0.5	<0.5	<0.5
Ethylbenzene	<0.5	<0.5	<0.5	<0.5	<0.5
m- + p-Xylene	<0.5	<0.5	<0.5	<0.5	<0.5
o-Xylene	<0.5	<0.5	<0.5	<0.5	<0.5
Results Corrected to mg/Nm ³					
Benzene	<0.5	<0.5	<0.5	<0.5	<0.5
Toluene	<0.5	<0.5	<0.5	<0.5	<0.5
Ethylbenzene	<0.5	<0.5	<0.5	<0.5	<0.5
m- + p-Xylene	<0.5	<0.5	<0.5	<0.5	<0.5
o-Xylene	<0.5	<0.5	<0.5	<0.5	<0.5
°C	Degrees Celsius				
°F	Degrees Fahrenheit				
mbar	Millibar				
NA	Not applicable				
L	Liter				
mg/m ³	Milligrams per actual cubic meter (based on actual temperature and pressure conditions)				
mg/Nm ³	Milligrams per normal cubic meter (based on 273 Kelvin and 1.013 bar, dry)				

TABLE 5C

SUMMARY OF THE RESULTS OF THE UNTREATED GAS

DAY 3 (8/6/96), SAMPLE LOCATION S1

Sample Description	ZUB 2-1-1-1-S-1	ZUB 2-1-1-2-S-1	ZUB 2-1-1-3-S-1	Mean	Standard Deviation
Dry Gas Meter Correction Factor	0.906	0.906	0.906	--	--
Temperature	25.9 °C 78.7 °F	27.4 °C 81.4 °F	27.8 °C 82.1 °F	--	--
Atmospheric Pressure (mbar)	1020	1020	1020	--	--
Volume (L)	5.0	5.0	5.0	--	--
Results (mg/m ³)					
Benzene	440	450	360	420	49
Toluene	250	260	210	240	26
Ethylbenzene	10.4	11.4	8.5	10.1	1.5
m- + p-Xylene	190	190	170	180	12
o-Xylene	31	32	28	30	2
Results Corrected to mg/Nm ³					
Benzene	490	510	400	470	59
Toluene	280	290	230	270	32
Ethylbenzene	11.6	12.8	9.6	11.3	1.6
m- + p-Xylene	210	220	190	210	15
o-Xylene	35	36	32	34	2
°C	Degrees Celsius				
°F	Degrees Fahrenheit				
mbar	Millibar				
NA	Not applicable				
L	Liter				
mg/m ³	Milligrams per actual cubic meter (based on actual temperature and pressure conditions)				
mg/Nm ³	Milligrams per normal cubic meter (based on 273 Kelvin and 1.013 bar, dry)				

TABLE 5D

SUMMARY OF THE RESULTS OF THE TREATED GAS

DAY 2 (8/6/96), SAMPLE LOCATION S2

Sample Description	ZUB 2-2-1-1-S	ZUB 2-2-1-2-S	ZUB 2-2-1-3-S	Mean	Standard Deviation
Dry Gas Meter Correction Factor	0.979	0.979	0.979	--	--
Temperature	17.9 °C 64.3 °F	17.5 °C 63.5 °F	19.1 °C 66.4 °F	--	--
Atmospheric Pressure (mbar)	1020	1020	1020	--	--
Volume (L)	20.0	20.0	20.0	--	--
Results (mg/m ³)					
Benzene	<0.5	<0.5	<0.5	<0.5	<0.5
Toluene	<0.5	<0.5	<0.5	<0.5	<0.5
Ethylbenzene	<0.5	<0.5	<0.5	<0.5	<0.5
m- + p-Xylene	<0.5	<0.5	<0.5	<0.5	<0.5
o-Xylene	<0.5	<0.5	<0.5	<0.5	<0.5
Results Corrected to mg/Nm ³					
Benzene	<0.5	<0.5	<0.5	<0.5	<0.5
Toluene	<0.5	<0.5	<0.5	<0.5	<0.5
Ethylbenzene	<0.5	<0.5	<0.5	<0.5	<0.5
m- + p-Xylene	<0.5	<0.5	<0.5	<0.5	<0.5
o-Xylene	<0.5	<0.5	<0.5	<0.5	<0.5
°C	Degrees Celsius				
°F	Degrees Fahrenheit				
mbar	Millibar				
NA	Not applicable				
L	Liter				
mg/m ³	Milligrams per actual cubic meter (based on actual temperature and pressure conditions)				
mg/Nm ³	Milligrams per normal cubic meter (based on 273 Kelvin and 1.013 bar, dry)				

TABLE 5E

SUMMARY OF THE RESULTS OF THE UNTREATED GAS

DAY 3 (8/13/96), SAMPLE LOCATION S1

Sample Description	ZUB 3-1-1-1-S-1	ZUB 3-1-1-2-S-1	ZUB 3-1-1-3-S-1	Mean	Standard Deviation
Dry Gas Meter Correction Factor	0.901	0.901	0.901	--	--
Temperature	31.8 °C 89.3 °F	33.1 °C 91.6 °F	32.2 °C 90.0 °F	--	--
Atmospheric Pressure (mbar)	1014	1014	1014	--	--
Volume (L)	5.0	5.0	5.0	--	--
Results (mg/m³)					
Benzene	310	330	360	330	25
Toluene	210	210	230	220	12
Ethylbenzene	7.6	8.1	9.5	8.4	1.0
m- + p-Xylene	170	180	190	180	10
o-Xylene	28	30	31	30	2
Results Corrected to mg/Nm³					
Benzene	350	380	410	380	30
Toluene	240	250	270	250	15
Ethylbenzene	8.8	9.4	11	9.7	1.1
m- + p-Xylene	190	210	210	200	12
o-Xylene	32	35	36	34	2
°C	Degrees Celsius				
°F	Degrees Fahrenheit				
mbar	Millibar				
NA	Not applicable				
L	Liter				
mg/m ³	Milligrams per actual cubic meter (based on actual temperature and pressure conditions)				
mg/Nm ³	Milligrams per normal cubic meter (based on 273 Kelvin and 1.013 bar, dry)				

TABLE 5F

SUMMARY OF THE RESULTS OF THE TREATED GAS

DAY 3 (8/13/96), SAMPLE LOCATION S2

Sample Description	ZUB 3-2-1-1-S	ZUB 3-2-1-2-S	ZUB 3-2-1-3-S	Mean	Standard Deviation
Dry Gas Meter Correction Factor	0.979	0.979	0.979	--	--
Temperature	19.7 °C 67.5 °F	19.9 °C 67.9 °F	21.8 °C 71.3 °F	--	--
Atmospheric Pressure (mbar)	1014	1014	1014	--	--
Volume (L)	20.0	20.0	20.0	--	--
Results (mg/m ³)					
Benzene	<0.5	<0.5	<0.5	<0.5	<0.5
Toluene	<0.5	<0.5	<0.5	<0.5	<0.5
Ethylbenzene	<0.5	<0.5	<0.5	<0.5	<0.5
m- + p-Xylene	<0.5	<0.5	<0.5	<0.5	<0.5
o-Xylene	<0.5	<0.5	<0.5	<0.5	<0.5
Results Corrected to mg/Nm ³					
Benzene	<0.5	<0.5	<0.5	<0.5	<0.5
Toluene	<0.5	<0.5	<0.5	<0.5	<0.5
Ethylbenzene	<0.5	<0.5	<0.5	<0.5	<0.5
m- + p-Xylene	<0.5	<0.5	<0.5	<0.5	<0.5
o-Xylene	<0.5	<0.5	<0.5	<0.5	<0.5
°C	Degrees Celsius				
°F	Degrees Fahrenheit				
mbar	Millibar				
NA	Not applicable				
L	Liter				
mg/m ³	Milligrams per actual cubic meter (based on actual temperature and pressure conditions)				
mg/Nm ³	Milligrams per normal cubic meter (based on 273 Kelvin and 1.013 bar, dry)				

TABLE 6A

DAILY AVERAGE REMOVAL EFFICIENCIES

Compound	DAY 1 (6/13/96)			DAY 2 (8/6/96)			DAY 3 (8/13/96)		
	Average Concentration in Untreated Gas (mg/Nm ³)	Average Concentration in Treated Gas (mg/Nm ³)	Removal Efficiency Based on Daily Average Concentration (%)	Average Concentration in Untreated Gas (mg/Nm ³)	Average Concentration in Treated Gas (mg/Nm ³)	Removal Efficiency Based on Daily Average Concentration (%)	Average Concentration in Untreated Gas (mg/Nm ³)	Average Concentration in Treated Gas (mg/Nm ³)	Removal Efficiency Based on Daily Average Concentration (%)
Benzene	310	<0.5	>99.8	470	<0.5	>99.9	380	<0.5	>99.9
Toluene	220	<0.5	>99.8	270	<0.5	>99.8	250	<0.5	>99.8
Ethylbenzene	7.3	<0.5	>93.2	11.3	<0.5	>95.6	9.7	<0.5	>94.8
Xylene (m + p)	180	<0.5	>99.7	210	<0.5	>99.8	200	<0.5	>99.8
Xylene (o)	36	<0.5	>98.6	34	<0.5	>98.5	34	<0.5	>98.5

mg/Nm³ Milligrams per normal cubic meter (based on 273 Kelvin and 1.013 bar, dry)

averages) are presented in [Table 6B](#). For benzene, the overall average removal efficiency was greater than 99.9 percent. For toluene, the overall average removal efficiency was greater than 99.8 percent. For ethylbenzene, the overall average removal efficiency was greater than 94.7 percent. For m- and p-xylenes, the overall average removal efficiency was greater than 99.8 percent. For o-xylene, the overall average removal efficiency was greater than 98.6 percent.

In all cases, the exact removal efficiencies cannot be determined beyond “greater than” because the BTEX concentrations in treated gas were consistently below the detection limit of 0.5 mg/Nm³. For ethylbenzene, the overall average removal efficiency was greater than 94.7 percent, which appeared to deviate from the overall average removal efficiencies in the greater than 98 percent and 99 percent range for other compounds. This is because the overall average ethylbenzene concentration in untreated gas was only 9.4 mg/Nm³ compared to concentrations that were at least an order of magnitude higher for other compounds. Thus, with the detection level remaining at 0.5 mg/Nm³, it was mathematically not possible to calculate a higher removal efficiency for ethylbenzene.

These results indicate that the Züblin KNV catalytic oxidation system can significantly reduce BTEX concentrations in contaminated soil gas and stripping air. During the demonstration, all BTEX concentrations were reduced to a level of nondetect (with the detection level at 0.5 mg/Nm³).

2.4.1.2 Primary Objective P-2

Determine the critical contaminant concentrations in the treated gas at a confidence level of 95 percent.

The upper limits of BTEX concentrations at the 95 percent confidence level were to be calculated using the following equation:

$$C_{UCL} = C_T + \frac{t * s}{\sqrt{n}}$$

where:

C_{UCL} = 95 percent upper confidence level concentration (mg/Nm³)

C_T = mean concentration of the contaminant in treated gas (mg/Nm³)

t = critical value of “t” at 95 percent confidence level

TABLE 6B**OVERALL AVERAGE REMOVAL EFFICIENCIES**

	Overall Average Concentration in Untreated Gas (mg/Nm ³)	Overall Average Concentration in Treated Gas (mg/Nm ³)	Removal Efficiency (%)
Benzene	390	<0.5	>99.9
Toluene	250	<0.5	>99.8
Ethylbenzene	9.4	<0.5	>94.7
Xylene (m + p)	200	<0.5	>99.8
Xylene (o)	35	<0.5	>98.6

mg/Nm³ Milligrams per normal cubic meter (273 Kelvin and 1.013 bar, dry)

- s = standard deviation of contaminant concentrations (mg/Nm³)
- n = number of samples

Since the concentrations of BTEX in treated gas were consistently below the detection level of 0.5 mg/Nm³, exact values for the 95 percent upper confidence level concentrations cannot be calculated (exact numbers for \bar{x} and s cannot be obtained).

2.4.1.3 Secondary Objective S-1

Document key nonproprietary system operating parameters.

The stack gas flow rates ranged from 2,500 m³/hr to 3,300 m³/hr (at actual temperature and pressure). Reactor temperatures ranged from 520 °C to 580 °C (968 °F to 1076 °F). These parameters are listed in [Table 7](#).

2.4.1.4 Secondary Objective S-2

Document remediation cost per year of operation.

Cost data are presented in [Table 9](#) and were based on information provided by Züblin. Cost is further discussed in [Section 3.0](#)

2.4.2 Data Quality

This section summarizes data quality for samples collected and analyzed during the 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 known, defensible information employed to define investigation findings and draw conclusions.

A validation review of the sampling and analytical data was conducted to ensure that all data are scientifically valid, defensible, and comparable. Data were validated using both field and laboratory QC checks. Field QC checks included field blanks and trip blanks. No separate equipment blanks were collected as the field blanks also served as the equipment blanks. Laboratory QC checks included initial and continuing calibration, method blanks and laboratory method blanks, and blank spikes and blank spike duplicates. The QC results are presented in [Tables 8A](#) and [8B](#). All data quality indicators met the

TABLE 7**SUMMARY OF MEASURED PARAMETERS
IN SUPPORT OF THE SECONDARY OBJECTIVES**

	DAY 1 (6/13/96)	DAY 2 (8/6/96)	DAY 3 (8/16/96)
Stack Gas Flow Rates	2,900 m ³ /hr	2,900 m ³ /hr	2,500 to 3,000 m ³ /hr
Reactor Temperature	520 to 580 °C 968 °F to 1076 °F	520 to 580 °C 968 °F to 1076 °F	540 to 570 °C 1004 °F to 1058 °F

m³/hr Cubic meter per hour (based on actual temperature and press conditions)

°C Degrees Celsius

°F Degrees Fahrenheit

TABLE 8A**QC RESULTS OF BLANK SPIKES / BLANK SPIKE DUPLICATES**

DAY 1					
	Benzene	Toluene	Ethylbenzene	Xylene (m + p)	Xylene (o)
BS Recovery (%)	103.3	100.8	98.7	94.7	87.9
BSD Recovery (%)	102.4	99.0	101.7	95.1	90.0
RPD (%)	0.87	1.88	3.00	0.41	2.32
DAY 2					
	Benzene	Toluene	Ethylbenzene	Xylene (m + p)	Xylene (o)
BS Recovery (%)	102.5	103.8	98.8	94.9	93.0
BSD Recovery (%)	97.5	100.9	95.6	92.7	90.3
RPD (%)	5.03	2.86	3.27	2.40	2.98
DAY 3					
	Benzene	Toluene	Ethylbenzene	Xylene (m + p)	Xylene (o)
BS Recovery (%)	106.0	101.4	96.8	92.7	89.5
BSD Recovery (%)	104.3	104.5	99.5	92.2	88.6
RPD (%)	1.55	3.02	2.83	0.54	1.08
QC Criteria					
	Benzene	Toluene	Ethylbenzene	Xylene (m + p)	Xylene (o)
Spike Recovery (%)	39 to 150	46 to 148	26 to 162	32 to 160	32 to 160
RPD (%)	56	51	68	64	64
QC	Quality control				
BS	Blank spike				
BSD	Blank spike duplicate				
RPD	Relative percent difference				

TABLE 8B**QC RESULTS OF FIELD BLANKS**

	DAY 1	DAY 2	DAY 3	QC Criteria
Benzene (mg/m ³)	<0.5	<0.5	<0.5	< MDL (0.5)
Toluene (mg/m ³)	<0.5	<0.5	<0.5	< MDL (0.5)
Ethylbenzene (mg/m ³)	<0.5	<0.5	<0.5	< MDL (0.5)
Xylene (m + p) (mg/m ³)	<0.5	<0.5	<0.5	< MDL (0.5)
Xylene (o) (mg/m ³)	<0.5	<0.5	<0.5	< MDL (0.5)

mg/m³ Milligrams per cubic meter (based on actual temperature and pressure conditions)

MDL Method detection limit

QA objectives specified in the QAPP, indicating that the data quality was good and that the data are useable as reported. There are no QC results for the stack gas velocity and volumetric flow rates, and feed and exit gas temperatures. However, the anemometer was certified by the German Federal Calibration Agency and the thermometer was checked against a certified thermometer.

2.4.3 Deviations from QAPP

For secondary objective S-2, the QAPP was not clear on whether remediation cost per m³ or per year was the desired information. In this report, the remediation cost per year was documented as it is more useful information.

The following deviations were noted in the field log book provided by Probiotec:

Day One (6/13/96): For stack gas moisture content measurement, gas was drawn for 10 minutes at 10 liters per minute (L/min). 100 milliliter (mL) flasks were used.

Day Two (8/6/96): For stack gas moisture content measurement, gas was drawn at 6 to 7 L/min. 100 mL samples were taken.

Day Three (8/13/96): For stack gas moisture content measurement, gas was drawn at 6 to 7 L/min. 100 mL samples were taken. For BTEX sampling tubes, charcoal contents were 600 mg in the front section and 300 mg in the back section.

2.4.4 Conclusions

The Züblin KNV catalytic oxidation technology evaluation conducted through the bilateral SITE evaluation program concluded that the treatment system can significantly reduce BTEX concentrations in contaminated soil gas and stripping air. During the demonstration, BTEX concentrations were consistently reduced from the 700 to 1000 mg/Nm³ range (total BTEX) to less than the detection level of 0.5 mg/Nm³ (for each compound). Overall average removal efficiencies ranged from greater than 99.9 percent for benzene to greater than 94.7 percent for ethylbenzene (see [Table 6B](#)). The calculation of a higher removal efficiency for ethylbenzene was hindered by the low concentration in untreated gas (overall average of 9.4 mg/Nm³) relative to the 0.5 mg/Nm³ detection level. Information provided by Züblin on operation of the treatment system prior to the technology demonstration indicates that total BTEX concentrations had been reduced from the 3,000 to 4,000 mg/Nm³ range to below 1 mg/Nm³, which corresponds to greater than 99 percent removal efficiency.

Specific conclusions for each primary and secondary objective are summarized below:

- The overall average removal efficiency was greater than 99.9 percent for benzene, greater than 99.8 percent for toluene, greater than 94.7 percent for ethylbenzene, greater than 99.8 percent for m- and p-xylenes, and greater 98.6 percent for o-xylene. See [Section 2.4.1.1](#) for a more detailed discussion.
- Exact values for the 95 percent upper confidence level of BTEX concentrations in treated gas were not calculated because all six sample BTEX concentrations were below the 0.5 mg/Nm³ detection level.
- Stack gas flow rates ranged from 2,500 m³/hr to 3,300 m³/hr (at actual temperature and pressure). Reactor temperatures ranged from 520 °C to 580 °C (968 °F to 1076 °F).
- The annualized remediation cost is 754,000 Deutsche Mark (DM) (US\$439,550 at 1.00 DM to US\$0.59) based on information provided by Züblin. See [Section 3.0](#) for a more detailed discussion.

SECTION 3.0

ECONOMIC ANALYSIS

Cost data are summarized [Table 9](#) and were based on information provided by Züblin. The capital cost is 3,200,000 DM (US\$1,888,000); annual operating cost, including supplemental fuel, is 425,000 DM (US\$250,750); and the annualized remediation cost (operating cost plus 10-year amortized equipment cost) is 745,000 DM (US\$439,550).

The annualized remediation cost of 745,000 DM (US\$439,550) is applicable specifically to the treatment system demonstrated at the rated capacity of 5,000 Nm³/hr in operation for 10 years. Note that 50,000 DM (US\$29,500) was included to cover supplemental fuel (propane) cost. Depending on the concentrations and heat values of VOCs in the untreated gas, supplemental fuel may not be necessary.

The initial capital cost of 3,200,000 DM (US\$188,800) was supported by the City of Duisburg, with the state of Nordrhein-Westfalen funding 80 percent of this cost. Additional costs include service and maintenance by the plant operating contractor (Züblin) and by an engineering company contracted by the City of Duisburg to provide independent oversight. A portion of the operating costs are carried by the AAV (Abfallentsorgungs- und Altlastensanierungsverband Nordrhein-Westfalen), a partnership of cities and communities in the state of Nordrhein-Westfalen that is funded by its members to carry out project management and oversight of remedial projects.

In considering this technology to a specific site, detailed evaluation of the following cost categories (Evans 1990) should be conducted:

- Site preparation
- Permitting and regulatory requirements
- Capital equipment
- Startup
- Labor
- Consumables and supplies

- Utilities
- Effluent and waste shipping and handling
- Residuals and waste shipping and handling
- Analytical services
- Maintenance and modifications
- Demobilization

TABLE 9**ANNUALIZED REMEDIATION COST**

Item	Deutsche Mark (DM)	US Dollar (US\$)
10-year amortized capital cost (includes groundwater and soil gas treatment) (based on an initial capital cost of 3,200,00 DM over an assumed equipment life of 10 years)	320,000 DM	US\$188,800
Operating costs (per year)	250,000 DM	US\$147,500
Electricity (per year)	125,000 DM	US\$73,750
Propane (per year, if needed)	50,000 DM	US\$29,500
Total Annualized Cost:	745,000 DM	US\$439,550

Cost data were based on information provided by Züblin. The exchange rate used was 1.00 DM to US\$0.59.

SECTION 4.0

TECHNOLOGY APPLICATION ANALYSIS

This section discusses the general application of the Züblin KNV catalytic oxidation technology to contaminated sites. Information presented in this section is intended to assist decision makers in screening potential technologies for specific cleanup scenarios. 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 technology evaluation results and on information provided by Entsorgungsbetriebe Duisburg on treatment system operations prior to the technology demonstration.

4.1 FEASIBILITY STUDY EVALUATION CRITERIA

This section assesses the Züblin KNV catalytic oxidation 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 Züblin KNV catalytic oxidation technology provides both short-term and long-term protection to human health and the environment by significantly reducing the concentrations of VOCs in contaminated gaseous streams. (Removal efficiency is discussed in more detail in [Section 2.0](#).) VOCs are permanently destroyed through thermal oxidation. Contaminated gas is treated to meet air emission standards and is discharged 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 Züblin KNV catalytic oxidation 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 treatment system in removing contaminants and the site-specific cleanup level.

4.1.3 Long-Term Effectiveness and Permanence

The Züblin KNV catalytic oxidation system permanently removes VOCs from gaseous streams through destruction by thermal oxidation. This permanent destruction ensures long-term effectiveness. The high removal efficiency of the treatment system was documented through this technology demonstration and also in information provided by Züblin on past operations of the treatment system.

Potential long-term risks to the treatment system workers, the community, and the environment from emissions of treated gas are mitigated by ensuring that established emissions 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 Züblin KNV catalytic oxidation technology offers permanent thermal destruction of VOCs. As such, the toxicity, mobility, and volume of contaminants are also significantly reduced.

4.1.5 Short-Term Effectiveness

The permanent thermal destruction of VOCs in gaseous streams is achieved almost instantaneously, providing for short-term effectiveness, as well as long-term effectiveness discussed in [Section 4.1.3](#). Although the residence time of the reactor was not provided by the facility owner, it is assumed that the residence time, as is typical in other thermal oxidation systems, is relatively short based on the treatment system's high flow rate (5,000 Nm³/hr).

Potential short-term risks to the treatment system workers, the community, and the environment from emissions of treated gas are mitigated by ensuring that established emission standards are met, and also by the treatment system's fail-safe controls, which will shut down the system should malfunctions occur.

4.1.6 Implementability

As discussed in [Section 1.3.1](#), the Züblin KNV catalytic oxidation system is an integral part of the stationary Entsorgungsbetriebe Duisburg soil gas and groundwater treatment facility. Because the treatment facility is a fixed facility incorporating several processes, 5 months were required from installation to operations (June to November 1994). In addition to the treatment systems themselves, supplemental civil, mechanical, and electrical structures were required to house, integrate, and control the treatment systems. Operations and maintenance of the treatment facility require technical and engineering level personnel. In applying the Züblin KNV catalytic oxidation system to a specific site, implementation can range from simple if the system

is to be used only to treat offgas from an existing treatment system (for example, from a soil vapor extraction system), to complex if the system is part of a large treatment facility with several treatment process (as in the case of this technology demonstration).

4.1.7 Cost

The annualized remediation cost of 745,000 DM (US\$439,550) is applicable specifically to the treatment system evaluated at the rated capacity of 5,000 Nm³/hr in operation for 10 years. [Section 3.0](#) contains additional discussion on cost.

4.1.8 State Acceptance

State acceptance is anticipated because the Züblin KNV catalytic oxidation system is based on thermal oxidation, a well-proven means of achieving high destruction efficiency of organic contaminants, and is considered in many cases the best available control technology. If remediation is conducted as part of Resource Conservation and Recovery Act (RCRA) corrective actions, state regulatory agencies will require that permits, such as treatment permits and air emission permits, be obtained prior to installation and operation.

4.1.9 Community Acceptance

Because the Züblin KNV catalytic oxidation system is based on thermal oxidation, nearby communities may have concerns about the perceived risks associated with by-products of thermal oxidation. However, the high removal efficiencies documented through this technology demonstration and past operational history; the short-term and long-term effectiveness achieved through permanent destruction of VOCs; and proper management and operational control of the treatment system should relieve some of the public concerns.

4.2 APPLICABLE WASTES

This technology demonstration evaluated the removal efficiencies of the Züblin KNV catalytic oxidation system for BTEX only, although total organic carbon removal efficiencies were also documented, in historical operational information provided by Züblin, to be high (greater than 99 percent, see [Table 1](#)).

The technology is applicable to VOCs in gaseous streams only. Contaminants in soil and water must be volatilized prior to treatment by the Züblin KNV catalytic oxidation system. Furthermore, if the VOCs include chlorinated compounds, the compatibility of those compounds with the catalytic bed must also be evaluated.

4.3 LIMITATIONS OF THE TECHNOLOGY

As discussed in [Section 4.2](#), the technology is limited to VOCs in gaseous streams. The treatment system will have a maximum thermal input value; thus, dilution may be necessary for gas streams containing VOCs with high heat values at high concentrations. Likewise, low VOC concentration gas streams require supplemental fuel to maintain the required reactor temperature. Additionally, the applicability of the technology to chlorinated VOCs has not yet been established.

SECTION 5.0

TECHNOLOGY STATUS

To date, the Züblin KNV catalytic oxidation system has been applied only at the Entsorgungsbetriebe Duisburg soil gas and groundwater treatment facility, where its application is at full scale. According to Züblin, the system's expected period of operation currently at the treatment facility is indefinite. Also, there are currently no commercially operating systems in the U.S. presently.

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