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S S & Industrial Services, Inc.
1345 Pearl Street • Waukesha, WI 53186 • 414-548-8040 • FAX 414-548-8049

September 29. 1995

RECEIVED
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REMEDIAL & ENFORCEMENT
RESPONSE BRANCH

Ms. Eugenia Chow
U.S.E.P.A.
Region V
77 W. Jackson Blvd.
Chicago, IL 60604-3590

Dear Ms. Chow,

During a recent meeting in Chipawa Falls, WI concerning the status of the clean-up at National Presto, you met with Rick Schultz who briefly described a newly developed technology for rapid and complete remediation of contaminated soil and groundwater. This process is known as GEO-CLEANSE and utilizes a method of injecting hydrogen peroxide to oxidize contaminants. Our company is the licensed applicator for this process in the Mid-West and have just begun treating sites in Wisconsin. We recently did our first pilot treatment at a truck stop to remediate about 9 inches of free product (gasoline and diesel fuel) floating on the groundwater and in 2 days got a reduction of contaminants to 3.3 ppb total v.o.c.'s. We are going into full remediation of this site starting October 9th. GEO-CLEANSE INTERNATIONAL, which is based in New Jersey, has successfully completed about 18 remediations, all of them successful.

At the meeting, you asked Rick to get you additional information regarding this process which is enclosed. We would very much like to meet with you soon to discuss how this process might perform at the National Presto Site, as well as any other sites you might be looking at.

Thank you for your interest, and we will be in touch.

Sincerely,

J.A. Stuart, Jr.
President

HUDSON ENVIRONMENTAL SERVICES INTRODUCES Geo-Cleanse

"There must be a cost effective way to clean up groundwater contamination without having to spend hundreds of thousands of dollars and years, even decades to do it." This is the type of response Jim Wilson of Hudson Environmental Services (Hudson) has heard expressed by many owners and operators of businesses and property over the past decade. The problem has always been once contamination has found its way into the groundwater how do you then remove it?

This problem has produced several technologies, all designed to pump the contaminated groundwater to the surface for treatment and disposal. The approach is very difficult since the contaminants (i.e., oil, gasoline, etc.) usually do not mix with water and are, therefore, not responsive to being pumped to the surface by extracting large volumes of water from the ground. For this reason groundwater cleanup programs can extend into decades and are very expensive.

A new patent pending technology developed by Hudson changes the basic approach to the remediation of soil and groundwater by destroying the contamination where it exists (in-situ). This technology has the trademark Geo-Cleanse which refers to the in-situ oxidative contaminant reduction process.

The Geo-Cleanse process was developed by Hudson as an alternative remedial approach capable of rapidly remediating soil and groundwater contaminated with organic compounds including fuel oils, gasoline, solvents, chlorinated compounds, PCBs, and other organic based contaminants. Specially designed equipment and injectors diffuse and disperse a powerful solution of oxidizers, catalysts and other non-hazardous and environmentally safe compounds to the subsurface environment. The process increases the permeability of most subsurface soils and then chemically destroys the organic contamination in the treatment region.


Andrew Kondracki, left, and Jim Wilson, right, owners of Hudson Environmental


Steam is generated as Geo-Cleanse treats a waste oil contaminated site.

This process has been successfully utilized on several sites in New Jersey with the full approval of the New Jersey Department of Environmental Protection (NJDEP) for a significantly reduced overall cost. The Geo-Cleanse process requires only a minimal disruption of the site and business operations during the short remediation process (usually several days).

Hudson, a member of the UTCA, is a full service environmental consulting, design, and remediation firm which has developed Geo-Cleanse with the goal of offering its clients a better solution. Since Hudson's founding in 1987 by Jim Wilson and Andrew Kondracki, the firm's growth and reputation have been built by offering clients innovative approaches to their environmental problems along with consistent quality service. This innovative approach to its client's problems has helped keep Hudson personnel on the cutting edge when it comes to alternative low cost remedial technologies. The company's experience has ranged from environmental site assessments and audits, tank closure and bid programs, in-situ remediation programs, and groundwater cleanup projects. Clients include various manufacturers, oil refineries, military installations, school districts and municipalities, banking institutions, and other large and small companies.

■ Background of the Problem

Industrialized society has historically stored, discharged and disposed of various hazardous substances and waste products to the soil and groundwater over the years as a normal and acceptable form of disposal. In many cases these discharges have occurred without any indication or knowledge of the facility owner or operator. These discharges from tanks, lagoons, drum storage areas, and other areas may have been discharging over many years. The end result is severe damage to the local environment which has forced companies and individuals to extend a great deal of time and financial resources to clean up the situation.

These discharged compounds have contaminated drinking water supplies, contaminated the soil and reduced the ability of these mediums to support life. The compounds are typically discharged to the environment by failures in the structural integrity of underground storage tanks and piping systems. In addition, discharges resulting from past practices of purposefully discharging hazardous compounds in open pits, on surface soils, landfills and injection wells have had an extensive and long term adverse effect on the environment.

These compounds are comprised of aromatic and aliphatic organic compounds and solvents which are also carcinogenic and have the ability to migrate to great depths in ground water, and are therefore, difficult to remediate by conventional methodologies.

Typical remedial techniques to remove soil contamination from the environment includes excavation of the contaminant and either depositing these materials in a landfill as a temporary storage of the waste, or to transport the contaminated soil to an incinerator which further degrades the quality of the air and risks exposure of these contaminants to human health and the environment. Landfilling also increases owner liability, and should the landfill require remediation or go Superfund the generators of the waste would be responsible for the cleanup.

Groundwater remediation consists mainly of "pump and treat" procedures, which are typically expensive and can require years, decades or may never return the groundwater to an acceptable condition to serve as a drinking water source. These programs and the associated technology are inherently inefficient and more advanced methodologies are required to reduce costs and address the increasing problem throughout the country.

Vents evolve steam as Geo-Cleanse destroys xylenes and phthalates in ground water.

Recent technological advances to clean up organic contamination have included various in-situ technologies which treat the contaminant in its existing location, and thus, reduce overall program costs, operational disturbances to the site, and program time frames. The major in-situ options available include fixation, bioremediation and air sparging. These programs are also limited in that they typically require lengthy periods of time to complete the remediation and may create more hazardous compounds during the conversion process or result in restrictive use of the property.

■ Description of the Geo-Cleanse Process

Hudson's Geo-Cleanse technology utilizes strong oxidizing agents and other amendments which convert various organic contaminants into harmless, naturally occurring compounds which present no harm to the environment. This process has been proven effective in remediation of "tight" soils (i.e., silts and clays) contaminated with organic contaminants.

It is important to realize that strong oxidizing compounds in the presence of organic materials can and will form explosive reactions. The Geo-Cleanse process prevents and controls the rate of reaction, and thereby, eliminates explosive reactions while rapidly destroying the organic contaminants. This program has been fully reviewed by the NJDEP, has been determined safe and has received NJDEP approval for use on contaminated sites. Hudson's engineers, geologists and scientists will obtain all the necessary governmental permits prior to initiation of any on site remedial activities and will see the program to completion. Upon completion of the remediation process, the organic contaminants are either completely converted to carbon dioxide and water or have been reduced to a level where they are below regulatory limits. Any remaining reagents from the injection program are either converted to water and oxygen or are utilized by the soil and groundwater microorganisms as a nutrient source.

Remediation of soil, contaminated with discharges of organic contaminants (i.e., fuel oil and phthalates), has also been completed with the approval and under the supervision of the NJDEP. Once the contaminant volume of soil has been defined, reagent volumes and concentrations can be determined and the remediation system can be fabricated and installed on the subject site. The Geo-Cleanse System is then mobilized to the site and the injection program is initiated. The injection program will require several days to several weeks to complete, depending upon the extent of contamination. Upon completion of the injection program, the installations and equipment will be removed from the site and the remediation program will be terminated.

A post-remedial sampling and analysis is performed to document complete removal of the contaminants. One week following the treatment, the organic contaminants will have been substantially reduced or altogether eliminated by this process. Depending on the extent of contamination, the entire program, including permitting through cleanup and final evaluation, can be completed in approximately 4-6 months.

Hudson Environmental Services is an environmental consulting and remediation firm located in Kenilworth.

The firm specializes in innovative environmental solutions. (908) 686-5959

SITE CHARACTERIZATION
SUMMARY

CASE # GK_____

DATES:______________ **REVIEWED:**________________ **RETURNED:**___________

REVIEWER:____

SITE NAME: ____

CITY:___________________________ **STATE:**_______________________________

GEO-REP: _______________________________________ #________________

CONSULTANT:_____________________________________ #_______________

PROJECT MANAGER:_________________________________ #_______________

SOURCE OF DISCHARGE:____

TYPE OF CONTAMINATION (Product): _________________________________

LNAPL ___________ DNAPL____________

Free Product: No____ Yes____; Thickness_________; SQ FT_________.

SOILS:	Depth	Soil Type	Porosity	Conductivity

COMMENTS:____

____

Note: Identify plastic clays, peats, limestone, and organic soils.

SOIL VOLUME:

*** *Note: Attach Soil Data Summary Sheet.*

____________	SQ FT
____________	CU YDS
____________	Length
____________	Width
Isopleth Depth Range ____________	FT

Highest Present Soil Contamination Levels	Soil Remediation Standards

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GROUNDWATER VOLUME:
**** Note: Attach G.W. Data Summary Sheet.*

__________ SQ FT
__________ CU YDS
__________ GALLONS
__________ Length
__________ Width

Isopleth Depth Range ____ - ____ FT

Seasonal High Water Table: __________ FT
Seasonal Water Table Fluctuation: __________ FT

Highest Present Contamination Levels	Groundwater Remediation Standards

CURRENT PROPERTY USE: ____

STRUCTURES: (Are there any manmade structures above or below ground or immediately adjacent to the area to be remediated.)
NO ______ YES _______ If yes, explain.

____
____
____
____
____

OFFSITE: Does contamination exist offsite?
NO ______ YES _______ If yes, explain.

____
____
____
____
____

Is the offsite to be remediated under this proposal?
NO ______ YES _______

CONCLUSION: __________ Complete __________ Incomplete (see checklist)
__________ Suitable __________ Unsuitable __________ Complex

Note:* *** *Attach Groundwater/Soil Data Summary Sheets and Remediation Boxes.

Rev. 9/14/95

COMMENTS/QUESTIONS:

*Note: *** Attach Groundwater/Soil Data Summary Sheets and Remediation Boxes.*

Rev. 9/14/95

GEO-CLEANSE
SITE CHARACTERIZATION
GUIDELINES

In order to propose an initial treatment protocol and price quote, Geo-Cleanse needs at least one clearly defined portion of the plume which is generally representative of the soil and groundwater conditions on the site. In order to conduct a full treatment the complete soil smear zone and plume delineation will be required.

This full or partial plume characterization must include:

____ A SITE PLAN

- A detailed site plan, showing property lines, buildings, basement pits, underground utilities, existing or former tanks, product lines, pumps or other potential sources of contamination and the identified source of discharge profile.

____ A SOIL/GEOLOGY PROFILE (See Note 1)

- A detailed scaled soil/geology cross-section throughout the full depth of the contamination. (The data must be collected by a minimum of 3 continuous split spoon samples - with continuous recovery in the AOC.

____ A CONTAMINATION PROFILE (Isopleths) (See Note 2)

- At least two graphic depictions of the outer limit of the contaminated soil area (full smear zone) and groundwater area overlayed on the soil profile (i.e., front and side view).

____ GROUNDWATER FLOW DIRECTION

- A groundwater flow contour map.

____ SAMPLING LOCATIONS AND DEPTHS

- Drawings of the location of monitoring wells and soil borings in the area of contamination shown. These are to be overlayed on the soil profile, clearly indicating depths of samples and results of the most recent sampling on the drawing.

____ SOIL LOGS

- All monitoring well construction logs, boring and test pit logs.

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___ **ISO CONCENTRATION MAPS**

- The Iso concentrations of soil and groundwater contaminants above remediation levels shown on the site plan.

___ **SOIL CONTAMINATION**

- Provide a soil data summary sheet of the latest analytical results, highlighting those results above remediation standards.

___ **CAPILLARY FRINGE**

- Provide the known or estimated capillary fringe of groundwater in the lithographic unit in which the seasonal high water terminates.

___ **SOIL QUANTITY**

- Estimate the quantity of contaminated soil remaining in the smear zone from seasonal low water table to seasonal highwater table including the capillary fringe at the seasonal high.

___ **GROUNDWATER CONTAMINATION**

- Provide a groundwater data summary sheet of the latest analytical results, highlighting those samples above remediation standards.

___ **PLUME VOLUME**

- Estimate the volume of contaminated groundwater in need of remediation in gallons (provide calculations).

___ **POROSITY/HYDRAULIC CONDUCTIVITY**

- Provide the known or estimated porosity and hydraulic conductivity of each distinct lithographic unit in the profile of the contaminated soil and groundwater area.

___ **REMEDIATION BOXES** (See Notes)

- Draw a stacked set of two rectangular remediation boxes which encompass the full extent of contaminated soil and full extent of groundwater contaminated above remediation standards (top and side views, to scale - see technical notes).

___ **GROUNDWATER CHEMISTRY**

pH ________ TOC ________ Conductivity ________

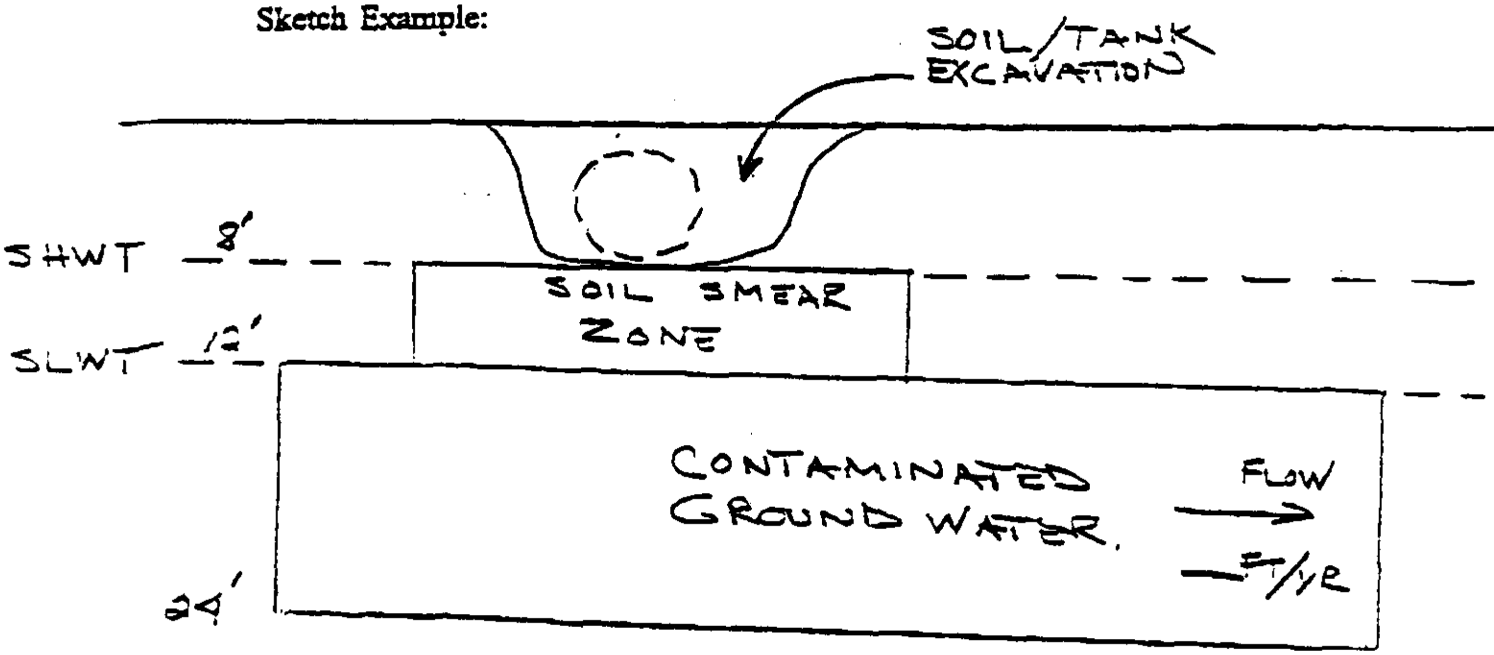
DO ________ TDS ________

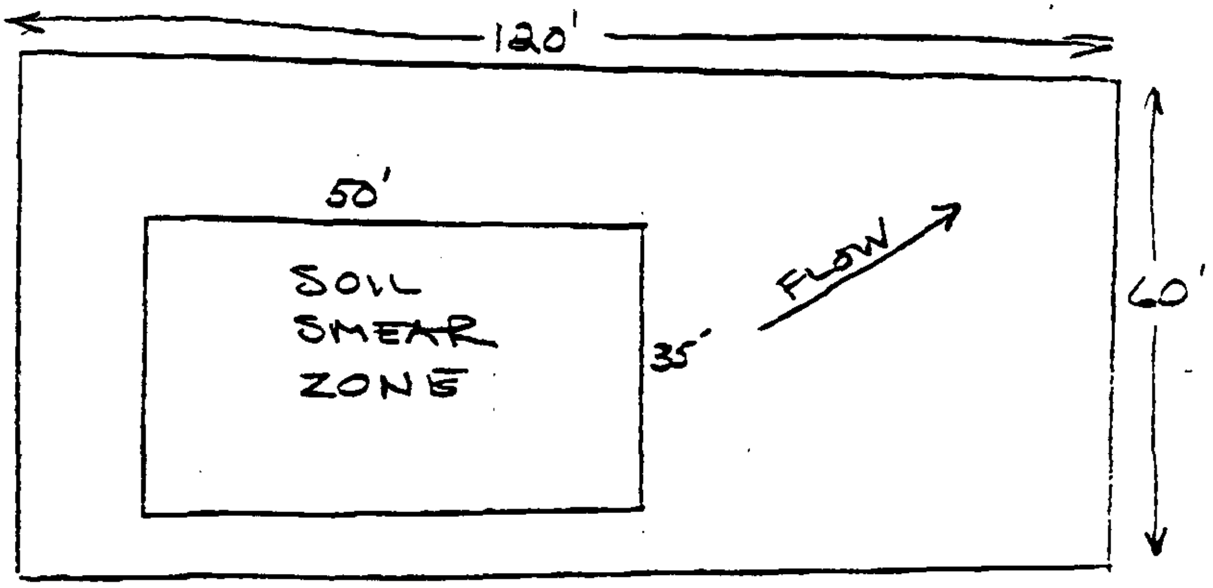
TECHNICAL NOTES

1. It is required to log continuous splitspoon soil samples in the area of contamination to be treated, to the depth of the estimated seasonal <u>low</u> water table (ie full smear zone) and through the entire thickness of the groundwater plume.

2. It is strongly recommended to Geo-Probe or bore the site on a 20 or 30' grid to define the configuration and outer limits of soil contamination.

3. Remediation Boxes -
Sketch Example:





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REMEDIAL ACTION REPORT

FOR

CHEMOS CORPORATION
225 EMMET STREET
NEWARK, NEW JERSEY

ISRA CASE #88216

SEPTEMBER 29, 1994

1.0 Introduction

The Chemos Corporation (Chemos) facility in Newark, New Jersey has been owned by Chemos since 1981 and was operated by Chemos between 1981 and 1988. Primary operations involved the manufacture of adhesives for the publishing industry. Similar operations were conducted by previous occupants dating back to the early 1900's.

The cessation of operations in 1988 triggered ECRA (now ISRA). Environmental investigations required by the New Jersey Department of Environmental Protection (the Department) since 1988 have targeted the two (2) areas of environmental concern at the site, the "Inner Court Yard" and the "Wright Street Yard", where fuel oil and raw materials were previously stored within underground storage tanks.

Significant correspondence between Chemos and the Department includes the February 25, 1988 *General Information Submission (GIS)* by Dames and Moore, the May 11, 1988 *Site Evaluation Submission (SES)* by Dames and Moore, the January 26, 1989 *Results of Sampling Plan Implementation* by Dames and Moore, the October 13, 1989 *Report of Findings* and *Site Cleanup Plan* by Groundwater Technology, Inc. (GTI), the June 22, 1990 *Revised Site Cleanup Plan* by GTI, the Department's September 21, 1990 comments to the *Revised Site Cleanup Plan*, GTI's January 1, 1991 *Addendum to the Revised Cleanup Plan*, and the Department's April 30, 1991 approval of the *Addendum to the Revised Cleanup Plan*. A more detailed chronology is included in Attachment 1.

Hudson Environmental Services, Inc. (Hudson) became the authorized environmental agent for this case in 1991. Pursuant to the April 30, 1991 approval, Hudson completed a soil excavation in the Inner Court Yard, and installed three (3) final groundwater monitoring wells; a fifty foot deep well (MW-6A) in the Wright Street Yard to provide vertical delineation, and two (2) off site wells (MW-8 and MW-9) to provide downgradient delineation. Two (2) rounds of baseline analysis groundwater sampling events ensued, and a quarterly groundwater sampling program was initiated in September 1992.

Following the fifth round of quarterly sampling, Hudson and Chemos met with the Department on August 11, 1993 to discuss the Department's precise requirements for case closure. Two (2) objectives were agreed upon; removal of free phase No. 2 heating oil in the Inner Court Yard; and reduction of di-n-butyl phthalate (DNBP) concentrations in soil and groundwater in the Wright Street Yard. Toward this end, a Remedial Action Workplan (RAW) was submitted to the Department on September 15, 1993 to propose a chemical oxidation treatment program for the DNBP impacted groundwater in the Wright Street Yard.

The Department conditionally approved of the RAW via correspondence dated December 27, 1993. Hudson addressed the Department's December 27 concerns and proposed chemical oxidation treatments for the DNBP impacted soil in the Wright Street Yard and for the No. 2 fuel oil within correspondence dated February 22 and March 4, 1994. By letter dated April 7, 1994 the Department approved of the chemical oxidation programs for the Inner Court Yard and the Wright Street Yard.

The chemical oxidation treatment programs have been completed as proposed. Post remedial sample analysis indicate that the treatments have been successful at removing the gross contamination from both areas of concern, and no further action is proposed. The results of the remediation activity are presented within sections 6.2 and 6.3 of this report. As a preface, a brief site characterization and summary of remedial investigation activity completed to date follows.

2.0 Physical Setting

A brief summary of the site characterization details follows. For further information, the reader is referred to the reports referenced within Section 1.0 of this report.

2.1 Site Description

The Chemos facility is located on Emmet Street, in Newark, Essex County, New Jersey (Location Map, Figure 1). The current tenant of the facility manufactures stainless steel containers.

2.2 Local Land Use and Topography

The Chemos facility is located in the "Ironbound District" of Newark, one of the oldest industrial areas in New Jersey. Approximately 90% of the property within one mile of the site is used for industrial or commercial purposes.

The surrounding area is flat, with little to no slope, and rests at an average elevation of 10 feet above mean sea level. The entire 0.75 acres of Chemos property is covered by building, asphalt, or concrete.

2.3 Geology and Hydrogeology

The site is underlain by sandstone and shale of the Passaic Formation; a member of the Newark Basin sedimentary deposits belonging to the Triassic Period of the geologic time scale. Above the Passaic Formation, there exists a glacial outwash deposit composed primarily of sand with lesser amounts of silt and gravel (F. C. Rodgers, et al., *Engineering Soil Survey of New Jersey*, Report No. 2, Essex County, 1951). Recent studies also suggest a lacustrine origin of the sands (White and Harper, 1991). Depth to the bedrock is expected to be approximately 80 feet (B. Nemickas, *Bedrock Topography and Thickness of Pleistocene deposits in Union County and Adjacent Areas, New Jersey*, 1974).

Site specific hydrogeology has been investigated to a total depth of 50 feet during the installation of monitoring wells at the site. Unconfined groundwater is encountered within the glacial overburden at an average depth of six feet below grade. Groundwater flow trends easterly at an average gradient of 0.003 ft/ft.

2.4 Environmental Receptors / Well Search

A well search was completed by prior consultants as part of the initial phase of site investigation. Permitted domestic supply or potable wells do not exist within a one mile radius of the facility. Salt water intrusion has been documented to have impacted industrial supply wells in the area.

3.0 Summary of Areas of Environmental Concern

Two (2) areas of environmental concern have been investigated since the initiation of the ISRA program in 1988: the Inner Court Yard and the Wright Street Yard (Site Map, Figure 2). A brief description of each area follows:

3.1 Inner Court Yard

The Inner Court Yard is approximately 60 ft. by 80 ft in size and enclosed on four sides. Five (5) underground storage tanks (USTs) formerly existed in the court yard. Methanol, toluene, butanol, No. 2 fuel oil, and methanol were stored. The methanol and No. 2 fuel oil USTs have been removed and the remaining USTs were properly abandoned.

3.2 Wright Street Yard

The Wright Street Yard is 50 ft by 70 ft in size. It is enclosed on three sides by buildings, and a loading ramp provides access on the Wright Street side. In August of 1989, three 4,000 gallon USTs were removed. The USTs formerly stored isopropyl alcohol, DNBP, and vinyl acetate.

4.0 Technical Overview

In lieu of reiterating the volumes of Quality Assurance / Quality Control (QA/QC) details that have been associated with this investigation since 1988, this section solely focuses upon the post remediation soil and groundwater sampling events. Reduced QA/QC Deliverables are included under separate cover. A sampling summary table is presented in Table 1. A brief chronology is presented below to assist the reader with the QA/QC review.

Date	Event
April 14, 1994	First Wright Street Yard injection for soil and groundwater.
April 20, 1994	First post remedial groundwater sampling event for the Wright Street Yard. Wells MW-1, 2, 6, 6A, and 5 were sampled. Also two (2) post remediation soil samples (PR-1 and PR-2) were collected from the Wright Street Yard.
April 27, 1994	Well MW-6 resampled due a determination of improper purging procedures on 4/20.
June 6, 1994	Inner Court Yard injection completed.
June 14, 1994	Second post remedial sampling event for the Wright Street Yard and first for the Inner Court Yard. Wells MW-1, 2, 3, 4, 5, 6, 6A, and 7 sampled.
July 21, 1994	Third post remedial sampling event for the Wright Street Yard and second for the Inner Court Yard. Wells MW-1, 2, 3, 4, 5, 6, 6A, and 7 sampled.

August 9, 1994	Second Wright Street Yard groundwater injection.
August 16, 1994	Final analysis of well MW-2.

The following text is presented in accordance with NJAC 7:26E-3.10(b)3 and 4.9(b)3.

4.1 Reliability of Laboratory Data

For the subject groundwater and soil sampling events, all sample jars were received from and samples returned to Veritech Laboratories of Butler New Jersey (NJ Certified Lab No. 14622) in iced coolers. QA/QC samples were collected in accordance with the May 1992 Field Sampling Procedures Manual.

The results of the post remedial soil sampling event in the Wright Street Yard are presented in Table 2. DNBP ground water concentration summary tables for the Wright Street Yard sampling events on April 20, April 27, June 14, July 21, and August 16 is presented in Table 3. Inner Court Yard trends for benzene, toluene, ethylbenzene, and total xylenes (BTEX) are presented in Table 4 and for BN+15 in Table 5.

4.1.1 Sample Holding Times

Laboratory holding times for the samples collected during the post remediation soil and groundwater sampling events were not exceeded.

4.1.2 Method Detection Limits

Method detection limits did not exceed the applicable remediation standard for DNBP concentrations in the Wright Street Yard soil sampling event.

Method detection limits did not exceed the Class II-A Groundwater Quality Criteria (N.J.A.C. 7:9-6) for DNBP concentrations in the Wright Street Yard groundwater sampling events.

Where non detect values are presented for the June 14 and July 21, 1994 groundwater sampling events for the Inner Court Yard, the Class II-A Groundwater Quality Criteria were exceeded for benzene and xylene concentrations.

4.1.3 Precision and Accuracy Criteria

Volatile organic compound (VOC) and base neutral extractable organic compound (BNC) concentrations in groundwater were respectively analyzed via EPA Methods 624+10 and 625+15. Instrument calibration summaries are found within the QA/QC Deliverables package, submitted under separate cover.

4.1.4 Treatability, Bench Scale, or Pilot Study Results

Bench tests were completed for the DNBP concentrations in soil and groundwater in the Wright Street Yard. The results indicated the contaminants were amiable to the hydrogen peroxide treatment and were discussed in a letter to the Department dated March 10, 1994.

4.1.5 Data Collected to Develop Permit Limitations

Permit limitations do not apply to this investigation.

4.1.6 Ecological Assessment Results

An ecological assessment was not completed for this site.

4.2 Sample Collection Techniques

All samples (with the exception discussed below) obtained by Hudson were collected in accordance with the Department's May 1992 Field Sampling Procedures Manual and the Technical Requirements for Site Remediation, N.J.A.C. 7:26E. All field sampling instruments were either laboratory decontaminated or new individually wrapped disposable bailers (groundwater sampling).

The purge of well MW-6 on April 20, 1994 was not completed in conformance with the May 1992 Field Sampling Procedures Manual. This error was discovered after a sampling technician noted to a project engineer that the purge line for MW-6 was not raised and lowered throughout the water column. Well MW-6 is screened from 25 to 30 ft depth and the purge only evacuated water below 20 ft. The bailer lowered into the well to collect the groundwater sample for lab analysis collected the first water encountered, which was stagnant water not impacted by the chemical oxidation program. After realization of this mishap, MW-6 was resampled on April 27, 1994.

4.3 Overall Nature of Contamination

The environmental investigation and remediation activity at this site has been completed in response to a release of No. 2 heating oil and di-butylphthalate from underground storage tank systems located in the Inner Court Yard Area and the Wright Street Court Yard Area, respectively. This remediation and resultant post remediation investigation concludes that the fuel oil related contamination has been reduced to meet the Department's site specific criteria for the Inner Court Yard. The di-n-butylphthalate exceeds Class II-A Groundwater Quality Criteria in one (1) Wright Street Yard well. However, the residual levels of this highly biodegradable compound are of low concentration and only exist in an isolated location within a non-use groundwater area.

4.4 Significant Events or Seasonal Variations

The areas of concern are capped and therefore, seasonal variations are not considered to have impacted the remediation or investigation activities.

5.0 Remedial Investigation Summary

Remedial investigation of the two (2) areas of concern was initiated in 1988. To date, ten (10) groundwater monitoring wells have been installed. The remedial investigation phase of this ISRA culminated in July 1993 after collection of the fifth round of quarterly groundwater samples. A summary of the remedial investigation activity for both areas of concern follows.

5.1 Inner Court Yard

Five USTs previously existed in the Inner Court Yard (Inner Court Yard Detail, Figure 3); three (3) have been properly abandoned and two (2) have been removed. Methanol, toluene, butanol, No. 2 fuel oil, and methanol were stored. Only No. 2 fuel oil is suspected to have leaked from the former system. The soil and groundwater investigation targeted the VOCs and BNCs related to No. 2 fuel oil.

5.1.1 Inner Court Yard Soil Conditions

Investigation of the Inner Court Yard progressed through several soil sampling events, results of which prompted a remedial soil excavation in September 1991. In accordance with the April 30, 1991 approved cleanup plan methodology, the remediation involved soil excavation to the maximum possible extent, followed by off site soil disposal. Post excavation samples were not required by the Department. The actual extent of excavation was measured by the environmental consultant at the time, GTI. However, given the structural concerns regarding soil removal adjacent to the existing buildings, it is assumed that four (4) soil samples collected by GTI in April 1989 (MW-4, IC-1, IC-2, and IC-3) represent remaining soil quality along the perimeter of the court yard. A review of base neutral compound analysis results from the four (4) samples does not reveal exceedences of cleanup guidance levels as attached in the Departments February 23, 1993 correspondence, although method detection limits were elevated above several PAH compound guidance levels. However, exceedences of the proposed total organic contaminant cleanup standard of 10,000 ppm per

NJAC 7:26D-3.2(c) exist at sample locations IC-1 and MW-4. The locations and tabulated sample analysis results are presented in Attachment 2.

The Inner Court Yard was covered with an impermeable cover on October 15, 1991. Removal of separate phase product from MW-4 was initiated in March 1992 with a hydrocarbon skimmer. Separate phase occurrences decreased significantly as a result of the soil remediation. The chemical oxidation program addressed the remaining amounts of free product as discussed in section 6.3.

5.1.2 Inner Court Yard Groundwater Conditions

The inner Court Yard was monitored with a total of three wells (MW-3, 4, and 7) for BTEX (EPA Method 624) and base/neutral extractable organics (BNCs, EPA Method 625+15) for five quarterly monitoring events by Hudson, beginning with the May 1992 event. Free phase fuel oil was sporadically encountered in MW-4 and MW-7. In general, benzene and xylene were detected above Class II-A groundwater quality criteria when free phase was not present (Table 4). The BNCs detected at the highest concentrations (Table 5), namely 1,2-dichloroethene and dichlorobenzenes, are considered to originate from an off site source. The concentrations of each of the compounds were significantly decreased by the June 6, 1994 chemical oxidation.

5.2 Wright Street Yard

In August of 1989, three 4,000 gallon USTs were removed from the Wright Street Yard area of concern (Wright Street Yard Detail, Figure 4). The USTs formerly stored isopropyl alcohol, DNBP, and vinyl acetate. During 1993, vinyl acetate and isopropyl alcohol were determined not to be present above regulatory concern. The Wright Street Yard work focuses upon the DNBP concentrations in soil and groundwater.

5.2.1 Wright Street Yard Soil Conditions

The Wright Street Yard progressed through several soil sampling events. The first samples, obtained during UST closure procedures, were retrieved too deep to represent vadose zone soil quality (i.e. retrieved from 10 ft, groundwater at 6 ft). Soil removed during UST closure was returned to the excavation above a plastic liner. An April 1990 sampling event targeted the di-n-butyl phthalate (DNBP) concentrations within the returned soil, results of which revealed exceedences of the 100 ppm impact to groundwater cleanup guidance level for DNBP with 1,600 ppm and 420 ppm in samples WC-3 and WC-4, respectively. The locations and DNBP concentrations of the subject soil samples is included in Attachment 3. In September 1992, a concrete cover of the Wright Street Yard was verbally approved by the Department and was subsequently completed by Chemos.

The DNBP in the Wright Street Yard has been addressed by the chemical oxidation program. See section 6.2.

5.2.2 Wright Street Yard Groundwater Conditions

The Wright Street Yard groundwater was monitored by eight (8) wells (MW-1, 2, 3, 5, 6, 6A, 8, & 9) for total xylenes (EPA Method 624) and DNBP (EPA Method 625) for five quarterly monitoring events by Hudson, beginning with the May 1992 event. The results of the quarterly sampling episodes indicated increasing DNBP concentrations in the wells within the Wright Street Court Yard (Table 3). During the July 8, 1993 sampling event (fifth quarterly event) monitoring wells MW-2, MW-6, and MW-6A contained opaque globules of free phase product which was visible in the purge water. The product was assumed to be DNBP, and the groundwater analysis of the affected wells was canceled. A sample of the purge water was collected for IR analysis of the product, and DNBP was confirmed. The globules were most prevalent in MW-2 and decreased in prevalence with depth.

5.3 Remedial Investigation Conclusion

In response to the DNBP conditions encountered in the Wright Street Yard, a meeting among NJDEP, Hudson Environmental Services, Inc., and Chemos Corporation personnel was held in Trenton on August 11, 1993. During the meeting, the following issues were resolved:

Elevated xylene concentrations in groundwater, which persisted in the off site well MW-5, were presented by Chemos to be attributable to an off site source. The Department agreed to review a proposal to eliminate the off site xylene monitoring. Subsequently, off site xylene concentrations were eliminated from further investigation.

By letter dated July 26, 1993, the Department disapproved of the proposed elimination of vinyl acetate and isopropyl alcohol for wells MW-8 and MW-9 from the quarterly sampling program. Subsequent to the August 11 meeting, the Department agreed to eliminate the parameters from further investigation.

Chemos proposed to submit a Remedial Action Workplan to address the only remaining contaminant concerns; fuel oil in the Inner Court Yard and DNBP in the Wright Street Yard. The remedial approach agreed to by the Department was an insitu peroxide treatment of soil and groundwater.

A proposal was submitted to the Department for remediation of the site via the use of hydrogen peroxide on September 17, 1993. The Department approved the use of the methodology by correspondence dated December 27, 1993. The remediation program was implemented on April 14, 1994. The remainder of this report presents the details of the remediation technology and the post remediation analysis results.

6.0 Findings / Remedial Action Report

The following text is presented in accordance with NJAC 7:26E-6.6.

6.1 Areas of Concern

Each of the areas of concern at the Chemos facility were addressed by the remedial investigation activity detailed in section 5.0. A remedial response to each is presented below.

Wright Street Yard; Former DNBP UST; Remedial actions were completed for this area of concern. See section 6.2.

Inner Court Yard; Former No. 2 Fuel Oil UST; Remedial actions were completed for this area of concern. See section 6.3.

6.2 Wright Street Yard Area

Remedial action was completed to address the DNBP contamination in the soil and groundwater within this area of concern as described below.

6.2.1 Overview of Remedial Action Technology

On August 11, 1993 a meeting was held in the among the Department, Chemos, and Hudson representatives to discuss the remedial approach to the DNBP conditions in the Wright Street Yard. Due to increasing concentrations of both free and dissolved phase DNBP, the groundwater sampling program was discontinued after the fifth quarterly episode. The increasing concentrations and free phase product which had begun to appear in February 1993 had increased significantly from the previous sampling episodes, and by the July 1993 event, the samples withdrawn from the Wright Street Yard well nest (wells MW-2,6, & 6A; see figure 2) contained high percentages of free product. The free product was fingerprinted by Veritech Laboratories as DNBP.

On the basis of the analytical reports for the Wright Street Yard, Chemos decided to propose an active remedial approach to address the source area soil and groundwater DNBP contamination. Since the DNBP contaminated soils were located adjacent to building structures and beneath a concrete capped surface, an in-situ remedial methodology was evaluated as the most viable and cost effective approach to the problem.

Initially bioremediation coupled with a traditional pump and treat program was considered, but due to length of time and cost associated with this approach, Chemos elected to utilize Fenton's Reagent Chemistry to physically oxidize the DNBP in the soil and groundwater. Hudson developed the methodology which is based on extensive studies and established treatment methodologies utilized by the waste water treatment industry. Details of the proposed remediation were presented in the RAW submitted to the Department on September 15, 1993 and February 22, 1994. By letter dated April 7, 1994 the Department approved of the chemical oxidation program for the Wright Street Yard. A brief recap of the submittals follows:

In the waste water industry, hydrogen peroxide is employed as an additive to breakdown organic contaminants into simple organic compounds which can be completely degraded (mineralized) by the microorganisms to carbon dioxide and water. The problem with utilizing this process to mineralize organic contaminants in groundwater, is the requirement for an intimate dispersion of the reagents throughout the affected groundwater region.

It was proposed during our meeting with the NJDEPE on Aug. 11, 1993, that a chemical oxidation of DNBP be explored through the use of peroxide formulation technology. The peroxide formulation process is capable of initiating and propagating Fenton's reaction to effect complete oxidation of organic contaminants to carbon dioxide and water (see reaction sequence below).

Fenton's Chemistry

H_2O_2 +	Fe^{+2} ----->	$OH\cdot$ +	OH^- +	Fe^{+3}	**Fenton's Reaction**
hydrogen peroxide	ferrous ion	hydroxyl free radical	hydroxyl ion	ferric iron	

Organic Reaction Sequence

Hydrogen Peroxide + Organic Contaminant ---> Carbon Dioxide + Water
(Hydroxyl free radical)

The chemical equation shown above illustrates the preferred sequence for the destruction of the organic compounds and the reaction sequence illustrates the hydrogen peroxide conversion of organic materials when taken to completion. During the reaction sequence, the organic compounds are successively converted to shorter chain mono- and di-carboxylic acid intermediates. These compounds are non-hazardous, high boiling point, naturally occurring substances which are further degraded by the process to carbon dioxide and water.

Injector System

To overcome the difficulties associated with dispersing the reagents through a "tight" aquifer, as in the Chemos case, a sealed subsurface mixing head was coupled to a sparging apparatus to permit circulation of the groundwater in the affected region and to utilize the injected air as a carrier for the peroxide. The system is designed to operate at high temperatures and pressures. The high temperature and pressure created in the subsurface environment are necessary to disperse and diffuse the reagents into the affected region. The pressures that are created and maintained during the injection program may promote fractures or channeling in the subsurface environment in a similar fashion to the fractures created during pneumatic fracturing which is utilized in Soil Vapor Extraction (SVE) remedial techniques. In this process, the fractures will assist in dispersion and circulation of the reagents through the region, with the fractures being less likely to collapse as in the case of vacuum extraction pressures applied in SVE designs. The heat of reaction generated by the process will create temperature gradients in the subsurface region which will also assist in the diffusion of the reagents through the aquifer. The effectiveness of the system would be extremely limited if the reagents were injected to groundwater via the use of the standard monitoring well designs. The injector system utilized in the Chemos project has the potential for dispersing other reagents and amendments to the subsurface region and is currently being processed for patent protection.

6.2.2 Remedial Action Completed for Soil

The first phase of the soil remediation comprised a bench test of soil from boring area WC-3 (previously tested and showing 1600 mg/kg of DNBP). Hydrogen peroxide, catalyst concentrations and pH ratio were determined and optimized prior to treatment of the DNBP affected region.

Upon completion of the bench tests and soil injector designs, the injectors were installed on March 30, 1994 (Wright Street Yard Injector Locations, Figure 5). Assumptions were that the volume of contaminated soil was approximately 370 cubic yards (1350 sq. ft. area by 7 foot depth to water) and that the contamination was uniformly distributed throughout the entire volume at a level of 1600 mg/kg (worst case level found in boring area WC-3). The quantity of DNBP in both the free phase capillary region and in the soil was estimated at approximately 2000 pounds. This was the basis for determining the stoichiometric ratio of hydrogen peroxide to DNBP for complete mineralization (39:1 molar ratio).

The soil remediation treatment program was initiated on April 11, 1994 prior to the groundwater treatment to eliminate the source of groundwater contamination. The treatment was initiated by injecting an aqueous mixture of 50% hydrogen peroxide in a pH solution of approximately 5.0 through the sealed mixing head injector. The reaction was immediately initiated as indicated by the evolution of steam emanating through ports cut through the concrete cap. The stream which is a byproduct of the reaction, was immediately screened with a PID to determine if there were any volatile organic compounds present in the gas stream. The results indicated no PID readings in the gas, as anticipated by the chemical reaction sequence. This was later confirmed by representatives of the Department during a site inspection and evaluation on April 13, 1994. The injection was completed with 18 x 55 gallon drums of 50% hydrogen peroxide injected through six (6) equally constructed soil injectors. Each injector mixed the peroxide with the aqueous based solution and dispersed the mixture into the soil. The reaction was considered complete upon addition of the required stoichiometric ratio of hydrogen peroxide and a reduction in the evolution of steam from the vents.

On August 9-10 a second hydrogen peroxide treatment (Additional Wright Street Yard Injector Locations, Figure 6) was performed on the soil following an increase in DNBP concentrations in the shallow groundwater (MW-2). This increase was attributable to residual quantities of DNBP in the soil inside the building beneath the former DNBP transfer pump. The source was discovered by collecting soil samples below the concrete floor and by performing soil-water agitation field tests. This procedure was also performed in other areas surrounding the treatment region but the results indicated no residual contamination present. The likely reason for the residual DNBP remaining in the area may have been due to the plastic sheeting which was placed against the wall before backfilling the excavation with the contaminated soil and/or the barrier created by the building foundation preventing the diffusion of the hydrogen peroxide beneath the building. The second treatment was conducted by injecting 10 x 55 gallon drums of 50% hydrogen peroxide solution, in an aqueous mix, in the area shown in figure 2.

6.2.3 Remedial Action Completed for Groundwater

Due to the continuing and increasing presence of DNBP in the groundwater (both free product and dissolved phase), Chemos proposed a groundwater injection system to oxidize the DNBP utilizing hydrogen peroxide. The groundwater removed from the monitoring wells within the Wright Street Court Yard during the July 1993 sampling event exhibited free phase globules of DNBP and had a "milky white" appearance. Groundwater sampling had been discontinued after the July 1993 event and the hydrogen peroxide injection program was proposed.

The program was designed for two groundwater injectors to disperse hydrogen peroxide and other reagents to the groundwater (Figure 5). There were originally two injectors installed but due to silt fouling one of the injectors was rendered inoperable. The viable injector system (described above) was installed within the Wright Street Court Yard, in an area previously occupied by the DNBP UST. The injector was screened from a depth of 30-35 feet, which corresponds to the depth of monitoring well MW-6. This depth was chosen to permit greater fracturing and better circulation over a shallow injector installation and the location was considered to be within the source area.

Following the installation of the injector and treatment of the soil, 6 x 55 gallon drums of 50% hydrogen peroxide were injected into the groundwater with the sparger system and aqueous pH adjusted mixture. The injection program was completed on April 14, 1994. A second treatment was conducted on August 9-10, 1994 due to increasing concentrations of DNBP found in the post remedial analysis. A residual "pocket" of DNBP contaminated soil was the cause of the increasing concentration and following the second soil treatment program, an additional 5 x 55 gallon drums of 50% hydrogen peroxide solution with the other required amendments was added to groundwater via the injection system.

6.2.4 Applicable Remediation Standards and Post Remediation Results

The source area of concern was the backfilled DNBP contaminated soil surrounding the former UST and the transfer pump located on the inside wall adjacent to the Wright Street Yard. The applicable remediation standard for DNBP of 100 ppm in soil is contained in the Department's current guidelines for "impact to groundwater". The Department's Groundwater Quality Criteria for Class II-A areas is 900 ppb for DNBP. These were the remedial design objectives for the Wright Street Yard remediation program.

The results of the post remediation evaluation program indicated a maximum concentration of 2.6 ppm of DNBP in the area soil (Table 2), which is below the Department's most stringent guidelines for this contaminant in soil. Chemos proposes no further action with regard to the Wright Street Yard soil.

The results of the post remediation evaluation of the Wright Street Yard groundwater indicate that the hydrogen peroxide injection program has successfully eliminated the free phase DNBP (Table 3). In addition, the program has reduced the concentration of DNBP in the affected area in monitoring wells MW-1, 5, 6, and 6A to concentrations below the Department's Groundwater Quality Criteria for Class II-A (potable water) areas. The only monitoring well with concentrations above the Department's standards is the shallow monitoring well (MW-2).

The concentration of DNBP in MW-2 is 3.000 ppb with no free product present and source area soil below impact to groundwater standards. The exceedance in the shallow monitoring well is confined to a limited area within the boundaries of the site. The compound is considered to be highly biodegradable under aerobic conditions. The oxygen levels in the area groundwater are currently elevated due to the hydrogen peroxide injected during the remediation program, and therefore, the compounds are likely to degrade to below regulatory standards. The impacted groundwater is in a non-use area and has not been detected off site above regulatory concern. The residual contaminants do not pose a threat to human health or the environment.

6.2.5 Proposed Action for Wright Street Yard

Chemos requests no further action for soil and groundwater conditions in the Wright Street Yard and proposes to seal the Wright Street Yard monitoring wells.

6.3 Inner Court Yard Area

Remedial action was completed to address this area of concern as described below.

6.3.1 Remedial Action Completed

Chemos personnel have inspected the hydrocarbon skimmers in the Inner Court Yard wells on a weekly schedule. Free product accumulations of oil have not been reported in MW-4 since December of 1993. In order to address the residual oil which may have been present beneath the building, which was not removed during the soil removal program, a peroxide injection was performed in the Inner Court Yard Area on June 6, 1994.

The program involved the installation of one soil injector system which was located approximately 10 feet south of monitoring well MW-4 (Inner Court Yard Injector Location, Figure 7). The same treatment process described for the Wright Street Yard was utilized for the Inner Court Yard. The reagents used in the injection program involved 5 x 55 gallon drums of 50% hydrogen peroxide in an aqueous based solution with a pH of 5.0. The injection produced steam which emanated from a vent installed in the adjacent loading dock area. The steam was screened with a PID with no volatile organic compounds found to be present in the gas.

6.3.2 Applicable Remediation Standards and Post Remediation Results

The purpose of the Inner Court Yard remediation was to reduce the amount of free phase No. 2 heating oil in the area. Based upon the absence of free product in well MW-4 and the results of the post remedial groundwater sampling events (Tables 4 and 5), this objective has been achieved.

6.3.3 Proposed Action for Inner Court Yard

No further action is requested for the Inner Court Yard area of concern and each of the Inner Court Yard wells are proposed to be sealed.

6.4 Summary of All Remedial Costs Incurred to Date

The following estimated costs have been incurred since the initiation of this ISRA in 1988:

Tank Removal and Disposal Fees	$11,945.00
Consulting Costs and Labor Costs	
(Engineers, Hydrogeologists, Draftsman, & Technicians)	$282,264.16
Analytical Costs	$86,955.23
Subcontractor Costs	
soil boring and drill rig subcontractors	$3,869.00
excavator and loader subcontractors	$11,875.00
land survey subcontractors	$2,234.00
Off Site Soil Disposal Fees	$7,627.00
Chemical Oxidation Treatment Program	$15,224.00
NJDEP Fees	$23,850.61
Miscellaneous	
equipment rental, express mail, fees, etc.	$24,816.89
total costs incurred	$470,660.89

7.0 Effectiveness Analysis and Certification

An analysis and certification is required to verify that the completed remedial actions meet the criteria contained in Section 35(g) of P.L. 1993, c.139. In the case of this site, remedial action was necessary to address soil and groundwater contamination associated with No. 2 fuel oil and DNBP. Remedial action was completed via chemical oxidation. The following discussion addresses the certification and analysis of this completed remedial action.

The initial screening of the remedial alternatives considered the effectiveness, implementability, timeliness, and cost of each. By applying these controlling factors to the technologies available to remediate DNBP and fuel oil contamination, chemical oxidation was chosen as the most cost effective alternative.

The chosen remedial alternative is considered an effective on site remedial technique for the subject contaminants. Further evaluation of this alternative for; its ability to reduce toxicity, mobility or volume, employ reuse or recycling, ability to address threats to human health and the environment, implementability, long term effectiveness, short term effectiveness, cost, and community concerns, all prove favorable. Application of this chemical oxidation technology has reduced the contaminants to levels which are considered protective of human health and the environment for this industrial area of Newark.

TABLES

TABLE 1
POST REMEDIAL SAMPLING SUMMARY TABLE

FOR

CHEMOS CORPORATION

LOCATION	MATRIX	SAMPLE DEPTH	ANALYTICAL PARAMETERS	SAMPLING METHOD	DATE
PR-1	soil	6.5-7'	BN+15	Sp/Tr	4/20/94
PR-2	soil	6.5-7'	BN+15	Sp/Tr	4/20/94
MW-1	water	water table	BN+15	bailer	4/20/94
MW-2	water	water table	BN+15	bailer	4/20/94
MW-5	water	water table	BN+15	bailer	4/20/94
MW-6	water	water table	BN+15	bailer	4/20/94
MW-6A	water	water table	BN+15	bailer	4/20/94
MW-6	water	water table	Di-N-Butyl Phthalate	bailer	4/27/94
MW-1	water	water table	Di-N-Butyl Phthalate	bailer	6/14/94
MW-2	water	water table	Di-N-Butyl Phthalate	bailer	6/14/94
MW-3	water	water table	BN+15, BTEX	bailer	6/14/94
MW-4	water	water table	BN+15, BTEX	bailer	6/14/94
MW-5	water	water table	Di-N-Butyl Phthalate	bailer	6/14/94
MW-6	water	water table	Di-N-Butyl Phthalate	bailer	6/14/94
MW-6A	water	water table	Di-N-Butyl Phthalate	bailer	6/14/94
MW-7	water	water table	BN+15, BTEX	bailer	6/14/94
MW-1	water	water table	Di-N-Butyl Phthalate	bailer	7/21/94
MW-2	water	water table	Di-N-Butyl Phthalate	bailer	7/21/94
MW-3	water	water table	BN+15, BTEX	bailer	7/21/94
MW-4	water	water table	BN+15, BTEX	bailer	7/21/94
MW-5	water	water table	Di-N-Butyl Phthalate	bailer	7/21/94
MW-6	water	water table	Di-N-Butyl Phthalate	bailer	7/21/94
MW-6A	water	water table	Di-N-Butyl Phthalate	bailer	7/21/94
MW-7	water	water table	BN+15, BTEX	bailer	7/21/94
MW-2	water	water table	Di-N-Butyl Phthalate	bailer	8/16/94
Field Blank	water	water table	BN+15	bailer	4/20/94
Field Blank	water	water table	BN+15, BTEX	bailer	6/14/94
Trip Blank	water	water table	BTEX	bailer	6/14/94
Feild Blank	water	water table	BN+15, BTEX	bailer	7/21/94
Trip Blank	water	water table	BTEX	bailer	7/21/94
Field Blank	water	water table	Di-N-Butyl Phthalate	bailer	8/16/94

Sp/Tr = SAMPLE COLLECTED WITH A STAINLESS STEEL SPOON FROM A BOREHOLE ADVANCED WITH A TRIER.

TABLE 2

WRIGHT STREET YARD POST REMEDIAL SOIL SAMPLE ANALYSIS RESULTS

FOR

CHEMOS CORPORATION

RESULTS REPORTED IN mg/kg
(PARTS PER MILLION)

			SAMPLE LOCATION	WRIGHT STREET YARD	
			FIELD SAMPLE IDENTIFICATION	PR-1	PR-2
			LAB SAMPLE IDENTIFICATION	AA22686	AA22687
			SAMPLE DATE	4/20/94	4/20/94
			SAMPLE DEPTH	6.5-7'	6.5-7'
	NJDEPE SOIL CLEANUP CRITERIA				
PARAMETER (UNITS)	RESIDENTIAL DIRECT CONTACT	NON-RESIDENTIAL DIRECT CONTACT	IMPACT TO GROUNDWATER		
BASE NEUTRALS (ppm)					
DILUTION FACTOR				333	167
MDL A - LOWEST				0.72	0.37
MDL B - HIGHEST				3.6	1.8
N-Nitrosodimethylamine	Not Published	Not Published	Not Published	ND < 1.8	ND < 0.92
Pyridine	Not Published	Not Published	Not Published	ND < 1.8	ND < 0.92
Bis(-2-Chloroethyl)Ether	0.66	3	10	ND < 1.8	ND < 0.92
1,3-Dichlorobenzene	5100	10000	100	ND < 1.8	ND < 0.92
1,4-Dichlorobenzene	570	10000	100	1.3 J	0.55 J
Benzyl Alcohol	10000	10000	50	ND < 1.8	ND < 0.92
1,2-Dichlorobenzene	5100	10000	50	2.1	1.5
Bis(-2-Chloroisopropyl)ether	2300	10000	10	ND < 1.8	ND < 0.92
N-Nitroso-Di-n-propylamine	0.66	0.66	10	ND < 1.8	ND < 0.92
Hexachloroethane	6	100	100	ND < 1.8	ND < 0.92
Nitrobenzene	28	520	10	ND < 1.8	ND < 0.92
Isophorone	1100	10000	50	ND < 1.8	ND < 0.92
Benzoic Acid	Not Published	Not Published	Not Published	ND < 3.6	ND < 1.8
Bis(-2-Chloroethoxy)Methane	Not Published	Not Published	Not Published	ND < 1.8	ND < 0.92
1,2,4-Trichlorobenzene	68	1200	100	ND < 1.8	ND < 0.92
Naphthalene (PAH)	230	4200	100	ND < 1.8	1.1
4-Chloroaniline	230	4200	Not Published	ND < 1.8	ND < 0.92
Hexachlorobutadiene	1	21	100	ND < 1.8	ND < 0.92
2-Methylnaphthalene	Not Published	Not Published	Not Published	ND < 1.8	0.19 J
Hexachlorocyclopentadiene	400	7300	100	ND < 1.8	ND < 0.92
2-Chloronaphthalene	Not Published	Not Published	Not Published	ND < 1.8	ND < 0.92
2-Nitroaniline	Not Published	Not Published	Not Published	ND < 1.8	ND < 0.92
Dimethyl Phthalate	10000	10000	50	ND < 1.8	ND < 0.92
Acenaphthylene (PAH)	Not Published	Not Published	Not Published	ND < 1.8	ND < 0.92
3-Nitroaniline	Not Published	Not Published	Not Published	ND < 1.8	ND < 0.92
Acenaphthene (PAH)	3400	10000	100	ND < 1.8	ND < 0.92
Dibenzofuran	Not Published	Not Published	Not Published	ND < 1.8	ND < 0.92
2,4-Dinitrotoluene	1	4	10	ND < 1.8	ND < 0.92
2,6-Dinitrotoluene	1	4	10	ND < 1.8	ND < 0.92
Diethylphthalate	10000	10000	50	ND < 1.8	ND < 0.92
4-Chlorophenyl-phenylether	Not Published	Not Published	Not Published	ND < 1.8	ND < 0.92
Fluorene (PAH)	2300	10000	100	ND < 1.8	ND < 0.92
4-Nitroaniline	Not Published	Not Published	Not Published	ND < 1.8	ND < 0.92
N-Nitrosodiphenylamine	140	600	100	ND < 1.8	ND < 0.92
4-Bromophenyl-phenylether	Not Published	Not Published	Not Published	ND < 1.8	ND < 0.92
Hexachlorobenzene	0.66	2	100	ND < 1.8	ND < 0.92
Phenanthrene (PAH)	Not Published	Not Published	Not Published	ND < 1.8	ND < 0.92
Anthracene (PAH)	10000	10000	100	ND < 1.8	ND < 0.92
Di-n-Butylphthalate	5700	10000	100	2.6	2.2
Fluoranthene (PAH)	2300	10000	100	ND < 1.8	0.35 J
Pyrene (PAH)	1700	10000	100	ND < 1.8	0.31 J
Benzidine	Not Published	Not Published	Not Published	ND < 3.6	ND < 1.8
Butylbenzylphthalate	1100	10000	100	ND < 1.8	ND < 0.92
3,3'-Dichlorobenzidine	2	6	100	ND < 1.8	ND < 0.92
Benzo(a)Anthracene (PAH)	0.9	4	500	ND < 1.8	ND < 0.92
Bis(2-Ethylhexyl)Phthalate	49	210	100	ND < 1.8	2.4
Chrysene (PAH)	9	40	500	ND < 1.8	ND < 0.92
Di-n-octyl phthalate	1100	10000	100	ND < 1.8	ND < 0.92

TABLE 2 (CONT.)

WRIGHT STREET YARD POST REMEDIAL
SOIL SAMPLE ANALYSIS RESULTS

FOR

CHEMOS CORPORATION

RESULTS REPORTED IN mg/kg
(PERTS PER MILLION)

			SAMPLE LOCATION	WRIGHT STREET YARD	
			FIELD SAMPLE IDENTIFICATION	PR-1	PR-2
			LAB SAMPLE IDENTIFICATION	AA22686	AA22687
			SAMPLE DATE	4/20/94	4/20/94
			SAMPLE DEPTH	6.5-7'	6.5-7'
	NJDEPE SOIL CLEANUP CRITERIA				
PARAMETER (UNITS)	RESIDENTIAL DIRECT CONTACT	NON-RESIDENTIAL DIRECT CONTACT	IMPACT TO GROUNDWATER		
BASE NEUTRALS (cont.)					
Benzo(b)Fluoranthene (PAH)	0.9	4	50	ND < 1.8	ND < 0.92
Benzo(k)Fluoranthene (PAH)	0.9	4	500	ND < 0.72	ND < 0.37
Benzo(a)Pyrene (PAH)	0.66	0.66	100	ND < 1.8	ND < 0.92
Indeno(1,2,3-cd)Pyrene (PAH)	0.9	4	500	ND < 1.8	ND < 0.92
Dibenzo(a,h)Anthracene (PAH)	0.66	0.66	100	ND < 1.8	ND < 0.92
Benzo(g,h,i)Perylene (PAH)	Not Published	Not Published	Not Published	ND < 1.8	ND < 0.92
TENTATIVELY IDENTIFIED BASE NEUTRAL COMPOUNDS (TICs)					
Unknown				73.63	36.922
Benzene, 1,2,3-trimethyl-				5.92	2.968
Octadecane, 2,6-dimethyl-				2.96	1.484
Hexadecanoic acid				4.44	2.226
15-Tetracosenoic acid, methy				210.9	105.766
Tetradecanoic acid				51.8	25.977
Phosphonic acid, tris(2-ethy				7.03	3.525
BN TARGETED TOTAL				6	8.6
BN TICs TOTAL				356.68	178.868
BN + 15 TOTAL				362.68	187.468

ANALYTICAL METHOD:
BASE NEUTRALS - EPA METHOD 8270.

NOTE:
NA - NOT ANALYZED.
ND - INDICATES COMPOUND WAS ANALYZED FOR BUT NOT DETECTED ABOVE METHOD DETECTION LIMIT (MDL).
J - INDICATES AN ESTIMATED VALUE USED WHEN A COMPOUND IS DETECTED AT LESS THAN THE SPECIFIED MDL.
B - INDICATES COMPOUND IS ALSO PRESENT IN BLANK.

TABLE 3

WRIGHT STREET YARD GROUNDWATER
DI-N-BUTYL PHTHALATE ANALYSIS RESULTS

FOR

CHEMOS CORPORATION

RESULTS REPORTED IN ug/l (PPB)

WELL NUMBER	MW-1	MW-2	MW-5	MW-6	MW-6A
WELL DEPTH	17.5'	19'	20'	30'	50'
INTERVAL OF SCREEN	2.5-17.5'	4-19'	5-20'	25-30'	40-50'
SAMPLE DATE					
28-May-92	2	2	96	9200	8700
19-Aug-92	2	250	63	8800	2700
2-Dec-92	ND<5	220	ND<5	950	120
23-Feb-93	ND<5	61000	14	46000	42
8-Jul-93	ND<4	NT	30	NT	NT
11,14-Apr-94	FIRST PEROXIDE REMEDIAL TREATMENT PROGRAM				
20-Apr-94	44	250	ND<50	35000	38
27-Apr-94				4500 (repeat smpl)	
14-Jun-94	ND<10	1800	80	8800	ND<10
21-Jul-94	ND<3	13000	16	190	14
9,10-Aug-94	SECOND PEROXIDE REMEDIAL TREATMENT PROGRAM				
17-Aug-94		3000			

ANALYTICAL METHOD: BASE/NEUTRALS EPA METHOD 625.

NOTE: ND-INDICATES COMPOUND WAS ANALYZED FOR BUT NOT DETECTED ABOVE THE METHOD DETECTION LIMIT (MDL).

J-INDICATES ESTIMATED VALUE USED WHEN A COMPOUND IS DETECTED AT LESS THAN THE SPECIFIED DETECTION LIMIT.

B-INDICATES COMPOUND IS ALSO PRESENT IN THE BLANK.

NT-NOT TESTED, FREE PRODUCT SAMPLE COLLECTED.

TABLE 4

INNER COURTYARD GROUNDWATER
BENZENE, TOLUENE, ETHYLBENZENE, AND TOTAL XYLENE ANALYSIS RESULTS

FOR

CHEMOS CORPORATION

RESULTS REPORTED IN ug/l (PPB)

WELL NUMBER	MW-3				MW-4				MW-7			
WELL DEPTH	19'				19'				18'			
INTERVAL OF SCREEN	4-19'				4-19'				3-18'			
SAMPLE DATE	B	T	E	X	B	T	E	X	B	T	E	X
28-May-92	NA	NA	NA	NA	80	ND	90	370	NT	NT	NT	NT
19-Aug-92	ND	2	2	ND	NT	NT	NT	NT	NT	NT	NT	NT
2-Dec-92	ND<5	ND<5	ND<5	ND<5	NT	NT	NT	NT	NT	NT	NT	NT
23-Feb-93	ND<5	ND<5	ND<5	ND<5	73J	1900	74J	290J	ND<25	11J	77	91
8-Jul-93	ND<2	ND<2	ND<2	ND<2	NT	NT	NT	NT	ND<20	28	65	140
6-Jun-94	PEROXIDE TREATMENT COMPLETED											
14-Jun-94	ND<1	ND<2	ND<2	ND<2	ND<100	220	ND<200	ND<200	ND<100	ND<200	190J	290J
21-Jul-94	ND<1	ND<1.6	ND<1.9	ND<2.7	ND<200	500	ND<380	ND<780	99	160	280	520

ANALYTICAL METHOD: VOLATILE ORGANICS - EPA METHOD 624.

NOTE: ND - INDICATES COMPOUND WAS ANALYZED FOR BUT NOT DETECTED ABOVE METHOD DETECTION LIMITS (MDL).

NT - NOT TESTED DUE TO FREE PHASE PRODUCT IN WELL.

NA - NOT ANALYZED FOR BTEX.

J - INDICATES AN ESTIMATED VALUE USED WHEN A COMPOUND IS DETECTED AT LESS THAN THE SPECIFIED DETECTION LIMIT.

B - INDICATES COMPOUND IS ALSO PRESENT IN THE BLANK.

E - INDICATES THE ANALYTE CONCENTRATION EXCEEDS THE CALIBRATION RANGE OF THE GC/MS INSTRUMENT FOR THAT SPECIFIC ANALYTE.

TABLE 5

INNER COURTYARD GROUNDWATER
B/N + 15 ANALYSIS RESULTS

FOR

CHEMOS CORPORATION

		FIELD SAMPLE IDENTIFICATION	MW-3	MW-4	MW-7	FIELD BLNK	MW-3	MW-4	MW-7	FIELD BLANK
RESULTS REPORTED IN ug/l (PARTS PER BILLION)		LAB SAMPLE IDENTIFICATION	AA24267	AA24269	AA24268	AA24270	AA25056	AA25058	AA25057	AA25059
		SAMPLE DATE	5/14/94	5/14/94	5/14/94	5/14/94	7/21/94	7/21/94	7/21/94	7/21/94
		DEPTH OF WELL	19'	19'	18'	-	19'	19'	18'	-
		INTERVAL OF SCREEN	4-19'	4-19'	3-18'	-	4-19'	4-19'	3-18'	-
PARAMETER (UNITS)	GROUNDWATER CLASS II-A QUALITY CRITERIA	PRACTICAL QUANTITATION LEVEL								
BASE NEUTRALS (ppb)										
DILUTION FACTOR			2	20	2	2	4	4	2	2
VOL A - LOWEST			4	40	4	4	2.5	2.6	1.3	1.3
VOL B - HIGHEST			20	200	20	20	40	40	20	20
N-Nitrosodimethylamine	0.0007	20	ND < 10	ND < 100	ND < 10	ND < 10	ND < 3	ND < 3	ND < 1.5	ND < 1.5
Pyridine	Not Published	Not Published	ND < 10	ND < 100	ND < 10	ND < 10	ND < 20	ND < 20	ND < 10	ND < 10
Bis(-2-Chloroethyl)Ether	0.03	10	ND < 10	ND < 100	ND < 10	ND < 10	ND < 4.8	ND < 4.8	ND < 2.4	ND < 2.4
1,3-Dichlorobenzene	600	5	ND < 10	ND < 100	10 J	ND < 10	ND < 11	ND < 11	ND < 5.3	ND < 5.3
1,4-Dichlorobenzene	75	5	ND < 10	ND < 100	19	ND < 10	ND < 12	ND < 12	12	ND < 6
Benzyl Alcohol	2000	Not Available	ND < 10	ND < 100	ND < 10	ND < 10	ND < 2.8	ND < 2.8	ND < 1.4	ND < 1.4
1,2-Dichlorobenzene	600	5	ND < 10	130	15	ND < 10	ND < 11	59	14	ND < 5.5
Bis(2-Chloroisopropyl)Ether	300	10	ND < 10	ND < 100	ND < 10	ND < 10	ND < 6.8	ND < 6.8	ND < 3.4	ND < 3.4
N-Nitrosodi-n-propylamine	0.005	20	ND < 10	ND < 100	ND < 10	ND < 10	ND < 3.9	ND < 3.9	ND < 1.9	ND < 1.9
Hexachloroethane	0.7	10	ND < 10	ND < 100	ND < 10	ND < 10	ND < 13	ND < 13	ND < 6.6	ND < 6.6
Nitrobenzene	3	10	ND < 10	ND < 100	ND < 10	ND < 10	ND < 3.5	ND < 3.5	ND < 1.7	ND < 1.7
Isophorone	100	10	ND < 10	ND < 100	ND < 10	ND < 10	ND < 3.8	ND < 3.8	ND < 1.9	ND < 1.9
Benzoic Acid	Not Published	Not Published	ND < 20	ND < 200	ND < 20	ND < 20	ND < 40	ND < 40	ND < 20	ND < 20
Bis(2-Chloroethoxy)Methane	Not Published	Not Published	ND < 10	ND < 100	ND < 10	ND < 10	ND < 5.2	ND < 5.2	ND < 2.6	ND < 2.6
1,2,4-Trichlorobenzene	3	1	13 J	ND < 100	7 J	ND < 10	ND < 10	ND < 10	ND < 5.2	ND < 5.2
Naphthalene (PAH)	Not Published	Not Published	ND < 10	110	ND < 10	ND < 10	ND < 8.4	77	ND < 4.2	ND < 4.2
4-Chloroaniline	Not Published	Not Published	ND < 10	ND < 100	ND < 10	ND < 10	ND < 20	ND < 20	ND < 10	ND < 10
Hexachlorobutadiene	1	1	ND < 10	ND < 100	ND < 10	ND < 10	ND < 15	ND < 15	ND < 7.4	ND < 7.4
2-Methylnaphthalene	Not Published	Not Published	ND < 10	350	ND < 10	ND < 10	ND < 8	38	ND < 4	ND < 4
Hexachlorocyclopentadiene	50	10	ND < 10	ND < 100	ND < 10	ND < 10	ND < 13	ND < 13	ND < 6.4	ND < 6.4
2-Chloronaphthalene	Not Published	Not Published	ND < 10	ND < 100	ND < 10	ND < 10	ND < 8.4	ND < 8.4	ND < 4.2	ND < 4.2
2-Nitroaniline	Not Published	Not Published	ND < 10	ND < 100	ND < 10	ND < 10	ND < 4.8	ND < 4.8	ND < 2.4	ND < 2.4
Dimethyl Phthalate	Not Published	10	60	ND < 100	ND < 10	ND < 10	ND < 4.4	ND < 4.4	ND < 2.2	ND < 2.2
Acenaphthylene (PAH)	Not Available	10	ND < 10	ND < 100	ND < 10	ND < 10	ND < 5.2	ND < 5.2	ND < 2.6	ND < 2.6
3-Nitroaniline	Not Published	Not Published	ND < 10	ND < 100	ND < 10	ND < 10	ND < 20	ND < 20	ND < 10	ND < 10
Acenaphthene (PAH)	400	10	ND < 10	ND < 100	ND < 10	ND < 10	ND < 5.2	ND < 5.2	ND < 2.6	ND < 2.6
Dibenzofuran	Not Published	Not Published	ND < 10	ND < 100	ND < 10	ND < 10	ND < 4.4	ND < 4.4	ND < 2.2	ND < 2.2
2,4-Dinitrotoluene	Not Published	Not Published	ND < 10	ND < 100	ND < 10	ND < 10	ND < 4.4	ND < 4.4	ND < 2.2	ND < 2.2
2,6-Dinitrotoluene	Not Available	10	ND < 10	ND < 100	ND < 10	ND < 10	ND < 3.2	ND < 3.2	ND < 1.6	ND < 1.6
Diethylphthalate	5000	10	ND < 10	ND < 100	ND < 10	ND < 10	ND < 3.8	ND < 3.8	ND < 1.9	ND < 1.9
4-Chlorophenyl-phenylether	Not Published	Not Published	ND < 10	ND < 100	ND < 10	ND < 10	ND < 5.2	ND < 5.2	ND < 2.6	ND < 2.6
Fluorene (PAH)	300	10	ND < 10	ND < 100	ND < 10	ND < 10	ND < 4	ND < 4	ND < 2	ND < 2
4-Nitroaniline	Not Published	Not Published	ND < 10	ND < 100	ND < 10	ND < 10	ND < 5.2	ND < 5.2	ND < 2.6	ND < 2.6
N-Nitrosodiphenylamine	7	20	ND < 10	ND < 100	ND < 10	ND < 10	ND < 3.1	ND < 3.1	ND < 1.6	ND < 1.6
4-Bromophenyl-phenylether	Not Published	Not Published	ND < 10	ND < 100	ND < 10	ND < 10	ND < 4.8	ND < 4.8	ND < 2.4	ND < 2.4
Hexachlorobenzene	0.02	10	ND < 10	ND < 100	ND < 10	ND < 10	ND < 3.4	ND < 3.4	ND < 1.7	ND < 1.7
Phenanthrene (PAH)	Not Available	10	ND < 10	84 J	ND < 10	ND < 10	ND < 3.5	20	ND < 1.8	ND < 1.8
Anthracene (PAH)	2000	10	ND < 10	ND < 100	ND < 10	ND < 10	ND < 2.6	ND < 2.6	ND < 1.3	ND < 1.3
Di-n-Butyl Phthalate	900	20	ND < 10	150	ND < 10	10	ND < 3	40	ND < 1.5	ND < 1.5
Fluoranthene (PAH)	300	10	ND < 10	ND < 100	ND < 10	ND < 10	ND < 2.6	ND < 2.6	ND < 1.3	ND < 1.3
Pyrene (PAH)	200	20	ND < 10	ND < 100	ND < 10	ND < 10	ND < 4	ND < 4	ND < 2	ND < 2
Benzidine	0.0002	50	ND < 20	ND < 200	ND < 20	ND < 20	ND < 40	ND < 40	ND < 20	ND < 20
Butylbenzyl Phthalate	100	20	ND < 10	ND < 100	ND < 10	ND < 10	ND < 3.5	ND < 3.5	ND < 1.7	ND < 1.7
3,3'-Dichlorobenzidine	0.08	60	ND < 10	ND < 100	ND < 10	ND < 10	ND < 5.2	ND < 5.2	ND < 2.6	ND < 2.6
Benzo(a)Anthracene (PAH)	Not Published	10	ND < 10	ND < 100	ND < 10	ND < 10	ND < 3.6	ND < 3.6	ND < 1.8	ND < 1.8
Bis(2-Ethylhexyl)Phthalate	3	30	3 JB	60 JB	150 B	3 JB	ND < 6.4	40	6.3	ND < 3.2
Chrysene (PAH)	Not Published	20	ND < 10	ND < 100	ND < 10	ND < 10	ND < 3.8	ND < 3.8	ND < 1.9	ND < 1.9
Di-n-octyl phthalate	100	Not Available	ND < 10	ND < 100	ND < 10	ND < 10	ND < 9.2	9.9	ND < 4.6	ND < 4.6
Benzo(b)fluoranthene (PAH)	Not Published	10	ND < 10	ND < 100	ND < 10	ND < 10	ND < 12	ND < 12	ND < 6	ND < 6
Benzo(k)Fluoranthene (PAH)	Not Published	2	ND < 4	ND < 40	ND < 4	ND < 4	ND < 5.6	ND < 5.6	ND < 2.8	ND < 2.8
Benzo(a)Pyrene (PAH)	Not Published	20	ND < 10	ND < 100	ND < 10	ND < 10	ND < 4.4	ND < 4.4	ND < 2.2	ND < 2.2
Indeno(1,2,3-cd)Pyrene (PAH)	Not Published	20	ND < 10	ND < 100	ND < 10	ND < 10	ND < 3.8	ND < 3.8	ND < 1.9	ND < 1.9
Dibenzo(a,h)Anthracene (PAH)	Not Published	20	ND < 10	ND < 100	ND < 10	ND < 10	ND < 4.4	ND < 4.4	ND < 2.2	ND < 2.2
Benzo(g,h,i)Perylene (PAH)	Not Available	20	ND < 10	ND < 100	ND < 10	ND < 10	ND < 4.8	ND < 4.8	ND < 2.4	ND < 2.4

TABLE 5 (cont.)

INNER COURTYARD GROUNDWATER
B/N + 15 ANALYSIS RESULTS

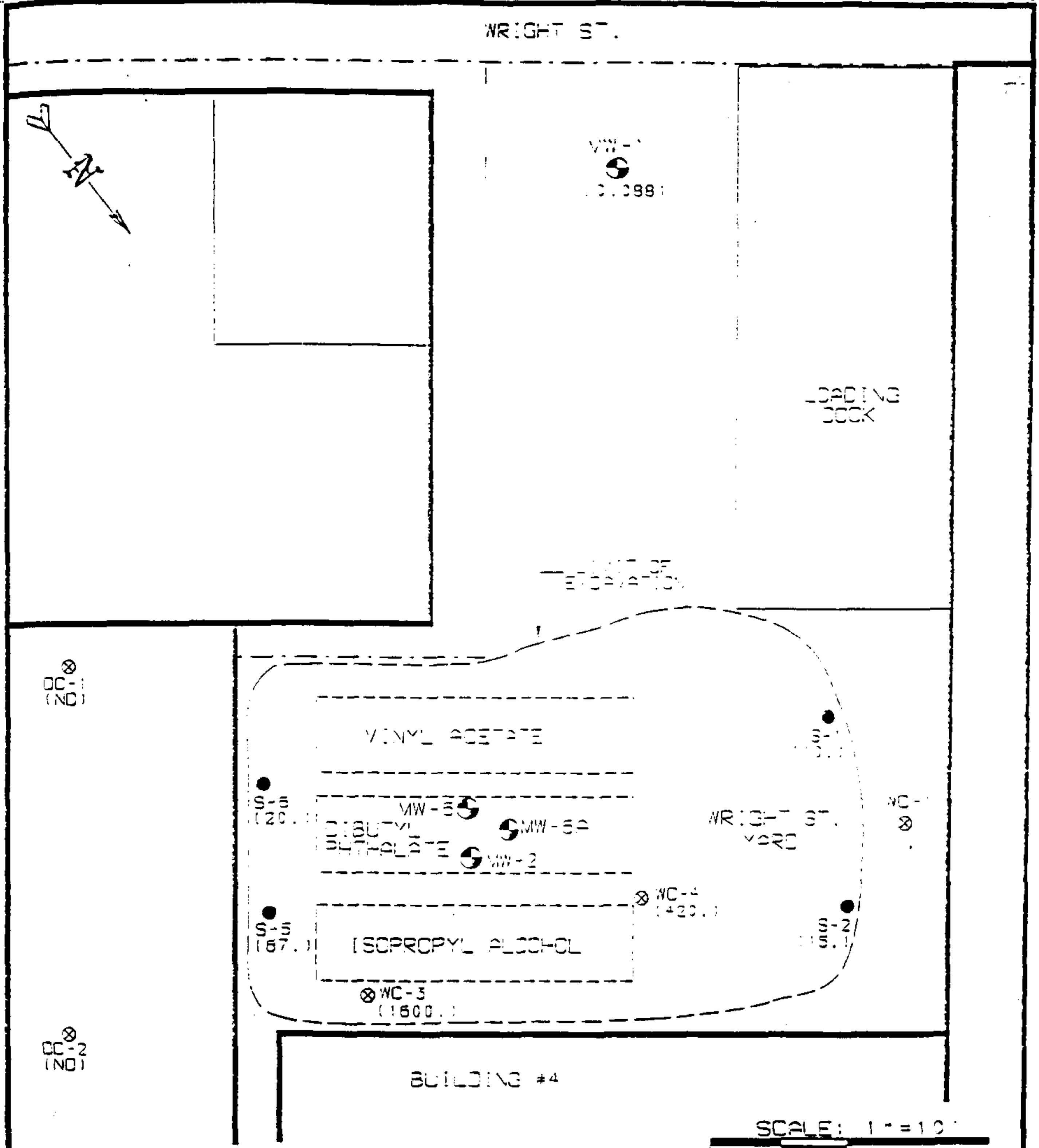
FOR

CHEMOS CORPORATION

RESULTS REPORTED IN ug/l
(PARTS PER BILLION)

PARAMETER (UNITS)	GROUNDWATER CLASS II-A QUALITY CRITERIA	PRACTICAL QUANTITATION LEVEL								
FIELD SAMPLE IDENTIFICATION			MW-3	MW-4	MW-7	FIELD BLNK	MW-3	MW-4	MW-7	FIELD BLANK
LAB SAMPLE IDENTIFICATION			AA24267	AA24269	AA24268	AA24270	AA25056	AA25058	AA25057	AA25059
SAMPLE DATE			6/14/94	6/14/94	5/14/94	5/14/94	7/21/94	7/21/94	7/21/94	7/21/94
DEPTH OF WELL			19'	19'	18'	-	19'	19'	18'	-
INTERVAL OF SCREEN			4-19'	4-19'	3-18'	-	4-19'	4-19'	3-18'	-
TENTATIVELY IDENTIFIED BASE/NEUTRAL COMPOUNDS										
Phenol, 4-(2,2,3,3-tetrameth			ND	ND	ND	ND	16	ND	26	ND
Unknown			152	1400	976	ND	100	440	166	ND
Phenol, 4-(1,1,3,3-tetrameth			ND	ND	ND	ND	20	ND	ND	ND
Heptane, 2,2,3,4,6,6-hexamet			ND	2600	ND	ND	ND	ND	54	ND
Decane, 2,6,8-trimethyl-			ND	ND	ND	ND	ND	ND	38	ND
Cyclohexanemethanol, .alpha.			ND	ND	ND	ND	ND	ND	22	ND
Heptane, 3-ethyl-5-methyl-			ND	ND	ND	ND	ND	ND	24	ND
Phenol, 4,4'-(1,2-diethyl-1.			24	ND	88	ND	ND	ND	24	ND
3-TERT-BUTYLPHENOL			38	ND	ND	ND	ND	ND	54	ND
Heptane, 4-ethyl-2,2,6,6-tet			ND	600	ND	ND	ND	240	ND	ND
Hexane, 2,2,4-trimethyl-			ND	ND	ND	ND	ND	520	ND	ND
Hexane, 2,2,5-trimethyl-			ND	2000	52	ND	ND	440	ND	ND
2,3-DIHYDRO-1-METHYLINDENE			ND	ND	ND	ND	ND	116	ND	ND
Pentane, 2,2,4,4-tetramethyl			ND	ND	ND	ND	ND	212	ND	ND
Unknown alkane			ND	2900	720	ND	ND	748	ND	ND
Undecane, 5-ethyl-			ND	ND	ND	ND	ND	292	ND	ND
Naphthalene, 1,8-dimethyl-			ND	ND	ND	ND	ND	200	ND	ND
Decane, 2,3,5-trimethyl-			ND	ND	ND	ND	ND	252	ND	ND
Tridecane, 5-propyl-			ND	240	ND	ND	ND	156	ND	ND
Tetradecane			ND	360	ND	ND	ND	188	ND	ND
Benzaldehyde, 3-methyl-, oxi			32	ND	ND	ND	ND	ND	ND	ND
Hexadecanoic acid, dioctyl es			10	ND	ND	ND	ND	ND	ND	ND
Decane, 2,2,3-trimethyl-			ND	ND	28	ND	ND	ND	ND	ND
Dodecane, 2,7,10-trimethyl-			ND	340	54	ND	ND	ND	ND	ND
Nonane, 3,7-dimethyl-			ND	ND	74	ND	ND	ND	ND	ND
Decane, 2,6,7-trimethyl-			ND	ND	50	ND	ND	ND	ND	ND
Phenol, nonyl-			ND	ND	76	ND	ND	ND	ND	ND
Octane, 2,2,6-trimethyl-			ND	1260	ND	ND	ND	ND	ND	ND
BN TARGETED TOTAL			76	884	202	13	ND	313.9	32.3	ND
BN TICs TOTAL			266	11900	2126	ND	136	3804	408	ND
BN + 15 TOTAL			342	12784	2328	13	136	4117.9	440.3	ND

ANALYTICAL METHOD: BASE NEUTRALS - EPA METHOD 625+15.
NA - NOT ANALYZED.
NOTE: ND - INDICATES COMPOUND WAS ANALYZED FOR BUT NOT DETECTED ABOVE METHOD DETECTION LIMIT (MDL).
J - INDICATES ESTIMATED VALUE USED WHEN A COMPOUND IS DETECTED AT LESS THAN THE SPECIFIED DETECTION LIMIT.
B - INDICATES COMPOUND IS ALSO PRESENT IN BLANK.
GROUNDWATER QUALITY CRITERIA AS PER NJAC 7:9-6.



SCALE: 1" = 10'

10 5 0 10

LEGEND

- ◒ MONITORING WELL LOCATION
- ● SOIL SAMPLE LOCATION(GAMES & MOORE)
- ⊗ SOIL SAMPLE LOCATION(GROUNDWATER TECH., INC.)
- ---- LIMITS OF FORMER UNDERGROUND STORAGE TANKS

(110.)-DI-N-BUTYL-PHTHALATE CONCENTRATION
IN PARTS PER MILLION

SAMPLES S-1, S-2, S-5, & S-6 RETRIEVED 9.5-10' BELOW GRADE.
ALL OTHER SAMPLES RETRIEVED 0-6" ABOVE GROUNDWATER(APPROX 5
MAP SOURCE: GROUNDWATER TECHNOLOGY, INC.

FIGURE 4

CHEMOS CORPORATION
WRIGHT STREET YARD DETAIL

HUDSON ENVIRONMENTAL SERVICES, INC.
4 MARK ROAD, SUITE C, KENILWORTH, NJ

DRAWN: DCD DATE: 8/10/93
REVISED: DCD DATE: 9/29/94

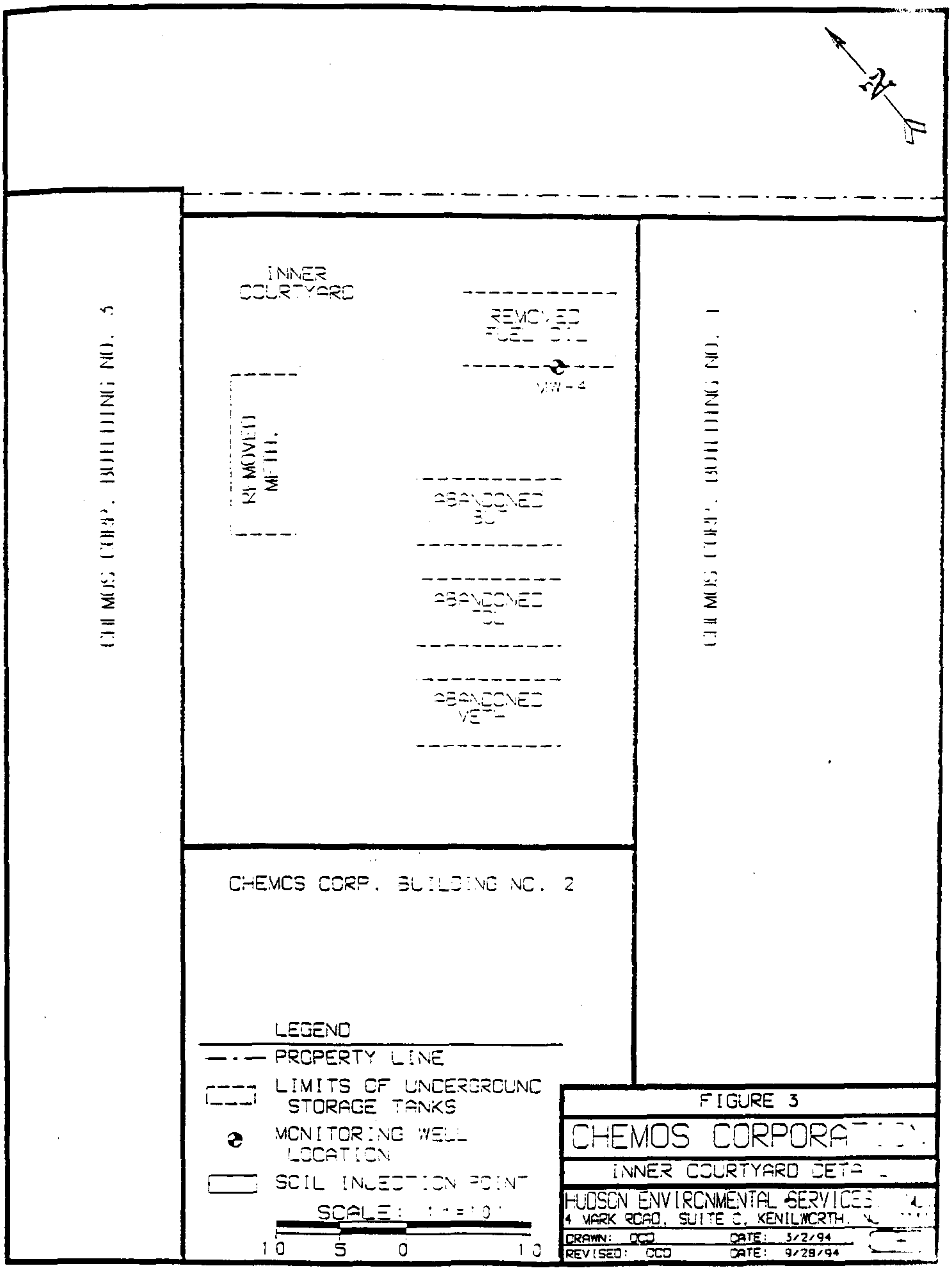


FIGURE 3

CHEMOS CORPORATION

INNER COURTYARD DETAIL

HUDSON ENVIRONMENTAL SERVICES, INC.
4 MARK ROAD, SUITE C, KENILWORTH, NJ

DRAWN: DCD DATE: 3/2/94
REVISED: DCD DATE: 9/28/94

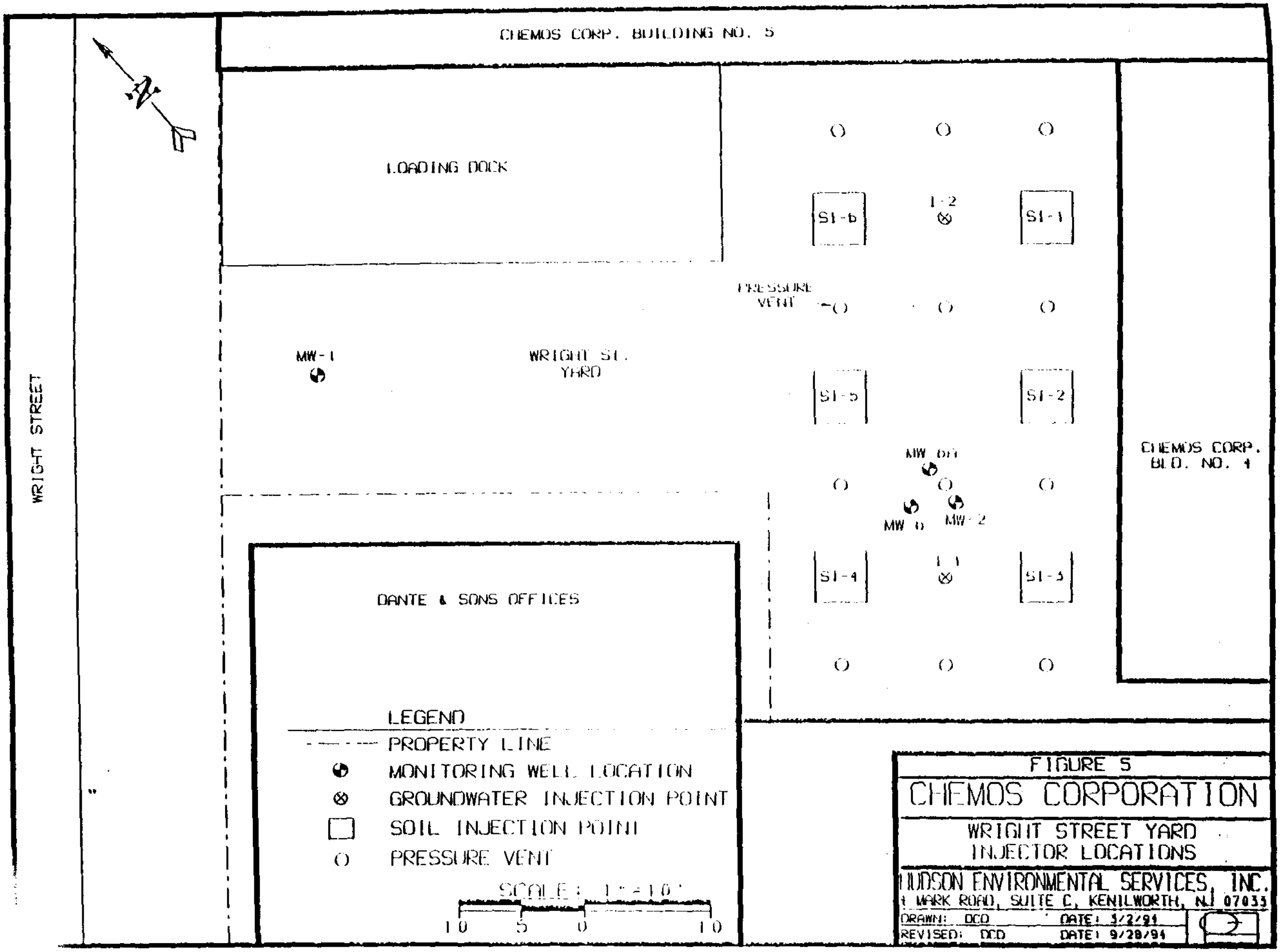


FIGURE 5

CHEMOS CORPORATION

WRIGHT STREET YARD
INJECTOR LOCATIONS

HUDSON ENVIRONMENTAL SERVICES, INC.
1 MARK ROAD, SUITE C, KENILWORTH, NJ 07033

DRAWN: DCD	DATE: 3/2/94
REVISED: DCD	DATE: 9/28/94

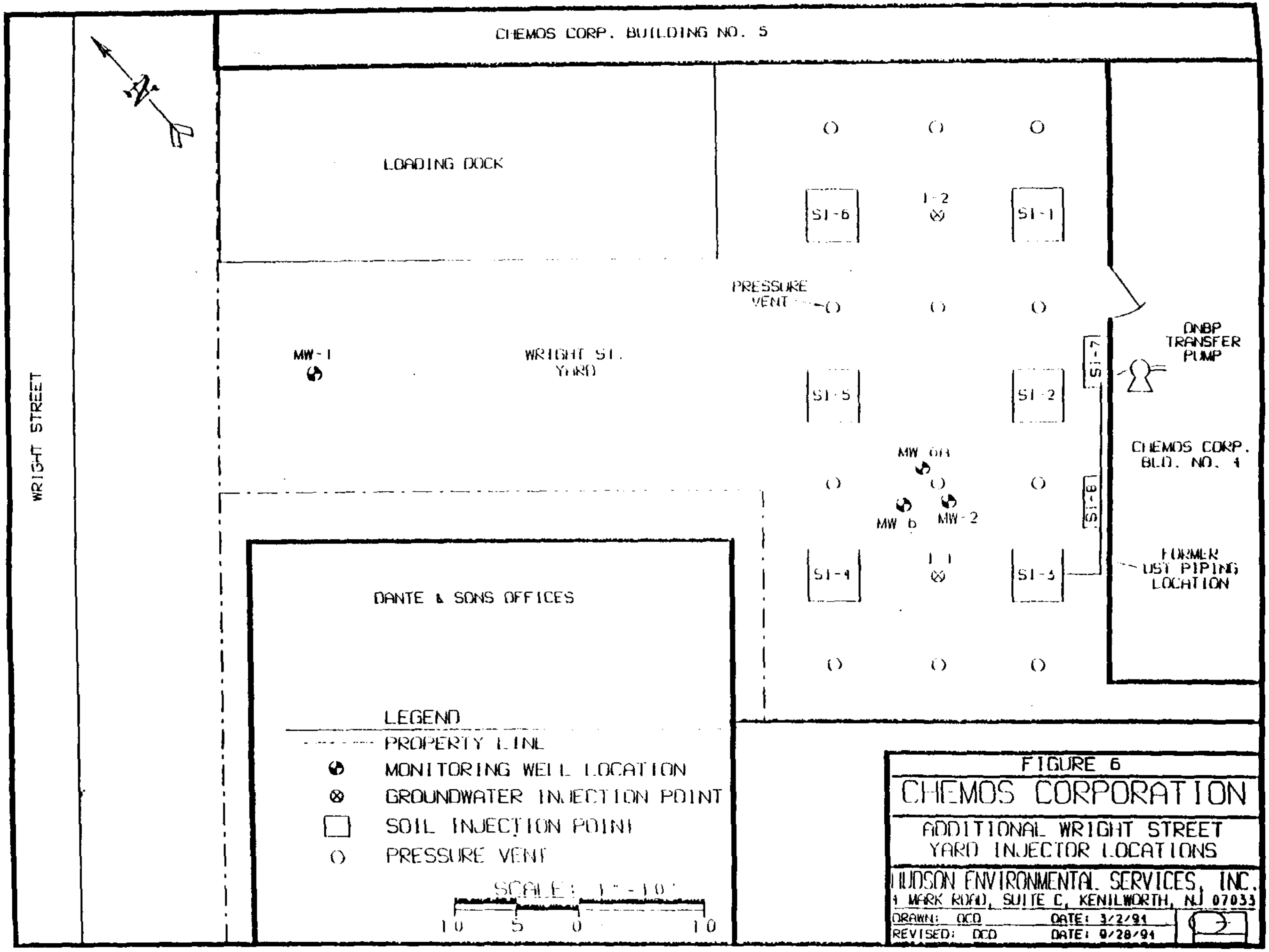


FIGURE 6

CHEMOS CORPORATION

ADDITIONAL WRIGHT STREET
YARD INJECTOR LOCATIONS

HUDSON ENVIRONMENTAL SERVICES, INC.
4 MARK ROAD, SUITE C, KENILWORTH, NJ 07033

DRAWN: DCD DATE: 3/2/94
REVISED: DCD DATE: 9/28/94

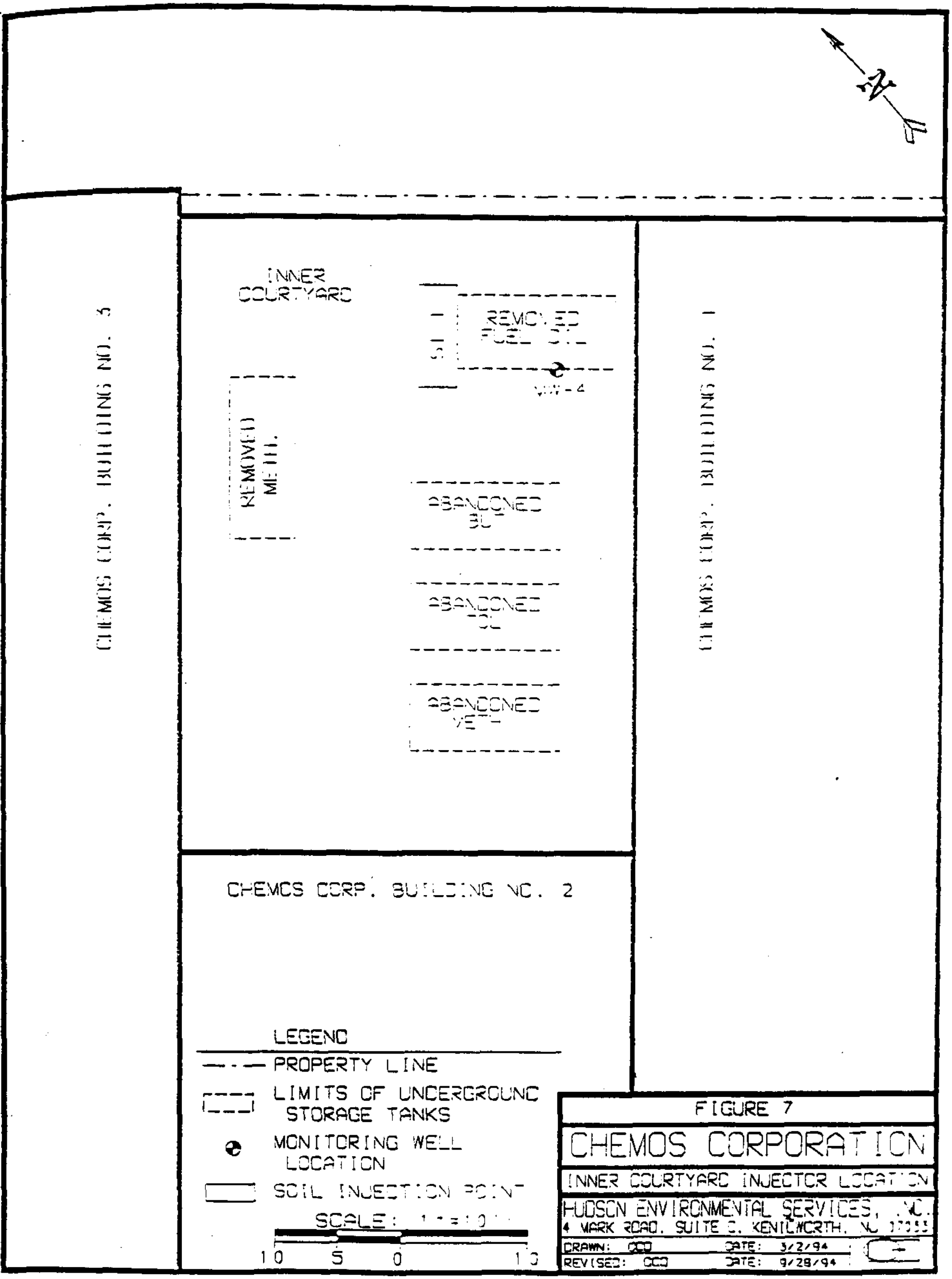


FIGURE 7

CHEMOS CORPORATION

INNER COURTYARD INJECTOR LOCATION

HUDSON ENVIRONMENTAL SERVICES, INC.
4 MARK ROAD, SUITE C, KENILWORTH, NJ 07033

DRAWN: CCD DATE: 3/2/94
REVISED: CCD DATE: 9/28/94

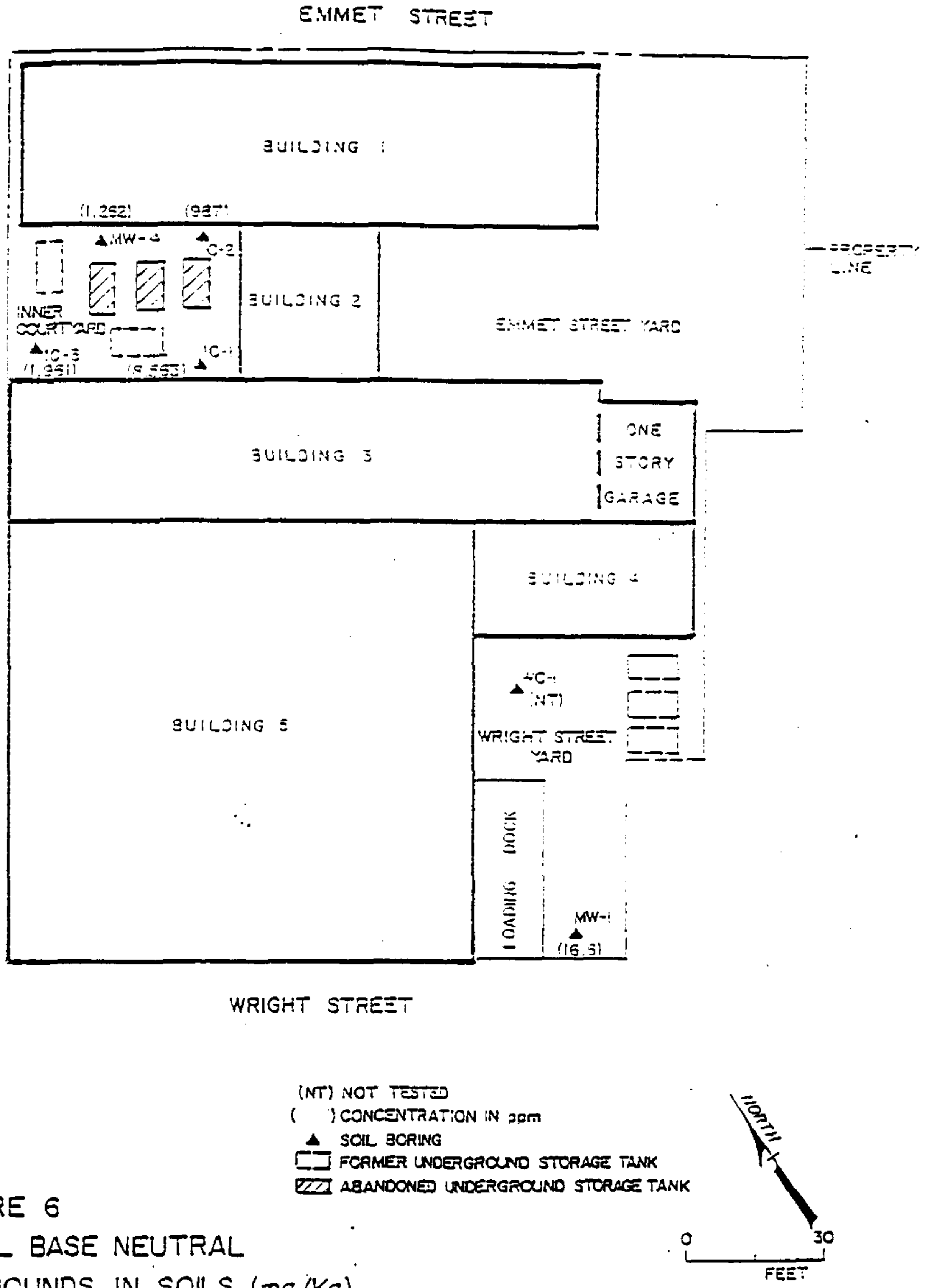
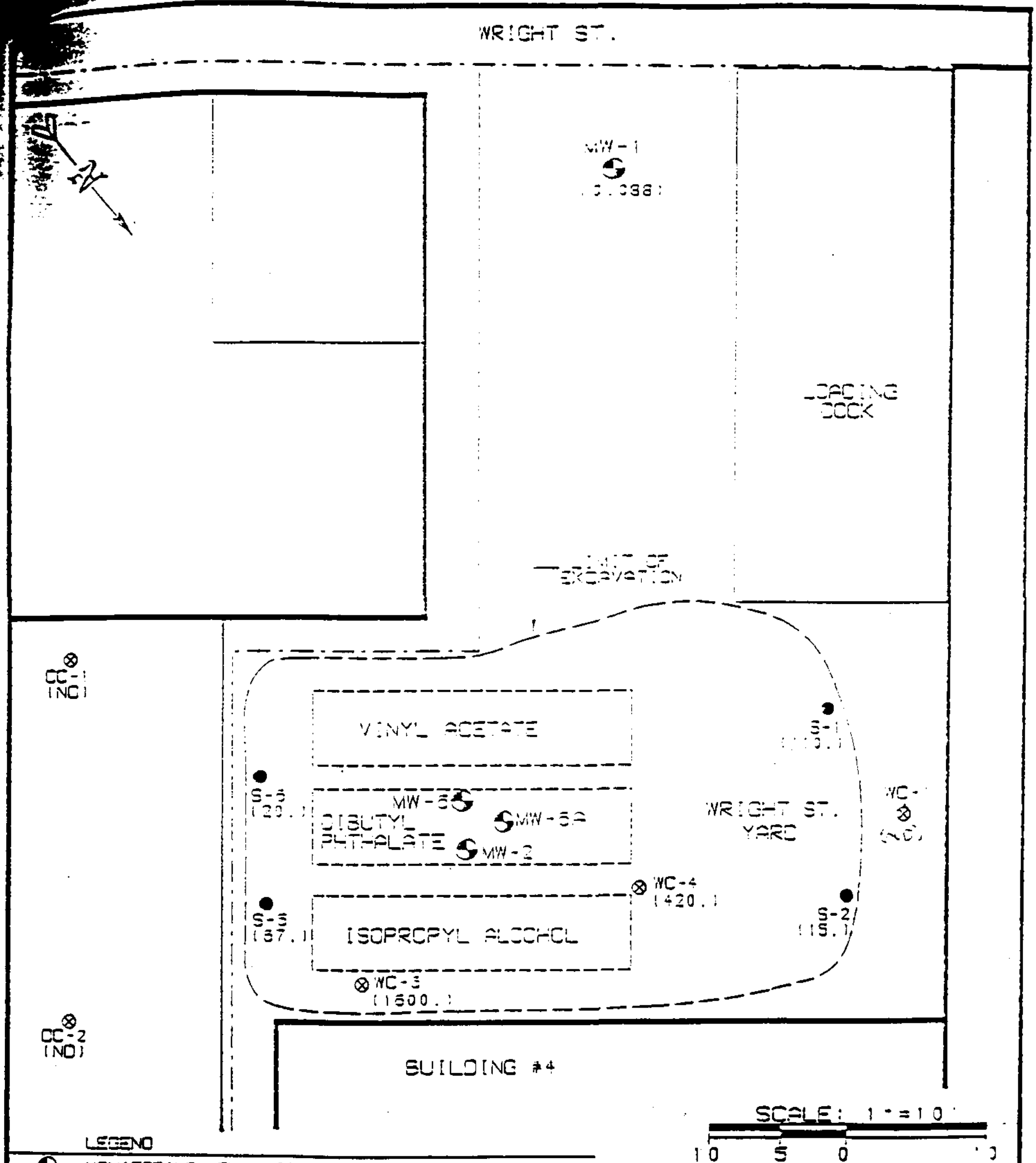


FIGURE 6
TOTAL BASE NEUTRAL
COMPOUNDS IN SOILS (mg/Kg)
CHEMOS CORPORATION
NEWARK, NEW JERSEY

GROUNDWATER TECHNOLOGY, INC



LEGEND

⊕ MONITORING WELL LOCATION

● SOIL SAMPLE LOCATION(DAMES & MOORE)

⊗ SOIL SAMPLE LOCATION(GROUNDWATER TECH., INC.)

---- LIMITS OF FORMER UNDERGROUND STORAGE TANKS

(110.)-DI-N-BUTYL-PHTHALATE CONCENTRATION
IN PARTS PER MILLION

SAMPLES S-1, S-2, S-5, & S-6 RETRIEVED 9.5-10' BELOW GRADE.
ALL OTHER SAMPLES RETRIEVED 0-6" ABOVE GROUNDWATER(APPROX 5')
MAP SOURCE: GROUNDWATER TECHNOLOGY, INC.

CHEMOS CORPORATION
WRIGHT STREET YARD DETA

DI-N-BUTYL PHTHALATE
CONCENTRATIONS IN SO

HUDSON ENVIRONMENTAL SERVICES, INC.
4 MARK ROAD, SUITE C, KENILWORTH, NJ 17033

DRAWN: DCD DATE: 8/10/93
REVISED: DATE:

TABLE 1
SOIL SAMPLE ANALYTICAL RESULTS
CHEMOS CORPORATION SITE
NEWARK, NEW JERSEY

SAMPLE	LOCATION	DEPTH (feet)	MATRIX	VINYL ACETATE (mg/Kg)	DIBUTYL PHTHALATE (mg/Kg)	TOTAL VOLATILE ORGANICS (mg/Kg)	TOTAL BASE NEUTRAL COMPOUNDS (mg/Kg)	TOTAL PETROLEUM HYDROCARBONS (mg/Kg)
WC-1	Wright St. Yard	6.5 - 7.0	Silty Sand	ND	ND	0.58 B	NT	NT
MW-1	Wright St. Yard	5.5 - 6.0	Silty Sand	ND	0.088	0.49 B	15.6	NT
IC-1	Inner Court Yard	6.5 - 7.0	Silty Sand	NT	7.2	NT	8,562.5	4,100
IC-2	Inner Court Yard	2.5 - 3.0	Silty Sand	NT	ND	NT	987.1	6,400
IC-3	Inner Court Yard	5.5 - 6.0	Silty Sand	NT	19	NT	1,960.8	5,500
MW-4	Inner Court Yard	6.0 - 6.5	Silty Sand	NT	10	NT	1,262.2	31,000
METHOD	Method blank	-----	Soil	NT	NT	1.11	20.9	ND
FIELD	Field blank	-----	Water	ND	ND	0.008 B	NT	NT
TRIP	Trip blank	-----	Water	ND	NT	0.021 B	NT	NT
METHOD	Method blank	-----	Water	ND	ND	0.017 B	NT	NT

NOTE:
B : Analyte found in method blank and sample.
NT : Not tested.
ND : Not detected.

Common Questions and Concerns Relating to GEO-CLEANSE

1) ***Who is Hudson Environmental?***

Hudson principals and personnel responsible for the development and application of the process have educational degrees in Chemical Engineering (Jim Wilson and Andrew Kondracki), Geological Engineering (Eric Schlauch), and Environmental Science (Paul McGaha). Jim Wilson is the developer of the technology and will be the patent holder. The other parties listed above provided much assistance with the continuing efficiency and application of the Technology. The research in this area was initiated in 1992 in response to problems various clients had with both soil and groundwater organic contamination in areas which were difficult to access and expensive to remediate (i.e., beneath buildings and loading docks). This patent pending process is proprietary with regard to the injection system and methodology, but not the Fenton's Chemistry employed in the treatment. Hudson personnel are fully qualified to implement the program at various sites across the country (see attached Qualifications Brochure).

2) *Are the chemicals and chemistry involved with the injection program safe and effective?*

H.J.H. Fenton developed a chemistry which oxidized malic acid through the use of hydrogen peroxide and iron salts in 1898. This chemistry has been, and is still widely used by the waste water industry for treatment of organic wastes (particularly non-biodegradable compounds). Hydrogen peroxide is the active ingredient in the oxidation of organic compounds by this methodology. Hydrogen peroxide is safe in the environment due to its low concentrations once it is dispersed into the soil or groundwater. Hydrogen peroxide injection to the subsurface environment results in the rapid disintegration of the organic compounds, generating carbon dioxide, water and oxygen. Other amendments added to the injection stream include trace amounts of ferrous salts in a pH balanced solution. Safety information is included in appendix 1.

The chemical efficiency of the process has been widely documented in the waste water industry and the mechanisms are well known. The principals of the oxidation process in which the hydroxyl free radical cleaves and oxidizes organic compounds results in the formation of successively smaller chained hydrocarbon compounds is also well documented. The intermediate compounds formed are mono- and di-carboxylic acids which are non-hazardous, naturally occurring substances that are easily oxidized to carbon dioxide and water (mineralized) during sequential reactions. The cleaving of the organic substrate does not and will not produce volatile organic compounds which can be liberated to the atmosphere. The most volatile organic compound which can be created during this process is Methanoic Acid, having a boiling point of 100.5 degrees centigrade. Documentation of the above information is contained in appendix 1 (Solvay Interox Corporation).

3) How much Hydrogen Peroxide is injected during the Pilot Treatment?

The quantity of hydrogen peroxide utilized in the pilot treatment is determined from the absolute mass quantity of contaminants within the contaminant region. This includes the dissolved phase loading, capillary region or free phase loading and the residual soil contamination. The calculated charge is based on the geological and chemical properties of the aquifer and contaminated soils. The program uses an excess of hydrogen peroxide in the injection to compensate for decomposition of the hydrogen peroxide to oxygen and water and losses due to mineralization of the contaminant substrate. The actual charge is generally an order of magnitude over the theoretical quantity. This amounts to an effective concentration of usually less than 1% hydrogen peroxide within the affected aquifer. In soil the quantities of injected materials are based on the concentration and distribution of the contaminant. The addition of hydrogen peroxide is also useful in increasing dissolved oxygen concentration in groundwater which would further stimulate biological consumption of the organic contaminant through natural remediation. Hydrogen peroxide has been widely evaluated in the literature and is shown to rapidly deteriorate in the environment by catalytic decomposition. Hydrogen peroxide amendments to the subsurface environment is a tool employed by the environmental bioremediation industry. Its fate and longevity have been well documented, and therefore any excess reagent will rapidly degrade and assist in the natural remediation process.

4) What is the method of Injection?

The system employed for the injection of the reagents is considered proprietary and a patent application is currently being processed for the protection of this technology. The injector contains a mixing head which is utilized for the intermixing of the reagents (i.e., hydrogen peroxide, catalyst charge in an aqueous based solution) and has components to stimulate the circulation of groundwater via pneumatic and hydraulic effects which are designed to promote rapid reagent diffusion and dispersion. The injector system is composed of steel or aluminum which is capable of withstanding the elevated temperatures and pressures generated by the reaction and degradation of the hydrogen peroxide. The injector is sealed beneath the subsurface at a predetermined depth and screened across the region of soil strata which will permit the transmissivity and optimize the distribution of the reagents to the contaminated region. It is imperative that a highly specialized injection system be utilized in this process in order for the reagents to be properly distributed to the maximum extent possible. The use of hydrogen peroxide in a Fenton's reagent treatment program cannot be effective distributed to the aquifer by the use of monitoring well type designs. The addition of strong oxidizers to a monitoring well containing organic materials will produce a highly localized, rapid exothermic condition. This will result in an explosive reaction with the reagents along with soil and groundwater being violently ejected to the unsaturated zone or to the atmosphere. The GEO-CLEANSE system generates these conditions under controlled rates utilizes the pressures and temperatures generated during the process to increase dispersion and diffusion of the reagents. In addition, by sealing the injector beneath the subsurface, the system utilizes gases, both injected and as generated by the reaction, to further circulate

Appendix 1

Interox Information

Hydrogen Peroxide Fate Information

7) What steps are involved in the remedial process?

The implementation of the program is highly dependent on an accurate characterization and delineation of the contaminant plume. Assuming a full evaluation has been accurately completed, a Pilot Treatment Program is conducted which is then followed by a Full Remediation Program. The Pilot Treatment Program is required and necessary to define the radial extent of effective treatment from one injector located within the contaminant plume. In the case of a small discharge, a single groundwater injector may be capable of remediating the site (i.e., small gasoline station discharge).

During Pilot Treatment, the groundwater will be evaluated for hydrogen peroxide concentration via test strips and measurements will be taken of the dissolved oxygen content, pH and millivolt potential of the groundwater. Monitoring wells at varying distances from the injector will be utilized for the evaluation in a similar methodology to that of a soil vapor extract study. This will provide real time evaluation parameters during the injection. Following the injection program, BTEX analysis (assuming a gasoline discharge) will be performed on the groundwater monitoring wells within the proposed treatment area. This data can be compared to previous test results and the radius of influence can be determined by interpolation or extrapolation of the data. This information will be utilized in determining the number and spacing of injectors for the full treatment program. The Pilot Treatment data is not necessarily collected to determine if the area has been successfully remediated, it is mainly utilized to determine if the area has been impacted by the Treatment and the radius of influence. A protocol for determining if the groundwater quality standards have been achieved will be proposed for regulatory approval in a Remedial Action Workplan(RAW) for the full scale remediation program.

8) How can a client/regulator be assured there will be no rebound in contaminant levels?

The post remedial evaluation sampling will be conducted one week following the completion of the treatment program. The sampling is conducted after one week to permit all residual hydrogen peroxide to decompose and to allow sufficient time for the aquifer to stabilize and equilibrate following the circulation and disturbance of the aquifer. Following the initial evaluation and pending satisfactory results, two additional sampling and analytical events will be conducted several moths from the Treatment Program to document the condition of the area of concern. The results of the program will then be submitted to the regulatory agency in the proper format for site closure.

It should be emphasized that both the chemistry and the reagents injected pose no hazard to human health and the environment. A health and safety plan is prepared for each job on a site specific basis. This program also uses substantially less hydrogen peroxide than would be required in a bioremediation program and the concentration injected is rapidly diluted to concentrations below health risk standards. This program will benefit the public by both reducing the costs to remediate environmental contaminants and improve the quality of the site more rapidly than any other current methodology.

the aquifer and disperse the reagents. The dispersion is enhanced by the chemical and gas fracturing features of the system. The reaction of the hydrogen peroxide on the aquifer has demonstrated this channeling and fracturing effect on commercial treatment sites. The diffusion methodology is created due to the temperature and pressure gradients established in the subsurface. By addition of these reagents to the subsurface through a monitoring well, most of the reagents and all the pressures would be transferred by the well packing material up the screened and cased sections and vented to the unsaturated zone thereby wasting the mechanic and thermal energy that could be applied to the aquifer to diffuse and disperse the materials to the maximum extent possible. Enclosed is the report from the University of Nevada outlining the chemistry employed by the process and is attached in appendix 2.

5) What is the rate of Injection and how is it determined?

The rate of injection is determined in the field and is based on the native formation pressure. As the hydrogen peroxide is injected, the pressure is monitored at the mixing head with a flow rate pressure not exceeding the formation pressure. The pressure is the determining parameter during the injection program which dictates the maximum flow rate. The rate of injection of hydrogen peroxide is maintained well below the formation pressure since maximum hydrogen peroxide efficiency is based on a more dilute flow rate which will minimize undesirable side reactions.

6) Why are Iron Catalyst Systems utilized in the Process and what are the implications for groundwater quality?

The iron catalyst in the Fenton's Reagent Chemistry has a well documented role and fate in the reaction sequence. Iron salts in the form of ferrous sulfate are added to the injection mix to generate the hydroxyl radical. In addition, other non-hazardous metallic salts aid in the reaction, but in most cases ferrous sulfate is the only proposed catalyst. During the optimum reaction sequence ferrous sulfate is mixed with hydrogen peroxide producing a hydroxyl radical and converting the ferrous sulfate to a ferric compound. The ferrous salt (Fe^{+2}) is soluble in the aqueous phase and is necessary for the generation of the hydroxyl radical, but the ferric ion (Fe^{+3}) will not generate the hydroxyl and is insoluble. However, the ferric ion can be regenerated to a ferrous form by a second reaction with another molecule of hydrogen peroxide. Therefore, the iron available in the ferrous form will be regenerated as long as there is an excess of hydrogen peroxide present in the aquifer. Eventually, the iron will precipitate out as the insoluble form of iron. This process will not adversely impact groundwater quality with respect to iron content, and will actually assist in precipitating out pre-existing quantities of iron and other metals. This process may assist in precipitating other hazardous metallic compounds from groundwater and further investigation is being conducted at this time. Additionally, since the iron will regenerate into a soluble phase there is no fouling related problems associated with the injectors or channels as long as ratios are properly maintained. In addition, iron content available in various soils and aquifers throughout the country may provide more than sufficient quantities of the ferrous ion to catalyze the reaction. This information is contained within University of Nevada study conducted in 1990 and attached in appendix 2.

Fenton's Reagent

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Fenton's Reagent: New Option For Hard-To-Treat Organics

Industry must increasingly manage the specific contents of the wastewater it creates, as regulatory agencies shift their emphasis from measures like BOD (Biological Oxygen Demand) to measuring specific toxic organic compounds. Some of these compounds, like phenols and dioxins, don't show up in BOD tests, even when present in large and potentially dangerous concentrations, though they can be detected through COD (Chemical Oxygen Demand) tests.

New guidelines, such as those of Organic Chemicals, Plastics, and Synthetic Fibers (OCPSF), require the total toxicity of an effluent to be measured, and that certain toxic chemicals be reduced to concentrations of parts per billion. This requires a treatment technology that is highly effective, yet cost-efficient and adaptable to meet many diverse needs and requirements.

Chemical oxidation generally meets these criteria. Over the last twenty years, hydrogen peroxide (H_2O_2) has found increased use as an oxidant in treating many contaminants. But when used in Fenton's reagent, hydrogen peroxide liberates one of the most powerful oxidants known—the hydroxyl radical.

Treatment Alternatives

Until recently, the preferred method for treating organic wastes was letting someone else do it off-site. Today, other alternatives allow for on-site treatments.

With chemical oxidation, newly emerging hydrogen peroxide applications allow destruction of a wide variety of organic compounds without the formation of toxic byproducts. Other oxidants, like chlorine and hypochlorite, will react with many organics to form toxic chlorinated hydrocarbons. Permanganate, a costly oxidizer, can precipitate out in the presence of air as manganese dioxide, causing a black stain. It also forms metal-bearing sludge.

Thermal oxidation, or incineration, may be the only other feasible solution for extremely high concentrations of toxicants, but is becoming more and more expensive and requires permits that can be difficult to obtain.

Phase transfer methods, such as vapor stripping and adsorption by activated carbon can change the form of the pollutant, but will not eliminate it. The carbon is costly and messy to regenerate. Additionally, vapor strippers discharge pollutants directly into the air.

Hydrogen Peroxide Advantages

Hydrogen peroxide offers an extremely cost effective source of hydroxyl radicals $\bullet OH$, one of the most reactive substances known. Produced by Fenton's reagent, the hydroxyl radical is a transient intermediate: as soon as it forms, it finds something to react with. It is an ideal means of oxidizing a large variety of organic compounds.

Major advantages include:

Power: As Table 1 shows, the hydroxyl radical is second only to fluorine among common oxidants.

Versatility: Hydrogen peroxide, via the hydroxyl radical, can detoxify a broad range of organic wastes and is effective over a wide range of contaminant concentrations.

Safety: Handled properly, hydrogen peroxide is quite safe. As with all powerful chemicals, however, improper application or careless handling could create hazardous conditions or cause injuries to personnel. (We strongly recommend you consult with a manufacturer of H_2O_2 before experimenting with designing, installing, or modifying an application system using this chemical.)

Ease of Handling: Hydrogen peroxide, unlike chlorine, does not require large cylinders for storage. It can be stored on-site in quantities appropriate to user requirements.

Economy: Compared to alternative treatment systems, hydrogen peroxide is cost-effective in combatting a wide variety of contaminants, including phenol, cresol, chlorophenol, dichlorophenol, trichlorophenol, benzene, and aniline. Because partial oxidation breaks toxic rings, reduced toxicity can be achieved without complete oxidation; thus, less than stoichiometric amounts of hydrogen peroxide may be required.

Table 1

Speciation Chart.

Species	*Relative Oxidation Power (Cl=1.0)*
Fluorine	2.23
Hydroxyl radical	2.06
Atomic oxygen (singlet)	1.78
Hydrogen peroxide	1.31
Perhydroxyl radical	1.25
Permanganate	1.24
Hypobromous acid	1.17
Chlorine dioxide	1.15
Hypochlorous acid	1.10
Hypoiodous acid	1.07
Chlorine	1.00
Bromine	0.80
Iodine	0.54

Fenton's Reagent Chemistry

When it comes to environmental issues, the demands for advanced treatment technology may be new, but the chemistry behind the technology dates back to 1894, when H.J.H. Fenton reported that ferrous iron promoted the oxidation of malic acid by hydrogen peroxide. Subsequent work showed that this combination could oxidize a variety of organic compounds, but it was not until the 1930s that the reaction mechanism was elucidated and the hydroxyl radical was identified as the reactive species.

While some organics, notably organic amines and aldehydes, may undergo alkaline hydrolysis by hydrogen peroxide, the oxidation of most organic wastes requires the hydroxyl radical. This is easily accomplished by Fenton's reagent, which industry uses increasingly to treat wastes. Fenton's systems continue to find new uses as regulations tighten.

The hydroxyl radicals are generated in acidic, aqueous solution by the catalytic decomposition of H_2O_2 with Fe^{2+}:

$$H_2O_2 + Fe^{2+} \rightarrow Fe^{3+} + OH^- + OH\bullet$$

The subsequent oxidation of organic substrates proceeds via free radical attack by the hydroxyl radical, which has an oxidation potential of 2.8 volts. Additionally, the major parameters controlling the reaction are well-defined: hydrogen peroxide concentration, temperature, time, pH, and catalyst concentration.

The Fenton's reagent reaction occurs optimally at a final pH of 3 or 4, where iron exists in the reduced (ferrous) state. This also avoids the precipitation of ferric hydroxide, which would occur under alkaline conditions.

The following illustrates the oxidation of phenol using Fenton's reagent. Table 2 shows the reaction sequence to the benzoquinone intermediates. Table 3 represents further oxidation of orthobenzoquinone to carbon dioxide and water.

Theoretically, 14 moles (5 parts by weight) of hydrogen peroxide are required to oxidize 1 mole of phenol to carbon dioxide and water. Operationally, the extent of phenol destruction is determined by the hydrogen peroxide/phenol ratio while the rate of oxidation is determined by the initial iron concentration. Table 4 shows this relationship based on results from Interox laboratory work.

Table 2

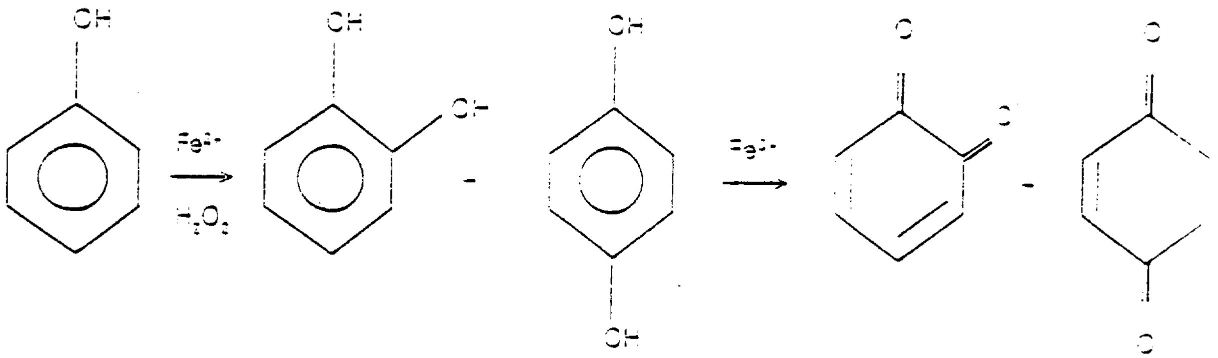
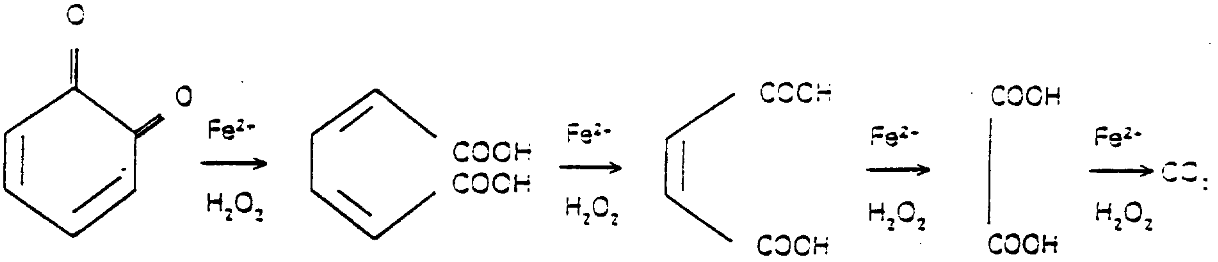


Table 3



Iron plays a critical role in the reaction. Low iron concentrations seem to favor production of the parabenzoquinone intermediate. High iron concentrations favor production of the orthobenzoquinone intermediate.

However, the hydrogen peroxide/phenol ratio is critical for driving the reaction to completion. Additionally, as the number of functional groups on the aromatic ring increases, the quantity of hydrogen peroxide required for the oxidation also increases.

Table 4 also shows that an optimum reaction time, temperature, and hydrogen peroxide application level exists for every situation. Because the reaction is exothermic, concentrated solutions may require dilution or cooling.

Typical Applications

Interox has assisted in the development of treatment systems for many different toxicants. The following examples show the diversity of suitable applications.

Pretreatment of creosoting wastes: A forest products company uses the Fenton's system for pretreatment of phenolic wastewaters generated by creosoting operations at several wood treating plants. Wastewater flows average 30,000 gallons per day with a phenolic concentration of 200 mg/L (range 20-1200 mg/L). While standards vary by municipality, total phenols of treated wastewater generally fall within the range of 25-45 mg/L.

Reduction of BOD/COD: A Gulf Coast chemical manufacturer normally has no trouble meeting BOD/COD effluent standards, but occasional upsets lead to storage of relatively high concentrations of organics. This is treated on a batch basis with a Fenton's system, discharged into a pond, and bled off into a biological treatment system.

Batch treatment: A manufacturer of surfactants generates phenolic wastes in a batch manufacturing process. The wastewater is batch-treated with a Fenton's system prior to discharge.

Pretreatment of a segregated waste stream: A chemical manufacturer creates a nitrophenol effluent stream from one of its processes. This waste is treated with Fenton's reagent, after which it can be safely discharged with the rest of the wastewater to the plant's treatment system.

Removal of phenols and chromium from paint-stripping waste: An aircraft manufacturer uses a phenolic-based paint stripper as a part of routine maintenance. After solids have settled out, a Fenton's system eliminates phenols. Then the pH is raised to 11 with lime, which precipitates chromium and reduces the color of the effluent. This system handles phenols at concentrations up to 1000 mg/L and chromium up to 100 mg/L or more.

Oxidation of pentachlorophenols in soil: Under a grant from the EPA, a Southwestern university is investigating soil treatment alternatives for pentachlorophenol contamination. Early results indicate that low levels of Fenton's reagent, mixed with the soil, can decontaminate it at a cost of $50-$100 per ton compared with up to $1000 per ton for incineration

Table 4

Contact wastewater total phenols oxidation with hydrogen peroxide catalyzed with ferrous iron.

Initial pH	*H_2O_2: Phenol (w/w)*	*Iron (ppm)*	*Total Phenols Concentration (ppm)* *Time 0*	*15 min.*	*30 min.*	*60 min.*	*Final pH*	*Residual H_2O_2*
4.0	2:1	220	1190	230	180	180	2.7	0
4.0	2:1	100	1190	280	210	210	2.8	0
4.0	3:1	100	1190	115	50	<10	2.4	0
4.0	3:1	100	1190	130	35	25	2.5	0

Process Description

Historically, batch processing has been utilized. Today, continuous tower and sequential batch reactors are in service. Figure 1 illustrates the process flow of a typical batch Fenton's system.

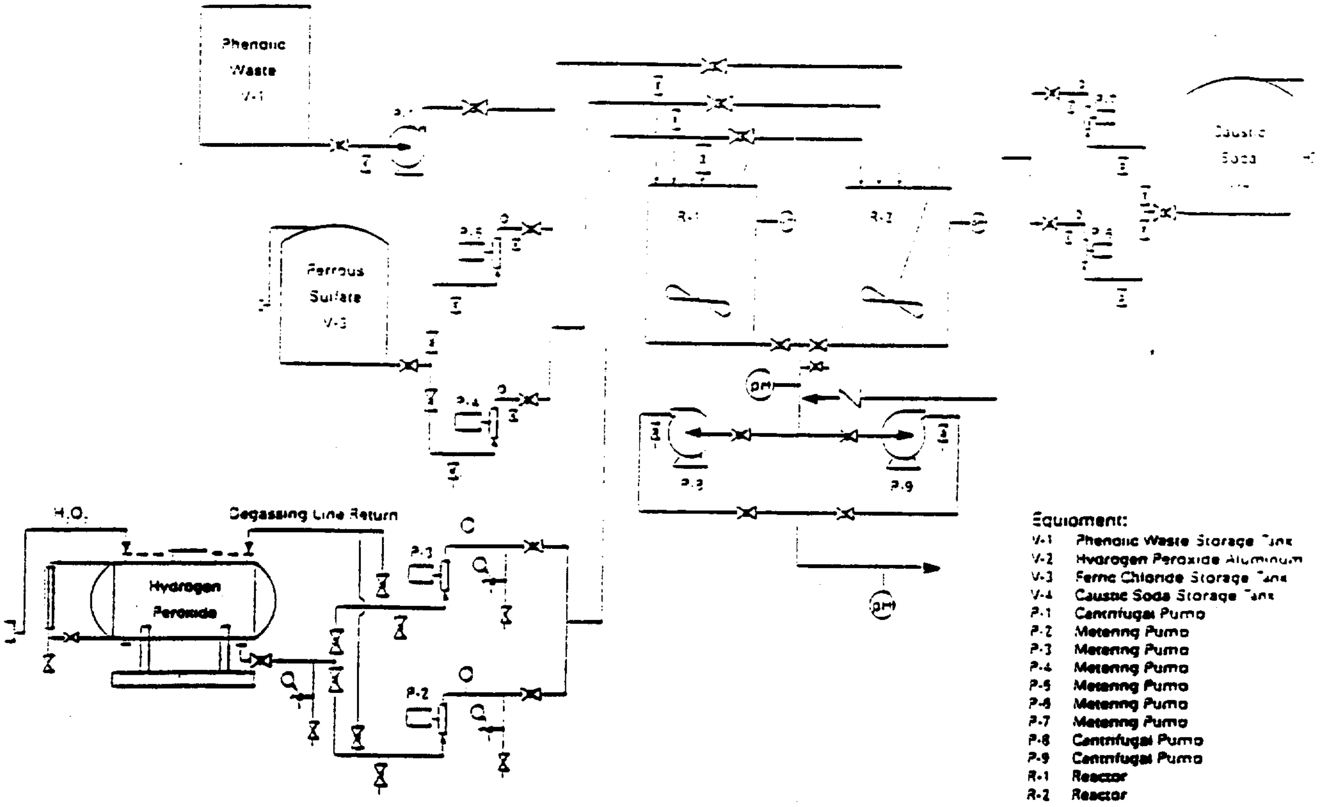
Wastewater enters at or near ambient temperature. At temperatures near or above 150°F (66°C), the hydrogen peroxide will tend to dissociate more rapidly and may not be available for reaction with the contaminant. Also, higher temperatures will reduce the required retention time by increasing the rate of reaction.

Ferrous sulfate, which is acidic due to the presence of sulfuric acid, is then added in the correct proportion. At this point, wastewater should be at the optimum pH, 5 or below, and may require acid addition to establish the proper pH. Sulfuric acid and sodium hydroxide are typically used for pH adjustment.

Hydrogen peroxide is then slowly added to the reactor at a 3:1 weight ratio, typically used for > 95% reduction. Throughout the process, complete mixing is essential. Some foaming may occur. Retention times of 30 - 60 minutes are common in batch systems. Ferrous sulfate, because of its low solubility in water, will sometimes form a small amount of solid which can typically be discharged to Publicly Owned Treatment Works (POTW).

Figure 1

Fenton's System for Phenol Destruction.



For batch systems, two reactors may be required for continuous operation; or, one reactor and a large holding tank. Normally, open-top reactors are used, but for contaminants requiring a closed-top reactor, a vent and scrubber system will be required.

As the reaction progresses, a rise in temperature occurs. Unless contaminant concentrations are very high, this does not present a problem.

The color of the wastewater will darken and toxicity may initially increase slightly as the reaction progresses. However, as the reaction continues, toxicities will decline markedly. After further reaction, the color will lighten. This is an indicator that the reaction is taking place.

The pH of the wastewater drops as reaction intermediates are formed. Because the reaction will slow down dramatically if pH drops below 3, it may be necessary to use a stepwise addition of hydrogen peroxide with intermediate pH adjustment. Once the reaction is complete, wastewater pH is adjusted to alkaline conditions where $Fe(OH)_3$ is precipitated out. A settling tank or a centrifuge may be used for removal of Fe^{+3}. This iron sludge can generally be used again as the reaction catalyst after reacidification.

Process equipment includes:

- H_2O_2 storage and dosing equipment
- $FeSO_4$ storage and dosing equipment
- Acid storage and dosing equipment
- Caustic storage and dosing equipment
- Reactor

Proper materials of construction should be used at all times. Materials compatible with hydrogen peroxide are shown in Table 5.

Table 5

- *Aluminum*
  99.5% minimum purity, and alloys with the following Aluminum Association Designations: 1060, 1260, 5254, 5652, or 6063

- *Stainless Steel*
  Types 304, 304L, 316, 316L

- *Other Materials*
  Chemical Glass
  Chemical Ceramic
  Polytetrafluoroethylene (PTFE, Teflon®)
  Polyvinylchloride (PVC)
  Polyethylene (High Density)
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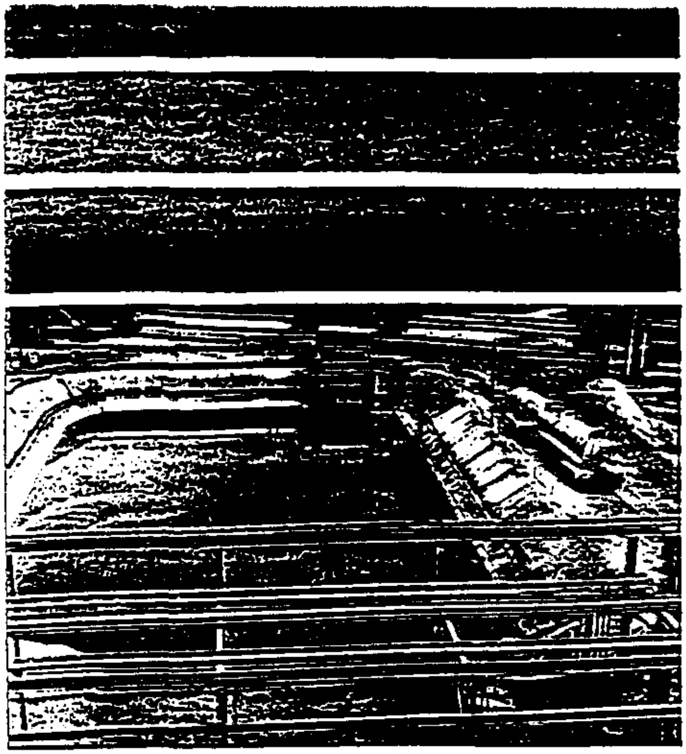

or Refractory Wastew with Hydrogen Peroxide

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Abstract

The partial oxidation of a variety of *non-biocompatible* organics using hydrogen peroxide was evaluated as a pretreatment step prior to biological oxidation of these organics. The compounds tested were 2, 4-dichlorophenol, dinitro-ortho-cresol and two unknown phenolic wastewaters of industrial origin. Fenton's Reagent, $FeSO_4$, was used as the catalyst for production of reactive free-radical species at pH 3.5. The residual by-products of hydrogen peroxide oxidation were evaluated based on toxicity (Microtox®), and biodegradability (*fed-batch* reactors) in relation to a typical municipal sludge and a *standard* acclimated laboratory sludge. In all cases, the by-products were about an order of magnitude less toxic than the initial compounds. For example, given 650 mg/l of 2, 4-dichlorophenol, the initial EC50 was 0.32% and the uptake rate (based on total organic carbon) by municipal sludge was 0.0 versus an EC50 of 2.5% and an uptake rate of 3.47 mg TOC/g VSS-hr after reaction with hydrogen peroxide.

Keywords

Hydrogen peroxide; toxic and refractory organics; toxicity reduction; increased biodegradability.

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Introduction

hemical oxidants may be used to treat aqueous wastewaters containing a wide variety of organic compounds. Typically, chemical oxidation is reserved for wastewaters containing compounds that are toxic, inhibitory or refractory to common microorganisms, i.e., *non-biocompatible* organic constituents. Otherwise, microbial oxidation of these wastes would be successful and economically more attractive than chemical oxidation.

When a refractory, toxic or inhibitory organic is reacted with a chemical oxidant, several types of degradation may occur:[1]

- *Primary degradation* - a structural change in the parent compound; biodegradability may be improved;
- *Acceptable degradation* - degradation to the extent that toxicity is reduced; or,
- *Ultimate degradation* - complete destruction to CO_2, H_2O and other inorganics.

A primary or acceptable degradation may occur at relatively low consumptions of oxidants and be much more efficient than ultimate degradation.

This work examines the use of hydrogen peroxide as a chemical oxidant for pretreatment of non-biocompatible organics. The effect of hydrogen peroxide oxidation on the biodegradability and toxicity of several pure compounds and industrial wastewaters has been evaluated.

Evaluation of oxidant performance

onitoring the course of oxidation reactions is not particularly straightforward. While measurement of the actual reacting species indicates a *primary degradation*, this does not indicate the degree of degradation or the acceptability of the reaction products. Conventional parameters, such as Total Organic Carbon (TOC) and Chemical Oxygen Demand (COD), indicate the amount of ultimate conversion (TOC) and degree of oxidation (COD). In addition, the average oxidation state (OX) of organic carbon in the waste mixture may be expressed as: [2]

- $OX = 4\,(TOC - COD)/TOC$ (1)

In complex wastewaters (*biocompatible* and *nonbiocompatible organics*), there is no guarantee on which components have been altered. Therefore, the relation between the extent of reaction and biocompatibility of the wastewater is more difficult to quantify. Biochemical Oxygen Demand (BOD) is not a valid tool for measuring the original *non-biocompatible* components due to their toxic or refractory nature. Upon reaction with oxidants, these original species may be partially degraded, resulting in more *biocompatible* components. However, the BOD test requires an acclimated seed, and failure to exhibit a significant increase in BOD after reaction does not rule out the success of the chemical oxidation process. Instead, a continuous process should be evaluated using activated sludge which has been acclimated to the pretreated wastewater.

Toxicity of the wastewater may be evaluated before and after chemical oxidation by any of a variety of standard techniques. Typically, one would compare effluents based on the tests required by the discharge permit. However, tests based on Microtox® and/or LD_{50} (Daphnia Magna, misid shrimp, etc.) will reflect the effects of chemical oxidation on toxicity.

With these limitations in mind, a *fed-batch* reactor scheme was developed to evaluate the biodegradability of the components before and after reaction with hydrogen peroxide. In addition, a continuous sludge culture, acclimated to 2, 4-dichlorophenol and a variety of other organic compounds, was used as a standard sludge throughout the testing.

Materials and methods

Hydrogen Peroxide Oxidation

The reaction of toxic and/or refractory organics was carried out in batch stirred reactors. The pH was maintained constant during the course of reaction by addition of NaOH or H_2SO_4 as required (pH ± 0.2). Free radical formation was catalyzed by ferrous sulfate (Fenton's Reagent) addition, 10 to 100 mg/l as Fe, *added from a stock solution of* $FeSO_4$ *(1000 mg/l as Fe)* which was stored under refrigerated conditions and replaced with fresh solution on a monthly basis.

Sample analysis during the reaction included Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), total phenolics (measured by the 4-aminoantipyrine, 4-AAP, colorimetric technique), and residual hydrogen peroxide (by potassium iodide-sodium thiosulfate titration procedure). To preserve the samples for tests *other than residual* H_2O_2*, the peroxide was quickly* destroyed by the addition of catalase (Fermcolase-1000, Finnsugar Biochemicals, Inc., Elk Grove Village, IL) and the absence of H_2O_2 was confirmed by H_2O_2 test strips (E.M. QUANT, EM Science, Inc., Cherry Hill NJ).

Initially, a standardized set of reaction conditions was established using 2,4-dichlorophenol (DCP) as the model compound. For DCP, the following ultimate reaction may occur:

- $C_6H_3OHCl_2 + 13\ H_2O_2 \rightarrow 6\ CO_2 + 15\ H_2O + 2Cl^-$ (2)

However, in this case, it is not desired to convert DCP to CO_2 but rather to cause a less extensive primary or acceptable degradation of DCP. Based on the initial screening, the following reaction conditions were found to be most suitable:

- pH = 3.5
- H_2O_2 : DCP = 4:1 (molar basis)
- $FeSO_4$ = 10 to 100 mg/l (as Fe)

The catalyst concentration was 10 mg/l for the synthetic wastewaters but was increased for the wastewaters collected from the field if the reaction was unacceptably slow. The optimum pH (3.5) correlates well with previous data and corresponds with the maximum rate of free-radical formation by the $FeSO_4$ catalyst.(3) Additionally, it *was found that a stepwise addition of* H_2O_2 *was more* effective than a large initial input. Therefore, the required H_2O_2 dosage was divided up and added in equal fractions at one-hour intervals over a four-hour reaction period.

Several points in the batch oxidation reactions were sampled for further study (toxicity and biodegradability). These points were identified as follows:

- *Point A* - the initial wastewater without H_2O_2 oxidation
- *Point B* - an intermediate point in the reaction corresponding to a *break point* in the COD/TOC *ratio* of the residual chemical species (15 minutes reaction time)
- *Point C* - the final point in the reaction corresponding to no further reaction with hydrogen peroxide (4 hours reaction time)

Toxicity Testing

Toxicity *was measured in terms of the* EC50 using the Microtox® toxicity analyzer. The EC50 is the percent sample volume required to inhibit light production of luminescent bacteria by 50%. All procedures were in accordance with standard operating procedures.(4)

Fed-batch Reactors

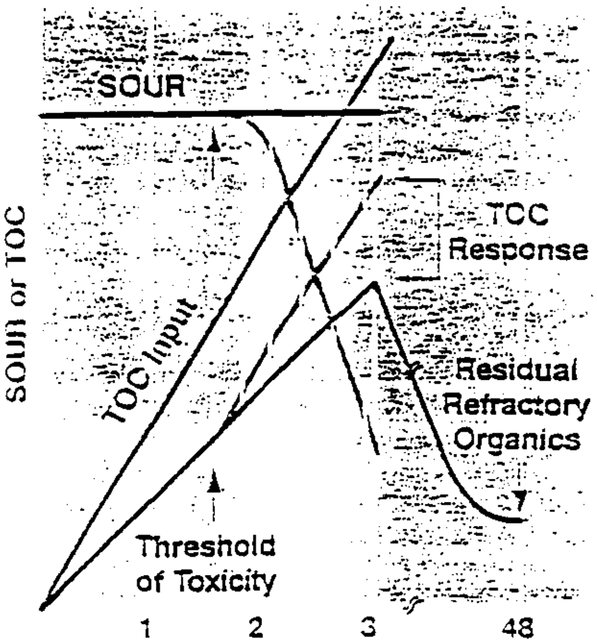
Fed-batch reactors (FBR's) were used to evaluate the biodegradability of the reaction products. The *fed-batch* reactor schema consists of pumping wastewater into a reactor at a rate faster than the microorganisms can utilize the substrates. This is accomplished by pumping in substrate at a very high concentration and low inflow rate, resulting in a semi-batch reactor without significant volume change. In addition, the reactor is well aerated and the dissolved oxygen levels are kept sufficient (> 4 mg/l). The FBR permits observations under conditions ranging from sub-lethal to toxic in the reactor.(5-8) The specific oxygen utilization rate (SOUR), 4-AAP *active substances,* COD *and* TOC were monitored during the reaction between the microorganisms and the substrates. At the end of the FBR test, 3 or 4 hours, the residual substrate was allowed to stand in contact (aerated) with the bacteria for 48 hours. After this time, the residual was measured for COD and TOC to determine the refractory compounds remaining.

A typical response for toxic and non-toxic substrates applied to a *fed-batch* reactor is shown in Figure 1. The *fed-batch reactors* provided an estimate of the threshold concentration where toxicity was introduced and/or a maximum specific substrate utilization rate (q_{max}), where q_{max} may be found from the difference in the slope of the substrate input and the substrate response within the reactor, or:

- $q_{max} = (S_{in} - S_r) / X$
- S_{in} = substrate input (mg l^{-1} hr^{-1})
- S_r = substrate response (mg l^{-1} hr^{-1})
- X = *mixed liquor volatile suspended solids* (mg l^{-1})

Figure 1

Typical results for a "fed-batch" reactor. A comparison of toxic (dashed lines) and non-toxic (solid lines) inputs.



Note: Input is shut off after 3 hours and COD and TOC are measured after 48 hours to determine residual refractory compounds.

Biological Sludge

The biodegradability was evaluated in FBR's using two separate biological sludges of different character. The first sludge was obtained from the Metro Nashville Central Wastewater Treatment Facility as needed. This sludge was considered to be typical of municipal waste treatment processes. Although it is recognized that some time-dependent variability in the sludge characteristics are unavoidable, this was the only way to evaluate the impact of reaction products on *unacclimated* municipal sewage sludge.

The second sludge was prepared in the laboratory as a standard *well acclimated* sludge. This sludge was acclimated to a variety of common organics and some more difficult, but biodegradable, organics of industrial origin. The feed used was a slight variation of that used by Kincannon, et. al.,[9] and consisted of the following:

• Acetic acid	10 mg/l
• Ethyl alcohol	4 mg/l
• Glutamic acid	9 mg/l
• Ethylene glycol	10 mg/l
• 2, 4-dichlorophenol	41 mg/l

These components were fed continuously at a rate of 1 liter per day. In addition, glucose and essential nutrients were fed to the sludge reactors in a semi-batch mode. This batch feed consisted of the following:

• Mg^{+2}	5 mg/l
• Fe^{+2}	0.3 mg/l
• NH_4^+	35 mg/l
• Phosphate buffer	1,463 mg/l K_2HPO_4 (as PO_4^{-3})
	1,051 mg/l KH_2PO_4 (as PO_4^{-3})
• Glucose	591 mg/l

This was added once per day in a 10-liter increment. In addition, the reactor operating characteristics were maintained as follows:

- $F/M = 0.15\ d^{-1}$ (COD basis)
- $X_v = 2{,}500$ mg/l
- $\theta_h = 2$ days (hydraulic residence time)

The sludge was acclimated by starting with a weakened continuous feed which was gradually strengthened until DCP was readily degraded (about 4 weeks) and then the full-strength feed was applied continuously.

Wastewater Characteristics

Synthetic wastewaters were prepared in the laboratory and several industrial wastewaters were obtained from industrial sources. The industrial wastewaters were characterized according to COD, TOC, pH, 4-aminoantipyrine (4-AAP) reactive compounds and color. The characteristics of all wastewaters tested are given in Table 1.

Results and discussion

Batch reaction with hydrogen peroxide

The wastewaters, synthetic or from industrial sources, were reacted with hydrogen peroxide dosages significantly less than that required for ultimate oxidation, e.g., 4:1 H_2O_2 to DCP versus 13:1 required for ultimate conversion. The intent of these reaction conditions was to induce a primary or acceptable conversion at a much smaller oxidant cost than ultimate conversion. Ideally, during the course of the oxidation reaction, the TOC would not change (indicating no ultimate removal) while the phenolics (as measured by the 4-AAP techniques for DCP and wastewaters I and II) would be completely removed and the COD would be greatly reduced. This would indicate at least a primary degradation of the original compounds. A typical set of batch reaction data is shown in Figure 2 for DCP.

The data are not ideal, as some ultimate conversion does occur. However, after an initial decrease, the TOC does remain fairly constant while the residual DCP drops to a small percentage of the original (< 10%) and the COD continues to decrease over the course of the reaction.

In general, the 4-AAP analytical technique is sensitive to a wide variety of phenolic compounds.[10] Therefore, the identity of the residual 4-AAP reactive compounds was not strictly known. To evaluate the validity of this technique as a measure of the original compound, one set of results was analyzed using gas chromatography for DCP and the 4-AAP technique. The results indicated a close agreement between DCP measured specifically and the equivalent DCP measured by the 4-AAP technique. Some additional compounds were measured by the 4-AAP technique (difference in DCP by GC = − 2.0 to 53.7% (average = − 27.3%)). However, it may be

Table 1

Characteristics of wastewaters used in this work.

Wastewater	*pH*	*COD (mg/l)*	*TOC (mg/l)*	*4-AAP (mg/l)*	*Color*
DCP	3.5	758	276	650	colorless
DNOC*	3.5	335	71	—	colorless
I	6.8	1,277	433	352	colorless
II	12.2	6,365	2,092	1,389	pale yellow

*DNOC = dinitro-ortho-cresol

concluded that few of the byproducts of DCP oxidation by hydrogen peroxide are still in the phenolic form and that the 4-AAP test is an excellent measure of the primary degradation of DCP and other phenolics.

The efficiency of the reaction process may be evaluated according to the fraction of the ultimate hydrogen peroxide used during the oxidation, or:

- $f = H_2O_2 / (2.13\ COD_0)$ (4)

  where
- f = fraction of ultimate hydrogen peroxide used
- H_2O_2 = hydrogen peroxide actually consumed during reaction
- COD_0 = initial COD of the wastewater

  and,
- 2.13 represents the conversion factor for O_2 demand to hydrogen peroxide demand.

A complete summary of the hydrogen peroxide reaction data is given in Table 2.

The data indicate quite clearly that the original compounds, such as DCP, are almost completely converted to other organics, or that a primary degradation has occurred. This was carried out with little ultimate conversion (12.1 to 36.1%) of the organics and at a much reduced chemical consumption (26 to 56%) compared to that required for ultimate conversion.

Table 2

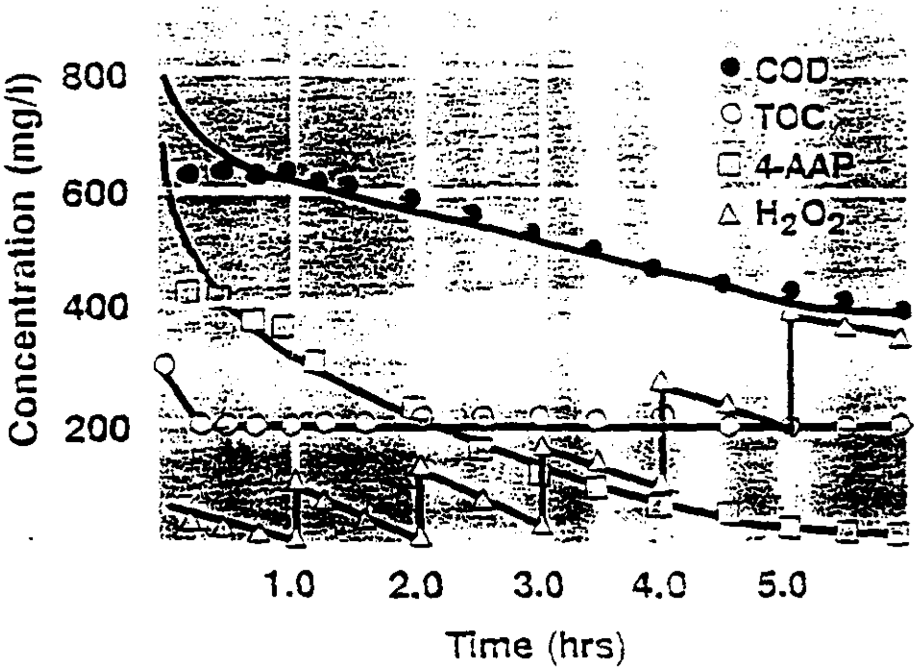
Summary of hydrogen peroxide reaction data.[a]

Wastewater[b]	*% Phenolics Converted*[c]	*% TOC Conversion*[d]	*f*[e]
DCP	95	36.1	0.29
DNOC	---[f]	30.2	0.56
I	94	12.1	0.26
II	88	22.4	0.34

a: based on essentially complete reaction (of C)
b: initial compositions as reported in Table 1
c: as measured by reduction in 4-AAP reactive compounds (DCP standard)
d: represents degree of ultimate conversion
e: based on Equation 4
f: DNOC is not 4-AAP reactive

Figure 2

Batch reaction data for DCP and hydrogen peroxide.



Note: H_2O_2 is applied in a stepwise fashion.

COD-TOC ratio

The role of COD and TOC in evaluation of the wastewaters and the reaction of hydrogen peroxide was twofold:

1. The amount of carbon converted to CO_2 could be readily determined from the TOC; and
2. The ratio of COD to TOC defined an average oxidation state of the carbon that was related to the degree of change in the structure of the organic compounds after oxidation with hydrogen peroxide.

The COD-TOC ratio was converted to the mean oxidation state for each of the wastewaters using Equation 1 (COD and TOC on a molar basis). The results are compared in Figure 3.

The data show conclusively that all of the hydrogen peroxide was not used for ultimate conversion of organic carbon, but rather the original compounds were drastically altered, leaving byproducts in which the mean oxidation state of the carbon were more highly oxidized (positive instead of negative). DNOC exhibited the greatest change (Δ OX = +2.22) and the smallest change was for DCP (Δ OX = +0.867).

Toxicity of oxidation byproducts

The hydrogen peroxide oxidation byproducts were examined to determine the change in toxicity with the primary degradation of the organics. A summary of the toxicity data is given in Table 3.

Table 3

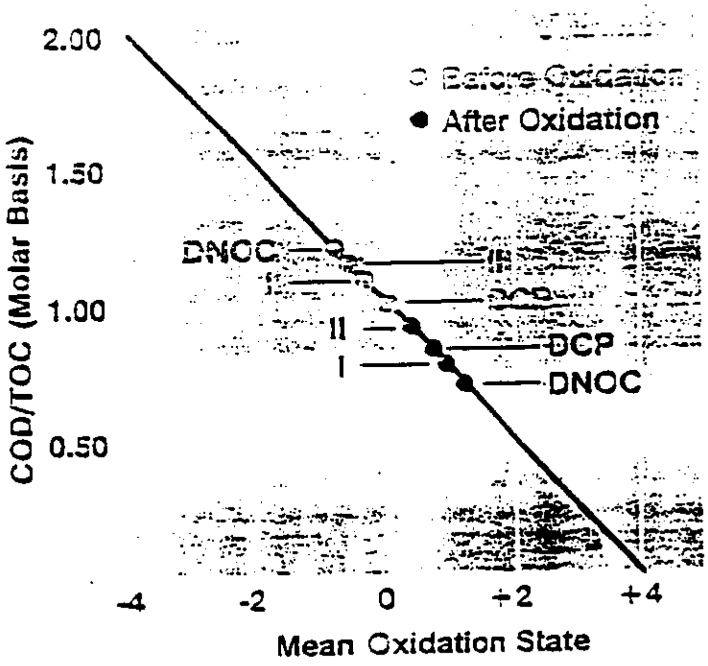
Toxicity results for various wastewaters.

Wastewater[a]	*Reaction Point*	*EC50(%)*[b]
DCP	A	0.32
	B	0.27
	C	2.53
DNOC	A	3.86
	C	> 100
I	A	1.05
	B	2.00
	C	33.1
II	A	1.30
	C	15.2

a Initial characteristics (at A) as reported in Table 1
b % volume to cause a 50% decrease in light production, based on Microtox®

Figure 3

COD/TOC ratio versus mean oxidation state of carbon in system.



Note: A + 4 oxidation state corresponds to inorganic carbon (CO_2) and a − 4 oxidation state corresponds to methane, after Stumm and Morgan.(2)

The results clearly show that the toxicity was substantially reduced by conversion of the original compounds to less toxic byproducts (pt C), i.e., an acceptable degradation. It should be noted that the intermediate byproducts (pt 3) were not significantly less toxic, and may have been more toxic, than the original organics. In addition, only a fraction of the organics were ultimately converted to carbon dioxide (see Table 2). Therefore, a series of parallel reactions appears to occur in which a variety of byproducts appear sequentially. This is illustrated schematically in Figure 4.

Evaluation of biodegradability

The biodegradability of the wastewaters was evaluated using the unacclimated municipal sludge and the standardized laboratory sludge that was acclimated to DCP. The results of these evaluations are reported in Table 4, based on TOC and COD.

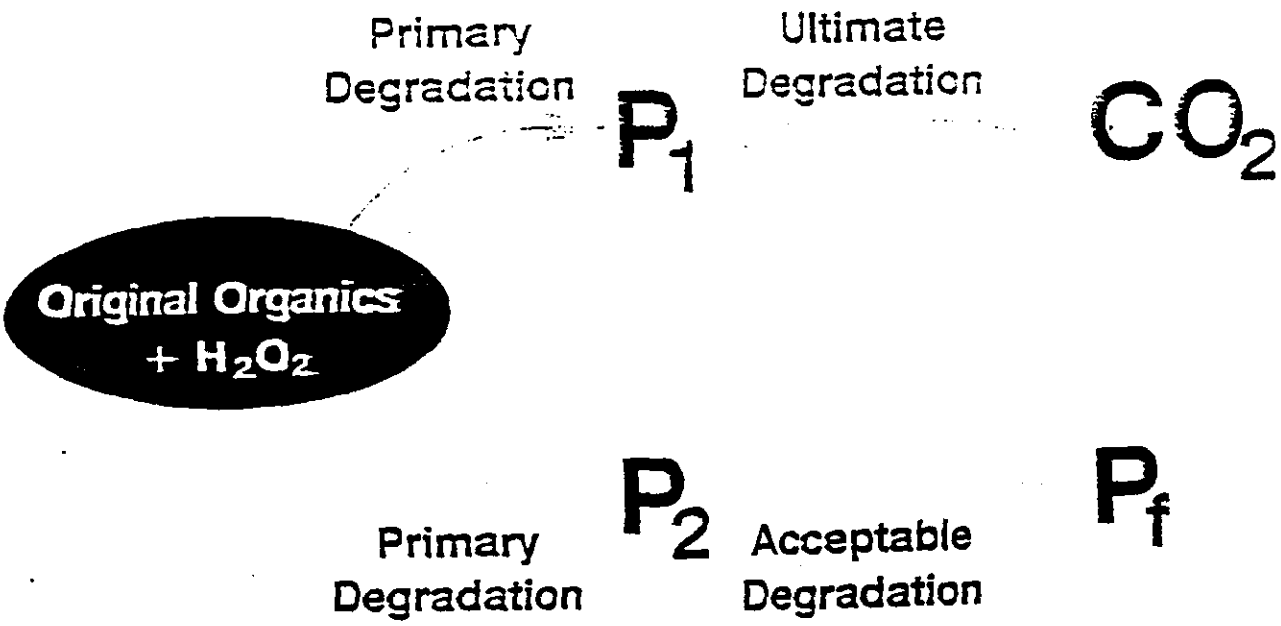
The data shown in Table 4 are encouraging. The results clearly indicate, on both a TOC and COD basis, that the biological uptake rate of DCP can be improved by reaction with H_2O_2. This was seen for the case of unacclimated municipal sludge and for the acclimated standard sludge. Wastewater I exhibited roughly the same biodegradability before and after reaction, while Wastewater II showed a marked improvement in biodegradability after reaction for both the municipal and the acclimated laboratory sludges, i.e., for municipal sludge Wastewater II exhibited a 50.6% increase in TOC uptake and a 51.7% increase in COD uptake.

Additional data regarding the toxicity and refractory nature of the compounds after biological treatment were collected by turning off the waste feed to the *fed-batch reactors and aerating for 48 hours*. At the end of this time, the mixture was sampled for residual TOC and COD (these compounds were considered refractory) and residual toxicity. The results of this testing are reported in Table 5.

The data indicate that the hydrogen peroxide pre-treatment results in a decreased toxicity of the final effluent after biological treatment was "complete", using either general municipal sludge or the standard laboratory sludge. Wastewater I showed a much improved toxicity compared to the raw wastewater but showed a slight deterioration in the residual refractory compounds, while Wastewater II showed equivalent toxicities (all minimal) but an improvement in the residual refractory compounds.

Figure 4

Proposed oxidation pathways for reaction of hydrogen peroxide and organics.



Note: P_1 = byproducts that are eventually degraded to CO_2, P_2 = byproducts that are eventually degraded to less toxic byproducts P_f.

Table 4

Biodegradability comparisons of wastewaters before and after reaction with hydrogen peroxide.

Wastewater[a]	Reaction Point	q_{max}[b] (mg TOC/g VSS-hr) Municipal	q_{max}[b] (mg TOC/g VSS-hr) Acclimated	q_{max}[b] (mg COD/g VSS-hr) Municipal	q_{max}[b] (mg COD/g VSS-hr) Acclimated
DCP	A	0	1.44	0	4.42
	B	0.66	1.51	0	5.23
	C	3.47	1.66	7.58	6.00
I	A	3.39	4.37	10.80	12.10
	B	5.10	5.37	11.76	11.38
	C	5.10	5.17	10.30	9.71
II	A	4.17	7.64	6.50	9.03
	C	6.28	7.60	9.36	9.02

a: Initial compositions as reported in Table 1

b: from fed-batch reactor data

Table 5

The residual organics and toxicity of wastewaters and reaction products after 48 hours of biological contact.

Wastewater	Reaction Point	48-Hour Toxicity, EC50(%) Municipal	48-Hour Toxicity, EC50(%) Acclimated	Refractory Compounds (%)[b] Municipal	Refractory Compounds (%)[b] Acclimated
DCP	A	3.66	>100 (22.6)	100	22.1
	B	4.92	>100 (42.0)	96.5	38.5
	C	14.10	>100 (31.1)	61.8 (43.1)	53.7 (37.4)
DNOC	A	13.83	13.22	100	96
	B	>100 (22.5)	>100 (27.7)	21.6 (15.6)	41.9 (30.2)
I	A	85.0	14.3	15.1	19.9
	B	>100 (38.8)[a]	87.2	29.2	33.5
	C	>100 (30)[a]	>100 (30)[a]	30.2 (26.5)[c]	28.7 (25.1)[c]
II	A	>100 (21.4)[a]	>100 (20.5)[a]	76.2	79.7
	C	>100 (30.4)[a]	>100 (24.5)[a]	49.7 (38.6)[c]	76.4 (59.4)[c]

a: values in parentheses are for undiluted samples which were not toxic enough to produce an EC50, the values represent the effect at 100% concentration

b: based on TOC

c: values in parentheses are adjusted to account for TOC lost by ultimate conversion to CO_2 during oxidation, 12% for wastewater I and 22.3% for wastewater II

Conclusions

Hydrogen peroxide oxidation was evaluated as a pretreatment process for toxic, inhibitory or refractory organics. Based on the Microtox® technique, DCP, DNOC and two industrial wastewaters were shown to have significant improvements in toxicity after oxidation with hydrogen peroxide. In addition, the biodegradability of the wastewaters and the residual toxicity after biological treatment were generally improved after oxidation with hydrogen peroxide as well. Most significantly, the final oxidation byproducts were biodegradable by an unacclimated municipal activated sludge.

The hydrogen peroxide pretreatment process, coupled with biological treatment, resulted in a substantial savings in the required oxidant dosage versus ultimate chemical oxidation, i.e., 26 to 56% of the ultimate requirement. This process has a variety of applications for industries that generate quantities of *non-biocompatible* organics. The hydrogen peroxide treatment may be used as pretreatment prior to discharge into a municipal sewer, pretreatment prior to on-site biological treatment, or post treatment to reduce the toxicity of an effluent that otherwise meets the discharge standards.

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Appendix 2

University of Nevada Study

TREATMENT OF CONTAMINATED SOILS USING CATALYZED HYDROGEN PEROXIDE

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ABSTRACT

The on site and in situ generation of strong oxidants is a potential mechanism for treating refractory organic contaminants in soils. One method of introducing oxidants into soils is the catalyzed decomposition of hydrogen peroxide by iron (II) to form hydroxyl radical, which is commonly known as Fenton's reagent. Hydroxyl radical has over twice the oxidation potential of chlorine and is 25% stronger than ozone. It reacts with organic compounds in aqueous solutions with rate constants of 10^7 to 10^{10} M^{-1} sec^{-1}. Hydroxyl radical is therefore a strong, nonspecific oxidant capable of widespread destruction of organic compounds.

Pentachlorophenol (PCP) was used as a model contaminant in the Fenton's reagent treatment of soils of varying complexity. Mineralization of PCP in a simple two-phase system (silica sand-Fenton's reagent) was demonstrated by the removal of the parent compound (PCP) and the total organic carbon associated with the PCP. In addition, stoichiometric quantities of chloride were recovered at the end of the experiment, which also supports mineralization. Fenton's reagent, when used to treat PCP in natural soils and silica sand, was most effective at pH 2-to-3. In soils of varied organic carbon content, no iron ammendment provided the most efficient reaction (i.e., the greatest ratio of the contaminant degradation rate to the peroxide consumption rate). The efficient reactions occurring with no iron addition in natural soils may have been due to the dissolution of iron minerals which promote catalyzed peroxide decomposition or Fenton-like heterogeneous catalysis occuring on the surfaces of iron minerals.

INTRODUCTION

The uncontrolled disposal of hazardous wastes prior to promulgation of the Resource Conservation and Recovery Act has resulted in the contamination of thousands of sites in the United States [1]. In addition, over 18,000 accidental hazardous materials spills occur each year in the U.S. transportation industry [2].

A large number of these sites which have resulted from uncontrolled and accidental hazardous waste releases are characterized by contaminated surface soils. Excavation and landfill disposal, incineration, and bioremediation have been used to clean up contaminated soils; however, not one process works universally for all sites and all contaminants. For [illegible] has been effective in treating soils contaminated with hazardous compounds [3]. However, some waste components are toxic to microorganisms and many are slowly biodegraded; half-lifes of up to several months for some compounds are not uncommon during bioremediation efforts [4]. Therefore, new processes are needed to clean up the range of contaminants commonly found at hazardous waste sites [5].

The on site introduction of strong oxidants into contaminated soils may provide a means of destroying biorefractory contaminants over time periods less than required for biological treatment. A documented process for generating strong oxidants in aqueous solutions is Fenton's reagent, which is the reaction of hydrogen peroxide and iron (II) to generate hydroxyl radical ($OH\cdot$) [6]:

$$H_2O_2 + Fe^{2+} \longrightarrow OH\cdot + OH^- + Fe^{3+} \qquad (1)$$

Hydroxyl radical is second only to fluorine in oxidation potential and is capable of nonspecific oxidations because it reacts with organic compounds with bimolecular rate constants of 10^7 to 10^{10} L/mole-sec [7]. Fenton's reagent also involves numerous competing reactions [6, 8, 9]:

$$H_2O_2 + Fe^{3+} \longrightarrow Fe^{2+} + H^+ + HO_2\cdot \qquad (2)$$

$$RH + OH\cdot \longrightarrow H_2O + R\cdot \qquad (3)$$

$$Fe^{2+} + OH\cdot \longrightarrow Fe^{3+} + OH^- \qquad (4)$$

$$R\cdot + Fe^{3+} \longrightarrow Fe^{2+} + \text{products} \qquad (5)$$

$$R\cdot + OH\cdot \longrightarrow ROH \qquad (6)$$

$$R\cdot + H_2O_2 \longrightarrow ROH + OH\cdot \qquad (7)$$

$$HO_2\cdot + Fe^{3+} \longrightarrow O_2 + Fe^{2+} + H^+ \qquad (8)$$

$$OH\cdot + H_2O_2 \longrightarrow HO_2\cdot + H_2O \qquad (9)$$

where RH represents an oxidizable substrate, $R\cdot$ is an alkyl radical and $HO_2\cdot$ is superoxide radical. The rate constant for Equation 1 is 76 L/mole-sec. Rate constants for Equations 3, 5, 6, and 7 are substrate specific [8]. The rate constant for Equation 4 is 3×10^8 L/mole-sec [6]; the rate constant for Equation 8 is pH dependent and ranges from 2×10^4 to 1×10^6 L/mole-sec [9, 10].

The fundamental aspects of Fenton's chemistry have been well documented. For example, Walling and Johnson (11) investigated the conditions that favor hydrogen abstraction vs. hydroxyl radical addition to substituted benzenes. Ingles [9] provided similar information with low molecular weight aliphatic alcohols.

Fenton's reagent has recently been applied to the treatment of organic contaminants. Barbeni et al. [12] investigated the Fenton's oxidation of di- and tri-chlorophenols in aqueous solution. A mass balance in their system involving the measurement of residual chlorophenol, chloride, and total organic carbon showed that the chlorophenols were mineralized by the treatment. Fenton's reagent also successfully oxidized a formaldehyde waste stream under bench-scale conditions [13]. The process has also been used to treat [illegible] containing sodium dodecylbenzenesulfonate [14], *p*-toluenesulfonic acid and *p*-[illegible] have systematically investigated the Fenton's reagent treat[illegible] comprehensive effort to study the Fenton's reagent treatment of soils, the purpose of our research has been to determine the optimum conditions for Fenton's soil treatment. Most Fenton's reagent research has used H_2O_2 concentrations from 0.05% to 1.0% [9]. However, this investigation used H_2O_2 concentrations in excess of what would be required to stoichiometrically oxidize the substrate in order to promote mineralization.

METHODS AND MATERIALS

MODEL CONTAMINANT

Pentachlorophenol, a widely-used wood preservative, was used as a model contaminant. Pentachlorophenol is moderately biorefractory. Mabey et al. [17] reported a biodegradation rate constant of 3×10^{-12} L/cell·hour, log K_{ow} of 5.01, and vapor pressure of 1.1×10^{-4} mm Hg at 20°C.

SOILS

Commercially-available silica sand (40-100 mesh) and one natural soil were used. The natural soil was a grayish-brown, gravelly-loamy coarse sand, mixed, mesic, torriothentic haploxeroll. The soil, which was sampled from an alluvial fan in the Carson Valley, Nevada, is one of low development; therefore, successive horizons provided a gradient of soil organic carbon contents, but were relatively uniform in particle size distribution, mineralogy, cation exchange capacity, and pH. Particle size analysis was determined by the pipette method [18]. Organic carbon was determined by combustion at 900°C with evolved CO_2 trapped in KOH and measured by back titration of unreacted KOH [19]. Amorphous and crystalline iron and manganese oxyhydroxides were determined by citrate-bicarbonate-dithionite extraction [20]. Cation exchange capacity was established by saturation with sodium acetate at pH 8.2 [21]. The soil characteristics are shown in Table 1.

PROCEDURES

The soils were spiked with 250 mg/Kg pentachlorophenol by adding a PCP-acetone solution to the soil; the acetone was allowed to evaporate. Experiments were conducted in batch, completely mixed systems. To 2.5 g of PCP-contaminated soil in a 40 mL borosilicate glass vial, 12.5 mL of 7% H_2O_2 were added followed by 1 mL of a $FeSO_4$ solution or deionized water to provide a final ammendment of 0, 240 mg/L (0.024%), or 400 mg/L (0.040%) iron in the aqueous phase.

Separate experimental units conducted in duplicate vials were used to monitor treatment effectiveness at a minimum of 5 time periods over 24 hours. At the time designated, an aliquot of the soil-water was collected for hydrogen peroxide analysis. The reaction was then stopped by the addition of eight drops of concentrated sulfuric acid to the vials. The ability of concentrated H_2SO_4 to quench PCP oxidation was documented by monitoring pentachlorophenol degradation in acidified samples over 8 hours. No PCP degradation was observed. The soil slurries were shake-extracted with 3 mL of ethyl acetate for 30 minutes and then centrifuged for 15 minutes at 1,200 rpm.

Solubie iron was measured in parallel samples by filtering the soil slurry through a GFC filter. Total organic carbon and chloride were also measured on experiments conducted in parallel. Total organic carbon was determined by conducting the reactions in sealed TOC ampules. At selected times, [illegible] CO_2 was measured on an OI 700 TOC analyzer.

TABLE I. SOIL CHARACTERISTICS

Organic carbon content (%)	0.2	0.5	1.0	1.7
% sand	85.3	86.5	86.3	86.1
% silt	12.3	11.0	10.9	10.3
% clay	2.4	2.5	2.8	3.1
Crystalline Fe oxides (%)	0.44	0.44	0.43	0.43
Crystalline Mn oxides (%)	0.01	0.01	0.01	0.01
Amorphous Fe oxides (%)	0..34	0.44	0.42	0.40
Amorphous Mn oxides (%)	0.01	0.01	0.01	0.01
Cation exchange capacity cmol/kg	4.04	4.28	4.59	4.90
pH	6.6	6.4	6.5	6.6

ANALYSES

Hydrogen peroxide concentrations were determined by iodometric titration with sodium thiosulfate. Residual pentachlorophenol was followed by gas chromatography after ethyl acetate extraction from the soil. A Hewlett-Packard 5890A gas chromatograph with a flame ionization detector and a 0.53 mm (ID) x 15m Supelco SPB-5 capillary column was used. Chromatographic conditions were: initial oven temperature 100°C; final oven temperature 240°C; program rate 30°C/min; injector temperature 200°C; detector temperature 240°C; and nitrogen carrier gas flow rate 20 mL/min. Soluble iron was analyzed using flame methodology on a Perkin Elmer 3030B atomic absorption spectrophotometer. Chloride was determined using a Fisher chloride electrode paired with a double junction reference electrode.

RESULTS AND DISCUSSION

TREATMENT KINETICS AND STOICHIOMETRY

Hydrogen peroxide consumption and pentachlorophenol degradation during a typical treatment experiment (250 mg/Kg pentachlorophenol, 7% hydrogen peroxide, and pH 3) as a function of time are shown in Figure 1. The data of Figure 1 show that pentachlorophenol and hydrogen peroxide first decomposed rapidly, with a slower decomposition rate after 3 hours of reaction. The expected rate in a Fenton's system is zero order because hydroxyl radical generation should approach steady state (Equation 1) with pentachlorophenol present in high concentrations: however, all decomposition rates, regardless of the hydrogen peroxide and iron ammendments, were not linear. The soluble iron concentrations as a function of time are also shown in Figure 1. Only 23% of iron added to the system could be recovered in solution at time zero. In addition, the soluble iron concentration decreased over the first three hours of treatment and the concentration remained relatively constant thereafter. A possible mechanism for iron precipitation may be:

$$Fe^{2+} + 1/2\,O_2 + 2OH^- \longrightarrow \gamma\text{-}FeOOH + H_2O \qquad (10)$$

which has a reaction half-life of 28 minutes at neutral pH [22]. The concentration of OH⁻ in the Fenton's system at pH 3 is four orders of magnitude less than in a system at neutral pH; a half-life adjusted for the difference in OH^- concentration may explain the 3 hour time requirement to reach the quasi-equilibrium soluble iron concentration of 9 mg/L.

The importance of soluble iron in catalyzing Fenton's reactions has been well documented [6]. Because the concentration of pentachlorophenol, peroxide, and soluble iron changed over time in the silica sand systems, rate quantitation was difficult. A turnover number commonly used in catalysis could not be used because the soluble catalyst concentration decreased over the course of the reaction. Therefore, pentachlorophenol and hydrogen peroxide concentrations as a function of time were fit to zero, first, and second-order models [23]. The first-order model provided the best fit of the data with $R^2 > 0.90$ for plots of the natural logarithm of concentration as a function of time. First-order fit of experimental data is a common practice for quantifying complex environmental processes, such as biochemical oxygen demand [24]. The reactions occurring in the Fenton's system are complex; however, the empirical fit of experimental data to the first-order model provided the most accurate means of comparing different treatment conditions.

The concentrations of pentachlorophenol, total organic carbon, and chloride over the course of the reaction followed in Figure 1 are shown in Figure 2. These data show that greater than 99.9% of the original pentachlorophenol was degraded in 24 hours and that the removal of total organic carbon closely followed pentachlorophenol degradation. These results are similar to those obtained by Barbeni et al. [12] who demonstrated the mineralization of di- and tri-chlorophenols in aqueous systems. The phenomenon that organic carbon was removed rapidly after pentachlorophenol degradation suggests that hydroxyl radical attack on the products is more rapid than on the parent compound. High rates of product degradation may be explained by the lower oxidation state of the ring as it is hydroxylated and the increased water solubility of the products. Substrate water solubility has been implicated in Fenton's reagent treatment reactivity [25]. The high oxidation state of halogenated organics also significantly affects reactivity with oxidizing species [26].

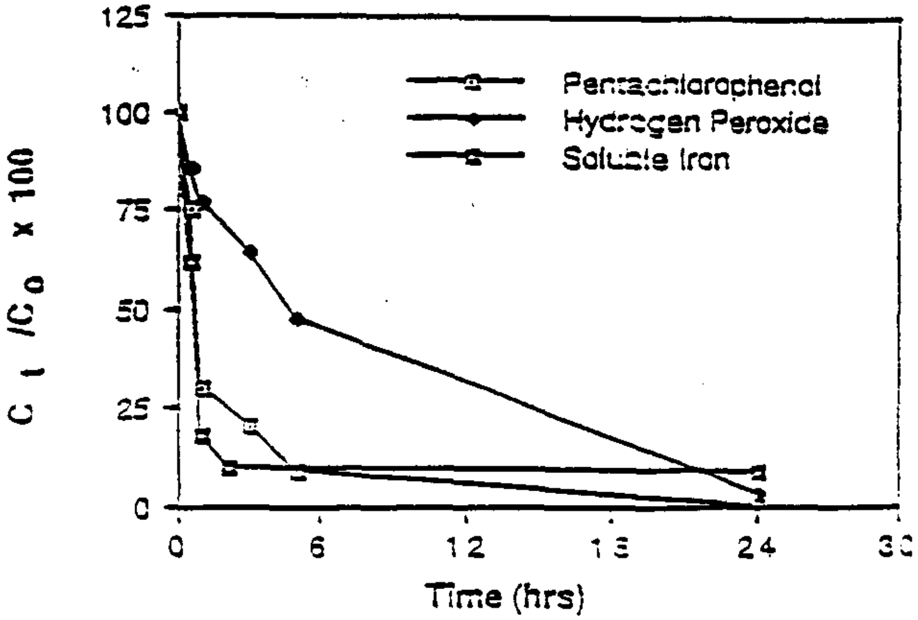

Figure 1. Concentrations of pentachlorophenol, hydrogen peroxide, and soluble iron during Fenton's treatment of 250 mg/Kg PCP in silica sand with 0.040% iron addition.

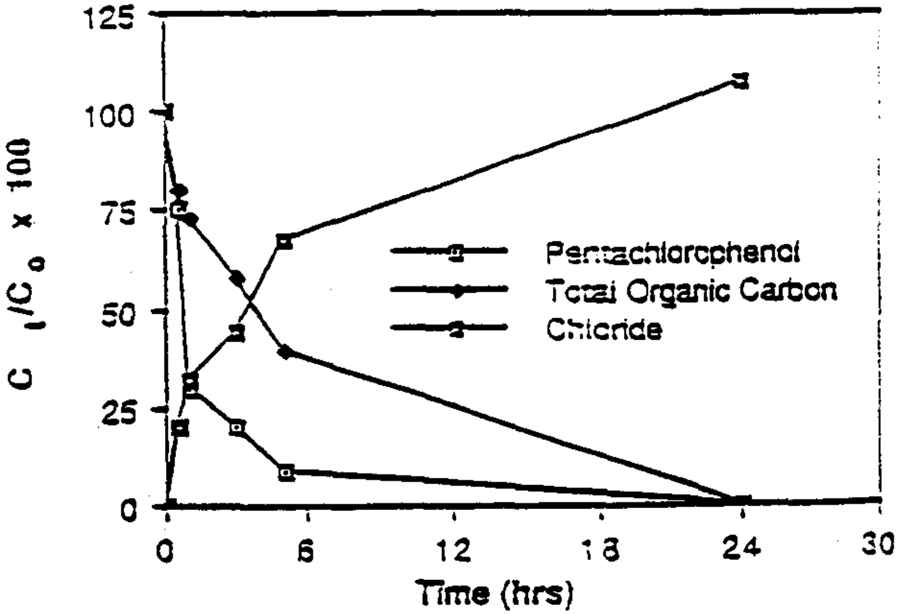

Figure 2. Concentrations of pentachlorophenol, total organic carbon, and chloride during Fenton's treatment of 250 mg/Kg PCP in silica sand.

EFFECT OF TREATMENT pH

First-order rate constants for PCP degradation and H_2O_2 decomposition as a function of pH in silica sand are shown in Figure 3 for experiments conducted with 0.040% iron addition. Treatment of pentachlorophenol in silica sand with no iron addition showed no degradation over 24 hours. With iron addition, PCP degradation rate constants increased significantly at low pH. Pentachlorophenol degradation was evident above pH 6 but at lower rates. The higher PCP degradation rate constants at low pH are probably related to the requirement of soluble iron in the system (6). In addition, the pH regime may enhance the cycling of iron (II) as described by Equations. 2, 5, and 8. While hydroxyl radical generation is enhanced at low pH, oxygen evolution is the predominant route of H_2O_2 decomposition at neutral pH [27]:

$$H_2O_2 \text{ -------> } 1/2\ O_2 + H_2O \qquad (11)$$

The primary cost of Fenton's reagent treatment is hydrogen peroxide at $1.72/gallon for a 50% aqueous solution. Therefore, the optimum treatment conditions will be characterized by a high rate of contaminant degradation with a <u>minimal</u> rate of H_2O_2 consumption. The data of Figure 3 show that the highest PCP degradation rate constants and the lowest peroxide decomposition rate constants were at pH 2 and 3. Similar results were obtained for reactions conducted in natural soils. In some cases PCP degradation rate constants at pH 4, 5, and 6 were higher than rate constants at pH 2 and 3. However, the corresponding rate constants for H_2O_2 decomposition increased above pH 3, which resulted in lower treatment efficiencies. Therefore, the optimum pH regime for all of the soil systems investigated was in the range of pH 2-to-3.

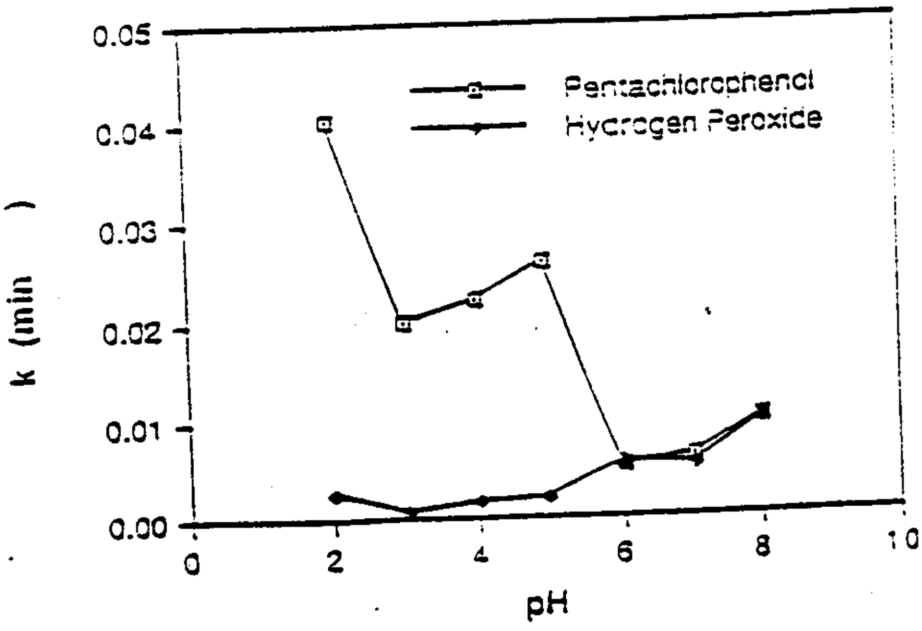

Figure 3. Effect of pH on the first-order rate constants for PCP degradation and H_2O_2 consumption.

EFFECT OF SOIL ORGANIC CARBON

First order rate constants for PCP degradation as a function of soil organic carbon are shown in Figure 4 for experiments conducted with 0, 0.024%, and 0.040% iron ammendments. Treatment of soils with 0.2% and 0.5% organic carbon and iron addition resulted in undetectable pentachlorophenol concentrations after 3 days. A factorial design analysis of variance (ANOVA) was used to evaluate equivalence of rate constant population means for the soils with the four soil organic carbon contents when iron was added. Pentachlorophenol degradation rate constants were significantly greater ($\alpha \leq 0.05$) in the soils with organic carbon < 1.0%. Degradation rate constants for pentachlorophenol degradation were not significantly different ($\alpha \leq 0.05$) when the soil organic carbon contents were ≥ 1.0%. These data suggest that soil organic carbon competed with PCP for hydroxyl radical generated by catalyzed peroxide decomposition.

Figure 5 shows the H_2O_2 decomposition rate constants as a function of soil organic carbon content for the systems with 0, 0.024% and 0.040% iron additions. Statistical analysis (ANOVA) showed that hydrogen peroxide decomposition rates were greater in systems with the addition 0.040% iron than in systems with 0.024% iron. Peroxide decomposition rates were also greater in systems with iron addition than systems without iron addition ($\alpha \leq 0.05$). In addition, no significant difference ($\alpha \leq 0.05$) was found between H_2O_2 decomposition rates as a function of soil organic carbon when no iron was added.

The optimum treatment efficiency in a Fenton's system is characterized by maximum contaminant degradation and minimum peroxide consumption. A ratio of contaminant degradation rate constants (k_{PCP}) to H_2O_2 decomposition rate constants ($k_{H_2O_2}$) is therefore an empirical measure of the relative efficiency of Fenton's reagent treatment. The

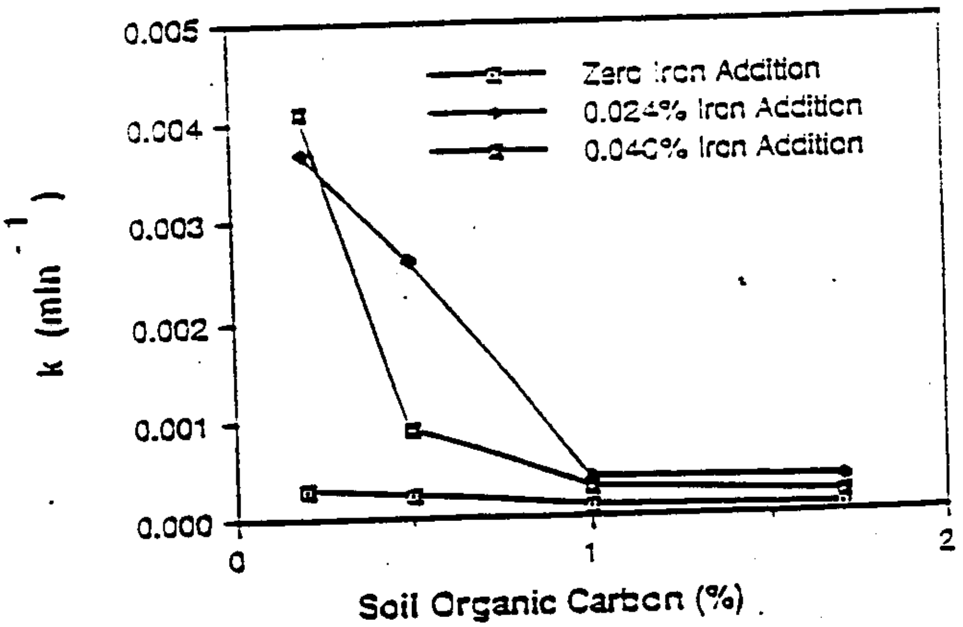

Figure 4. First-order rate constants for PCP degradation as a function of soil organic carbon.

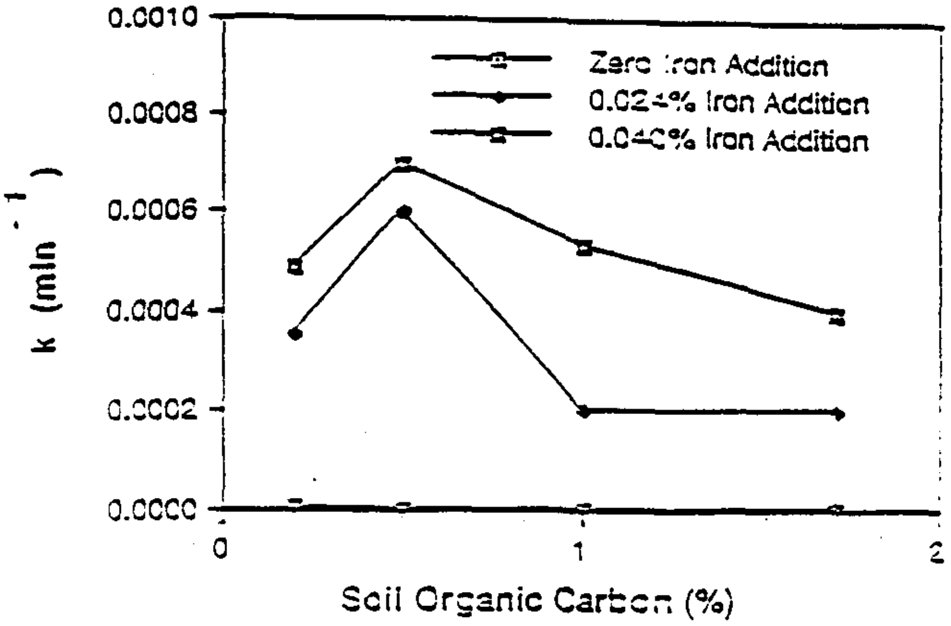

Figure 5. First-order rate constants for hydrogen peroxide consumption as a function of soil organic carbon

ratios were greater in the systems that did not receive the iron ammendment (Table II). In addition, the $k_{PCP}/k_{H_2O_2}$ ratios were higher in the soils with lower organic carbon contents for the treatment of pentachlorophenol. The data of Table II show that Fenton's treatment efficiencies were not only sensitive to the soil organic carbon content, but also to the iron ammendment. Therefore, the most efficient and economical Fenton's reagent treatment of PCP occurred without the addition of iron at low soil organic carbon contents.

The results of this research show that a range of biorefractory contaminants can be treated in soils at pH 3 in the presence of H_2O_2 without iron addition. The highest degradation rates for PCP *occurred with the addition of iron; however, the hydrogen peroxide decomposition* rates were also higher, which resulted in low treatment efficiencies. The process was most efficient when no iron was added to the system for all soil organic carbon contents evaluated. The PCP degradation efficiencies in natural soils (i.e., optimum treatment conditions requiring no iron amendment) suggest that crystalline and amorphous iron oxides may be promoting catalyzed peroxide decomposition.

Table II. ESTIMATION OF FENTON'S TREATMENT EFFICIENCY

Iron Addition	Organic Carbon			
	0.2%	*0.5%*	*1.0%*	*1.7%*
	k_{PCP} / $k_{H_2O_2}$			
0.040%	6.2	2.2	0.30	0.47
0.024%	13	1.5	0.59	1.0
0.00%	40	13	10	5.4

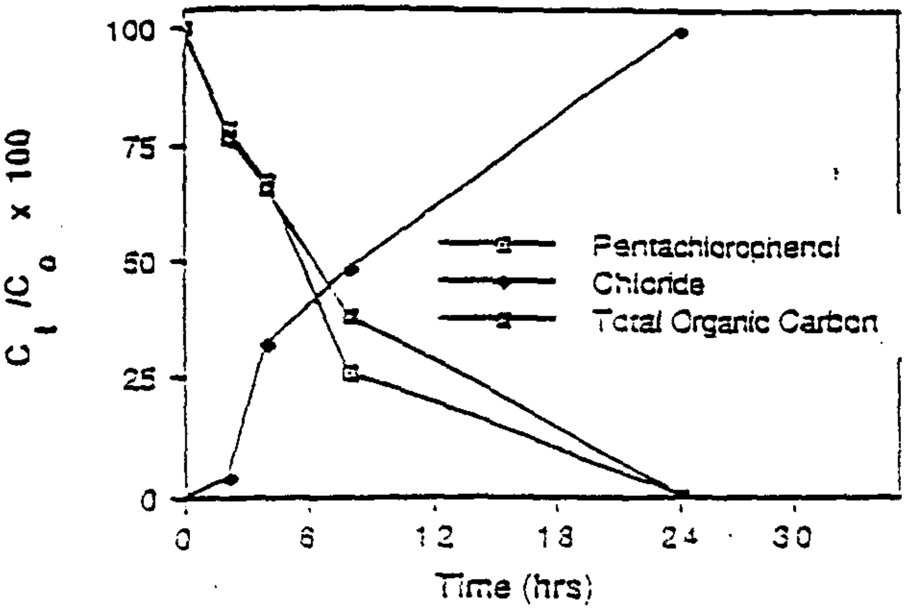

Figure 7. Concentrations of pentachlorophenol, total organic carbon, and chloride during Fenton's treatment of 250 mg/Kg PCP in silica sand with 16.7% magnetite as the sole iron source.

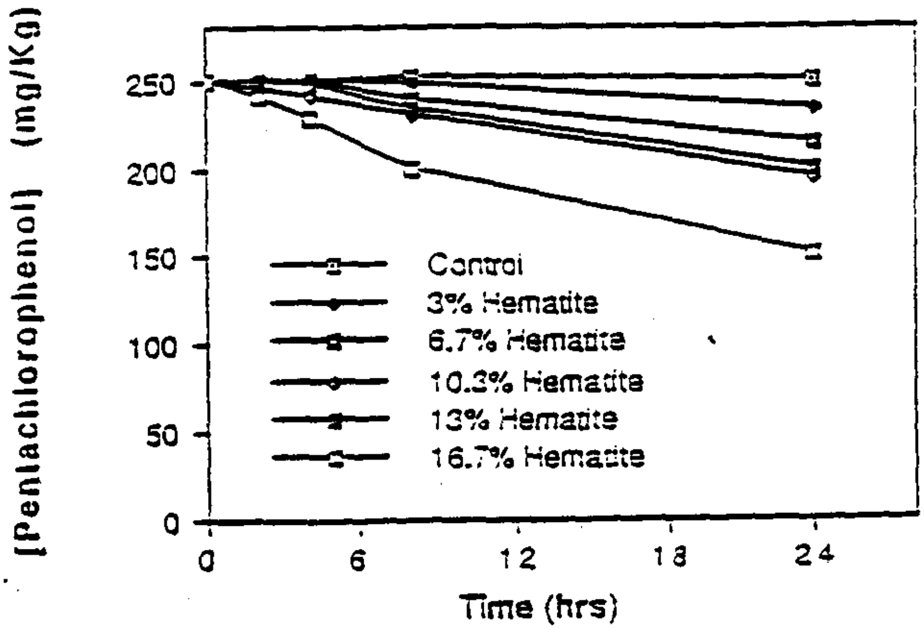

Figure 8. Degradation of pentachlorophenol with hematite as the sole iron source in silica sand.

In summary, the optimum regime for Fenton's treatment of contaminated soils was pH 2-to-3. In successive horizons of the natural soil investigated, the effects of Fenton's treatment was sensitive not only to organic carbon, but also iron addition. The optimum treatment efficiency was demonstrated with no iron addition. The ability of iron minerals to catalyze Fenton-like reactions provided efficient treatment with maximum PCP degradation and minimal hydrogen peroxide consumption.

Because of the complexity of Fenton's treatment systems, bench-scale treatability studies will probably be necessary to assess the efficacy of Fenton's reagent treatment on a site by site basis using a matrix of pH regimes and iron ammendments. Such bench-scale treatability studies are commonplace in assessing the potential for bioremediation of surface soils and groundwater (4). Further Fenton's research will provide predictive treatability models based on chemical structure-reactivity, catalysis by iron minerals, and the effect of soil organic carbon.

AKNOWLEDGEMENTS

Funding for this project was provided by the U.S. Environmental Protection Agency through Assistance Agreement No. R-814425-01-0. Additional support was provided by Interox America and the National Science Foundation through Engineering Research Equipment Grant No. CES-8704878. We thank Dr. Robert Monsen for useful discussions of peroxide chemistry. We also thank Bryan Tyre, Paul Rauch, and Robin Eppard for technical assistance.

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Hudson Environmental Services, Inc.

Introduces

GEO-CLEANSE

An In-Situ Oxidative Contaminant Reduction System for Remediation of Soil and Groundwater

HUDSON ENVIRONMENTAL SERVICES, INC.
4 Mark Road, Suite C
Kenilworth, N.J. 07033
TEL (908) 686-5959
FAX (908) 686-5676

Innovative Environmental Solutions

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INTRODUCTION

The **GEO-CLEANSE** process has the capability of rapidly remediating soil and groundwater contaminated with organic compounds including; fuel oils, gasoline, solvents, halogenated compounds, PCBs, and other organic based contaminants. Specially designed equipment and injectors diffuse and disperse a powerful solution of oxidizers, catalysts and other non-hazardous and environmentally safe amendments to the subsurface environment. The system has the effect of increasing the permeability of the subsurface soils and chemically destroying the organic compounds in the treatment region. The purpose of the **GEO-CLEANSE** process is to rapidly reduce or eliminate organic contamination in soil and groundwater without expensive remediation systems and the associated lengthy permitting. In addition, the process can be utilized to enhance pump rates from pump and treat recovery wells and deliver reactants to the subsurface for the treatment of other contaminants (i.e., heavy metal compounds). The **GEO-CLEANSE** process also requires only minimal disruption of the site and business operations during the short remediation process. **GEO-CLEANSE** is currently awaiting U.S. Patent Protection.

The compounds successfully remediated by the GC process include:

- Gasoline contaminants
- Heating Oil and Diesel Fuel
- Plasticizers (i.e., Di-butylphthalate)
- Chlorinated compounds (i.e., degreasers and dry cleaning solvents)

COMPANY BACKGROUND AND PHILOSOPHY

Hudson Environmental Services, Inc. (Hudson) is a full service environmental consulting, design, and remediation firm. Since its founding in 1987, Hudson's growth and reputation have been built by offering our clientele innovative approaches to their environmental problems along with consistent quality service. Our clients include various chemical, paint and varnish manufacturers, oil refineries, military installations, school districts and municipalities, banking institutions, and other large and small companies.

Through our experience and diversified backgrounds, Hudson personnel have provided our clients with new and innovative approaches to their respective problems with the goal of reducing program costs and time to completion. This experience has ranged from environmental site assessments and audits, tank closure and bid programs, in-situ remediation programs, and groundwater cleanup projects.

Hudson offers a wide range of environmental services designed specifically to address the needs of each of our clients. Our goal is to ensure compliance with the regulatory policies while minimizing the costs and time required to complete the programs. This approach benefits both Hudson and the client by completing the programs efficiently, thus increasing Hudson's growth and quality reputation.

DESCRIPTION OF PROCESS

The process injects and disperses specific non-hazardous chemical compounds and amendments to the subsurface environment for the purposes of increasing the permeability of the soil and destroying organic compounds which may pose an adverse impact to human health and the environment. The reagents employed in the process will degrade rapidly to water and oxygen upon completion of the treatment process, and thus, the materials injected pose no hazard to the environment or potable well systems. The process relates to the specific chemistry, procedures, and equipment necessary to disperse, diffuse, and oxidize the organic contaminants for the purpose of reducing the toxicity of the contaminant, reducing the concentration of the contaminant, or completely eliminating the contaminant from the subsurface soil and groundwater.

Historically, industrialized society has stored, discharged and disposed of various hazardous substances and waste products to the soil and ground water over the years as a normal and acceptable form of disposal. In many cases, these discharges have occurred without any indication or knowledge of the facility owner or operator. These discharges from tanks, lagoons, drum storage areas, and other areas may have been discharging over many years. The end result is severe damage to the local environment which has forced companies and individuals to expend a great deal of time and financial resources to clean up the problem.

These discharged compounds have contaminated drinking water supplies, contaminated the soil and reduced the ability of these mediums to support life. The compounds are typically discharged to the environment by failures in the structural integrity of underground storage tanks and piping systems. In addition, discharges resulting from past practices of purposefully discharging hazardous compounds in open pits, on surface soils, landfills and injection wells have had an extensive and long term adverse effect on the environment.

These compounds are comprised of aromatic and aliphatic organic compounds refined from petroleum hydrocarbons which include halogenated organic compounds and solvents which are also carcinogenic and have the ability to migrate to great depths in groundwater, and are therefore, difficult to remediate by conventional methodologies.

Typical remedial techniques to remove soil contamination from the environment includes excavation of the contaminant and either depositing these materials in a landfill as a temporary storage of the waste, or to transport the contaminated soil to an incinerator which further degrades the quality of the air and risks exposure of these contaminants to human health and the environment. Landfilling also increases owner liability, should the landfill require remediation or go Superfund. The truck and haul approach to soil remediation is expensive and the least preferred method of the regulatory agencies.

Groundwater remediation programs consist mainly of "pump and treat" procedures, which are typically expensive and can require years, decades or may never return the groundwater to an acceptable condition to serve as a drinking water source. These programs and the associated technology *are inherently inefficient* and *more advanced methodologies are required* to reduce costs and address an increasing problem throughout the country.

Recent technological advances to clean up organic contamination have included various in-situ technologies which treat the contaminant in its existing location, and thus, reduce overall program costs, operation disturbances to the site, and program time frames. The major in-situ options available include fixation, bioremediation, and air sparging. These programs are also limited in that they typically require lengthy periods of time to complete the remediation and may create more hazardous compounds during the conversion process or result in restrictive use of the property.

Hudson's **GEO-CLEANSE** technology utilizes strong oxidizing agents and other amendments which convert various organic contaminants into harmless, naturally occurring compounds which present no harm to the environment. This process has been proven effective in remediation of "tight" soils (i.e., silts and clays) contaminated with organic contaminants.

It is important to realize that strong oxidizing compounds in the presence of organic materials can and will form **explosive reactions**. The **GEO-CLEANSE** system controls the rate of reaction, and thereby, eliminates explosive reactions while rapidly destroying the organic contaminants. This program has been fully reviewed by the NJDEPE, has been determined safe and received **NJDEPE Approval** for use on contaminated sites. As part of our service, Hudson will obtain all the necessary governmental permits prior to initiation of any on-site remedial activities. Upon completion of the remediation process, the hydrocarbons are converted to carbon dioxide and water. Any remaining reagents from the injection program are either converted to water and oxygen or are utilized by the soil and groundwater microorganisms as a nutrient source.

Remediation of soil contaminated with discharges of organic contaminants is accomplished by injecting a mixture of strong oxidizers, trace metallic salts, stabilizers, and surfactants in an aqueous based solution. Prior to injection the hydrogeological parameters of the soils and groundwater are defined and a bench test program is conducted to determine the quantity and formulation of the injection mix. In addition, the horizontal and vertical extent of the contaminants with their respective characteristics and concentration gradients are defined and determined. This is necessary to determine the quantities of reagents for injection and the proper spacing of the injectors to permit remediation over the entire affected area. Once the contaminant region has been defined, reagent volumes and concentrations can be determined and the remediation system can be fabricated and installed on the subject site. The **GEO-CLEANSE** system is then mobilized to the site and the injection program is initiated. The injection program will require several days to several weeks to complete, depending upon the extent of contamination. Upon completion of the injection program, the installations and equipment will be removed from site and the remediation program will be terminated. Following the injection program, post remedial sampling and analysis is performed to document complete removal of the contaminants. As noted in the attached case studies, one week following the treatment, the organic contaminants will have been substantially reduced or altogether eliminated by this process. Depending on the extent of contamination, the entire program including permitting through cleanup and final evaluation, can be completed in approximately 4-6 months.

Case I: In-Situ Oxidation/Remediation of Soil and Groundwater Contaminant - Di-n-butyl phthalate

Abstract

An industrial establishment located in the industrial section of Newark had a discharge of contaminants to the soil and groundwater beneath its facility. The facility's operations consisted of manufacturing and packaging of various chemical compounds for the elastomer industry. The facility stored bulk quantities of solvents and various plasticizers which were stored in underground storage tanks for use in the operation. The tanks were located beneath a loading dock area which had a concrete cap over the top of the tanks with buildings surrounding the loading dock. The facility decided to close the tanks by abandoning the tanks in-place. Upon closure, it was discovered that the Di-n-butyl phthalate tank had leaked approximately 2000 pounds of the plasticizer into the soil and groundwater. The owner was then required to remove the tanks and take corrective action to remediate the discharge. The discharge contaminated the soil beneath the loading dock and under the adjacent buildings and was very difficult to remove without damaging the buildings. The facility owner was required by the NJDEPE to remove an additional 500 tons of soil for off-site incineration and to install a groundwater pump and treat system and conduct quarterly groundwater monitoring until the site was remediated to state standards. This program was projected to require 2 years to complete at a cost of approximately $260,000.00. The owner requested an alternative treatment be found for the remediation of the facility. A chemical oxidation process was recommended, approved by the NJDEPE, and implemented successfully to remediate both the soil and groundwater.

Background Of Site Remediation

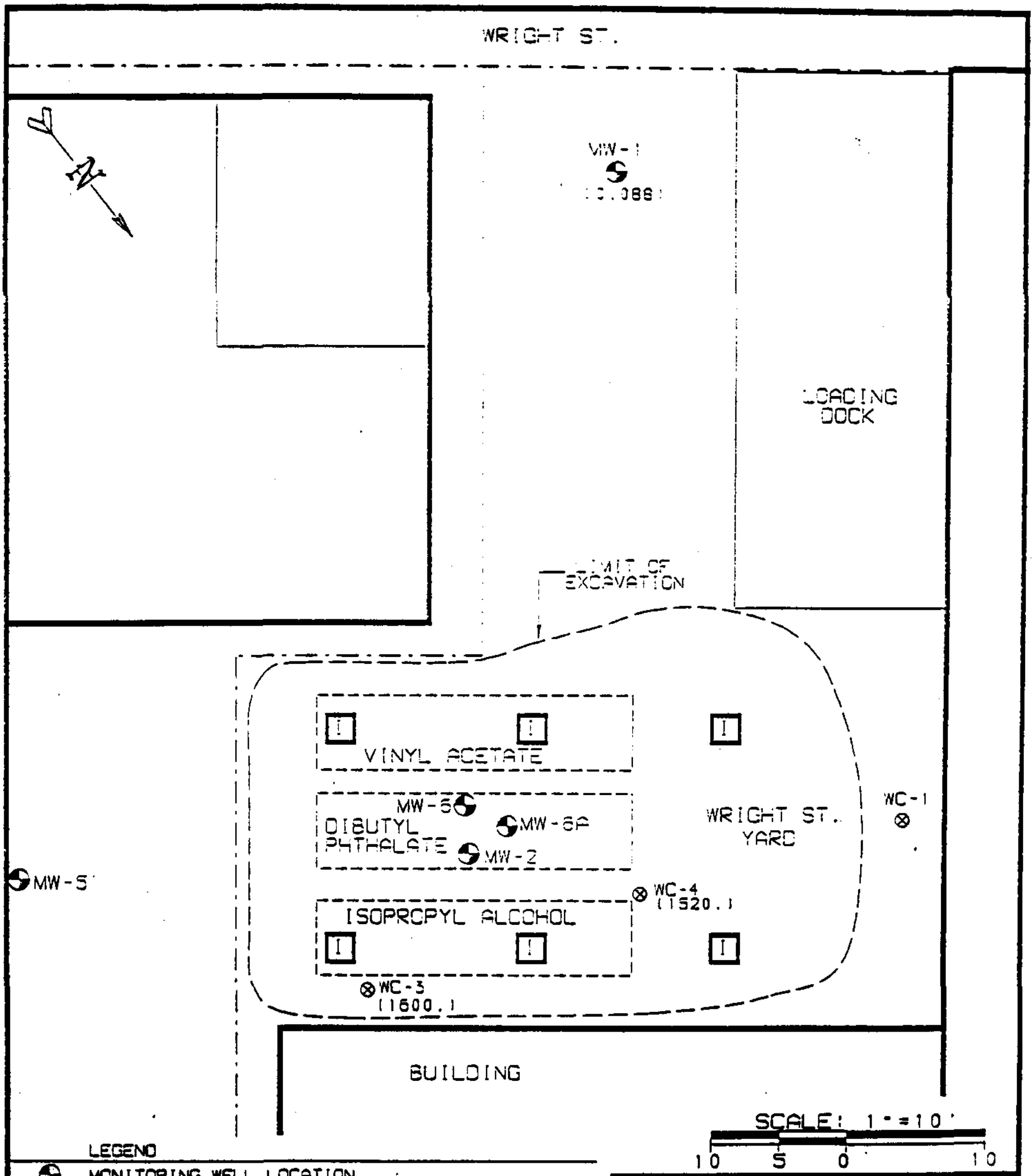
The chemical compounds discharged to the subsurface environment are considered a hazardous waste in accordance with Federal Statutes. The contaminant caused 500 tons of soil to be contaminated and there was free phase contamination and dissolved contamination in the groundwater.

The traditional method of remediating this problem is to; break up the concrete, shore up the surrounding structures, excavate and dispose of the contaminated soil, backfill the excavation, and install and operate a groundwater pump and treat system to clean up groundwater. These programs typically require years and hundreds of thousands of dollars to implement.

Hudson Environmental Services, Inc. proposed **GEO-CLEANSE** to clean both the soil and groundwater without the need to significantly disturb the site. The client agreed to the program and an NJDEPE Approval was secured for the in-situ chemical oxidation/remediation of the soil and groundwater.

The soil contained approximately 1600 ppm of the contaminant and the groundwater contained approximately 61,000 ppb of dissolved contamination in the shallow groundwater (See Attached Site Map). This contamination was found below both the surrounding buildings and the loading dock area. Special injectors were designed and installed into the soil and groundwater and a mixture of proprietary non-hazardous chemicals were injected into the effected areas over a period of one week, and in the presence of the NJDEPE. The results of the injection program, 72 hours after the final injection, revealed the soil and groundwater contamination to be below NJDEPE Standards, with the exception of one of five monitoring wells. That monitoring well was just above current standards upon completion of the injection program and has dropped ten fold from the original contaminant concentration. This well and the associated groundwater contamination in the region has been further reduced since the initial evaluation. This was anticipated since there is an excess of oxidizers and reagents added to the groundwater to completely destroy any remaining organic contaminants in the region. The NJDEPE is requiring two sampling events documenting acceptable groundwater conditions as a condition of no further action on the property. The attached analytical data, maps and tables provide before and after results of the remediation process for the referenced site. A listing of references from both the clients and Regulatory Agency involved in this project can be provided upon request.

The **GEO-CLEANSE** site remediation program is considered complete and the total program required approximately 4 months for permitting, design, treatment and post remedial evaluation. The cost of the program including all the above activities was approximately $48,000.00.



LEGEND

◐	MONITORING WELL LOCATION
●	SOIL SAMPLE LOCATION(DAMES & MOORE)
⊗	SOIL SAMPLE LOCATION(GROUNDWATER TECH., INC.)
----	LIMITS OF FORMER UNDERGROUND STORAGE TANKS
(1600)	-DI-N-BUTYL-PHTHALATE CONCENTRATION IN PARTS PER MILLION
I	INJECTOR POINT AND VENT

SAMPLES RETRIEVED 0-6" ABOVE GROUNDWATER (APPROX 6').
MAP SOURCE: GROUNDWATER TECHNOLOGY, INC.

XYZ CORPORATION
WRIGHT STREET YARD DETAIL
DI-N-BUTYL PHTHALATE CONCENTRATIONS IN SOIL

HUDSON ENVIRONMENTAL SERVICES, INC.
4 MARK ROAD, SUITE C, KENILWORTH, NJ 07033

DRAWN: OCD DATE: 8/10/93
REVISED: OCD DATE: 5/12/94

TABLE 1

PRE-TREATMENT GROUNDWATER CONTAMINANT CONCENTRATIONS
FOR
XYZ COMPANY

RESULTS REPORTED IN ug/l
(PARTS PER BILLION)

FIELD SAMPLE IDENTIFICATION			MW-1	MW-2	MW-5	MW-6	MW-6A	FIELD BLANK
LAB SAMPLE IDENTIFICATION			AA14014	AA14015	AA14016	AA14017	AA14018	AA14024
SAMPLE DATE			2/23/93	2/23/93	2/23/93	2/23/93	2/23/93	2/23/93
DEPTH OF WELL			15'	15'	15'	35'	50'	-
INTERVAL OF SCREEN			5-15'	5-15'	5-15'	30-35'	45-50'	-
PARAMETER (UNITS)	GROUNDWATER CLASS II-A QUALITY CRITERIA	PRACTICAL QUANTITATION LEVEL						
BASE NEUTRALS (ppb)								
DILUTION FACTOR			1	1+500+5	1	1+500	1	1
MDL A - LOWEST			5	5	5	5	5	5
MDL B - HIGHEST			10	2500	10	2500	10	10
1,3-Dichlorobenzene	600	5	ND < 5	2 J	1 J	ND < 5	ND < 5	ND < 5
1,4-Dichlorobenzene	75	5	29	6	4 J	ND < 5	ND < 5	ND < 5
1,2-Dichlorobenzene	600	5	50	12	3 J	ND < 5	7	ND < 5
Naphthalene (PAH)	Not Published	Noy Published	ND < 5	5 J	24	ND < 5	7	ND < 5
2-Methylnaphthalene	Not Published	Not Published	ND < 5	ND < 5	2 J	ND < 5	ND < 5	ND < 5
Di-n-Butyl Phthalate	900	20	ND < 5	61000	14	46000	42	ND < 5
Bis(2-Ethylhexyl)Phthalate	3	30	ND < 5	230	ND < 5	120	ND < 5	2 J
BASE NEUTRAL TENTATIVELY IDENTIFIED COMPOUNDS								
Hexadecanoic acid, mono(2-eth			ND	ND	ND	ND	ND	5
BN TARGETED TOTAL			79	61255	48	46120	56	2
BN TICs TOTAL			ND	ND	ND	ND	ND	5
BN + 15 TOTAL			79	61255	48	46120	56	7

ANALYTICAL METHOD: BASE NEUTRALS - EPA METHOD 625

NOTE: NA - NOT ANALYZED.
ND - INDICATES COMPOUND WAS ANALYZED FOR BUT NOT DETECTED ABOVE METHOD DETECTION LIMIT (MDL).
J - INDICATES ESTIMATED VALUE USED WHEN A COMPOUND IS DETECTED AT LESS THAN THE SPECIFIED DETECTION LIMIT.
B - INDICATES COMPOUND IS ALSO PRESENT IN BLANK.
GROUNDWATER QUALITY CRITERIA AS PER NJAC 7.9 6.

TABLE 2

POST REMEDIAL TREATMENT CONCENTRATIONS (SOIL)

FOR

XYZ COMPANY

RESULTS REPORTED IN mg/kg
(PERTS PER MILLION)

			SAMPLE LOCATION	WRIGHT STREET YARD	
			FIELD SAMPLE IDENTIFICATION	PR-1	PR-2
			LAB SAMPLE IDENTIFICATION	AA22686	AA22687
			SAMPLE DATE	4/20/94	4/20/94
			SAMPLE DEPTH	6'	6'
	NJDEPE SOIL CLEANUP CRITERIA				
PARAMETER (UNITS)	RESIDENTIAL DIRECT CONTACT	NON-RESIDENTIAL DIRECT CONTACT	IMPACT TO GROUNDWATER		
BASE NEUTRALS (ppm)					
DILUTION FACTOR				333	167
MDL A - LOWEST				0.72	0.37
MDL B - HIGHEST				3.6	1.8
1,4-Dichlorobenzene	570	10000	100	1.3 J	0.55 J
1,2-Dichlorobenzene	5100	10000	50	2.1	1.5
Naphthalene (PAH)	230	4200	100	ND < 1.8	1.1
2-Methylnaphthalene	Not Published	Not Published	Not Published	ND < 1.8	0.19 J
Di-n-Butylphthalate	5700	10000	100	2.6	2.2
Fluoranthene (PAH)	2300	10000	100	ND < 1.8	0.35 J
Pyrene (PAH)	1700	10000	100	ND < 1.8	0.31 J
Bis(2-Ethylhexyl)Phthalate	49	210	100	ND < 1.8	2.4
BN TICs TOTAL				356.68	178.868
BN + 15 TOTAL				362.68	187.468

ANALYTICAL METHOD:

BASE NEUTRALS - EPA METHOD 8270.

NOTE:

NA - NOT ANALYZED.

ND - INDICATES COMPOUND WAS ANALYZED FOR BUT NOT DETECTED ABOVE METHOD DETECTION LIMIT (MDL).

J - INDICATES AN ESTIMATED VALUE USED WHEN A COMPOUND IS DETECTED AT LESS THAN THE SPECIFIED MDL.

B - INDICATES COMPOUND IS ALSO PRESENT IN BLANK.

TABLE 3

POST REMEDIAL TREATMENT
GROUNDWATER CONTAMINANT CONCENTRATIONS

FOR

XYZ COMPANY

RESULTS REPORTED IN ug/l (PARTS PER BILLION)		FIELD SAMPLE IDENTIFICATION	MW-2	MW-6	MW-1	MW-6A	MW-5	FIELD BLANK
		LAB SAMPLE IDENTIFICATION	AA22688	AA22689	AA22690	AA22691	AA22692	AA22693
		SAMPLE DATE	4/20/94	4/20/94	4/20/94	4/20/94	4/20/94	4/20/94
		DEPTH OF WELL	15'	35'	15'	50'	15'	-
		INTERVAL OF SCREEN	5-15'	30-35'	5-15'	45-50'	5-15'	-
PARAMETER (UNITS)	GROUNDWATER CLASS II-A QUALITY CRITERIA	PRACTICAL QUANTITATION LEVEL						
BASE NEUTRALS (ppb)								
DILUTION FACTOR			10	114	1	1	10	1
MDL A - LOWEST			20	230	2	2	20	2
MDL B - HIGHEST			100	1100	10	10	100	10
1,3-Dichlorobenzene	600	5	ND < 50	ND < 570	3 J	ND < 5	ND < 50	ND < 5
1,4-Dichlorobenzene	75	5	ND < 50	ND < 570	60	ND < 5	ND < 50	ND < 5
1,2-Dichlorobenzene	600	5	ND < 50	ND < 570	130	2 J	ND < 50	ND < 5
Naphthalene (PAH)	Not Published	Noy Published	ND < 50	ND < 570	ND < 2	ND < 5	36 J	ND < 5
Di-n-Butyl Phthalate	900	20	250	4500	44	38	ND < 50	ND < 5
Bis(2-Ethylhexyl)Phthalate	3	30	ND < 50	ND < 570	3 J	ND < 5	ND < 50	ND < 5
BASE NEUTRAL TENTATIVELY IDENTIFIED COMPOUNDS								
Benzene, 1,2,3-trimethyl-			60	ND	ND	ND	ND	ND
2-Butenol, 2,3-dimethyl-			ND	ND	12	ND	ND	ND
Benzene, chloro-			ND	ND	140	ND	ND	ND
Unknown			ND	ND	16472	ND	50	ND
Cyclohexanemethanol, .alpha.			ND	ND	18	ND	ND	ND
Benzene, 1-methyl-2-(2-prope			ND	ND	7	ND	ND	ND
Naphthalene, 1,2,3,4-tetrahy			ND	ND	13	ND	ND	ND
Tricyclo[3.3.1.13,7]decan-1-			ND	ND	15	ND	ND	ND
Phosphoric acid, tris(2-ethy			ND	ND	4	ND	ND	ND
Benzene, ethyl-			ND	ND	ND	ND	830	ND
Benzene, 1,3-dimethyl-			ND	ND	ND	ND	3100	ND
Benzene, 1,2-dimethyl-			ND	ND	ND	ND	1100	ND
Benzene, 1-ethyl-2-methyl-			ND	ND	ND	ND	60	ND
1,3-Cyclopentadiene, 5-(1-me			ND	ND	ND	ND	50	ND
Benzene, 1-ethyl-3-methyl-			ND	ND	ND	ND	160	ND
BN TARGETED TOTAL			250	4500	240	40	36	ND
BN TICs TOTAL			60	ND	16681	ND	5350	ND
BN + 15 TOTAL			310	4500	16921	40	5386	ND

ANALYTICAL METHOD: BASE NEUTRALS - EPA METHOD 625.

NOTE: NA - NOT ANALYZED

ND - INDICATES COMPOUND WAS ANALYZED FOR BUT NOT DETECTED ABOVE METHOD DETECTION LIMIT (MDL)

J - INDICATES ESTIMATED VALUE USED WHEN A COMPOUND IS DETECTED AT LESS THAN THE SPECIFIED DETECTION LIMIT.

B - INDICATES COMPOUND IS ALSO PRESENT IN BLANK

GROUNDWATER QUALITY CRITERIA AS PER [illegible]

Case 2: In-Situ Oxidation/Remediation of Ground Water Contaminant - #2 Fuel Oil/Volatile Organic Compounds

Abstract

An industrial establishment located in Newark had a discharge of heating oil to the soil and groundwater beneath it's facility. The discharge originated from underground storage tanks (USTs) that supplied fuel to heat the facility. The tanks were located beneath a concrete area in a courtyard and surrounded by buildings. The facility owner decided to remove one of the accessible tanks and close the other tank by abandoning in-place. Upon closure, it was discovered that one of the USTs had leaked oil into the soil and groundwater. The owner was then required by the NJDEPE to remove the soil to the extent possible, and take corrective action to remediate the discharge to groundwater. The soil was removed for disposal from the areas which were accessible, but the discharge had contaminated the soil and groundwater beneath the courtyard and under the adjacent buildings. The facility owner was required by the NJDEPE to install monitoring wells within the courtyard and to install a groundwater pump and treat system and conduct quarterly groundwater monitoring until the site was remediated to NJDEPE Standards. This program was estimated to require 1-2 years to complete at a cost of approximately $125,000.00. The contamination was inaccessible by traditional remedial methods (i.e., excavation) since the contamination was within the courtyard and partially beneath the surrounding buildings. The **GEO-CLEANSE** process was utilized to successfully remediate groundwater by two successive injections over a period of one week. The total program charge including design, system fabrication, chemical reagents, permits, site work, and post-remedial evaluation was approximately $24,000.00.

Background Of Site Remediation

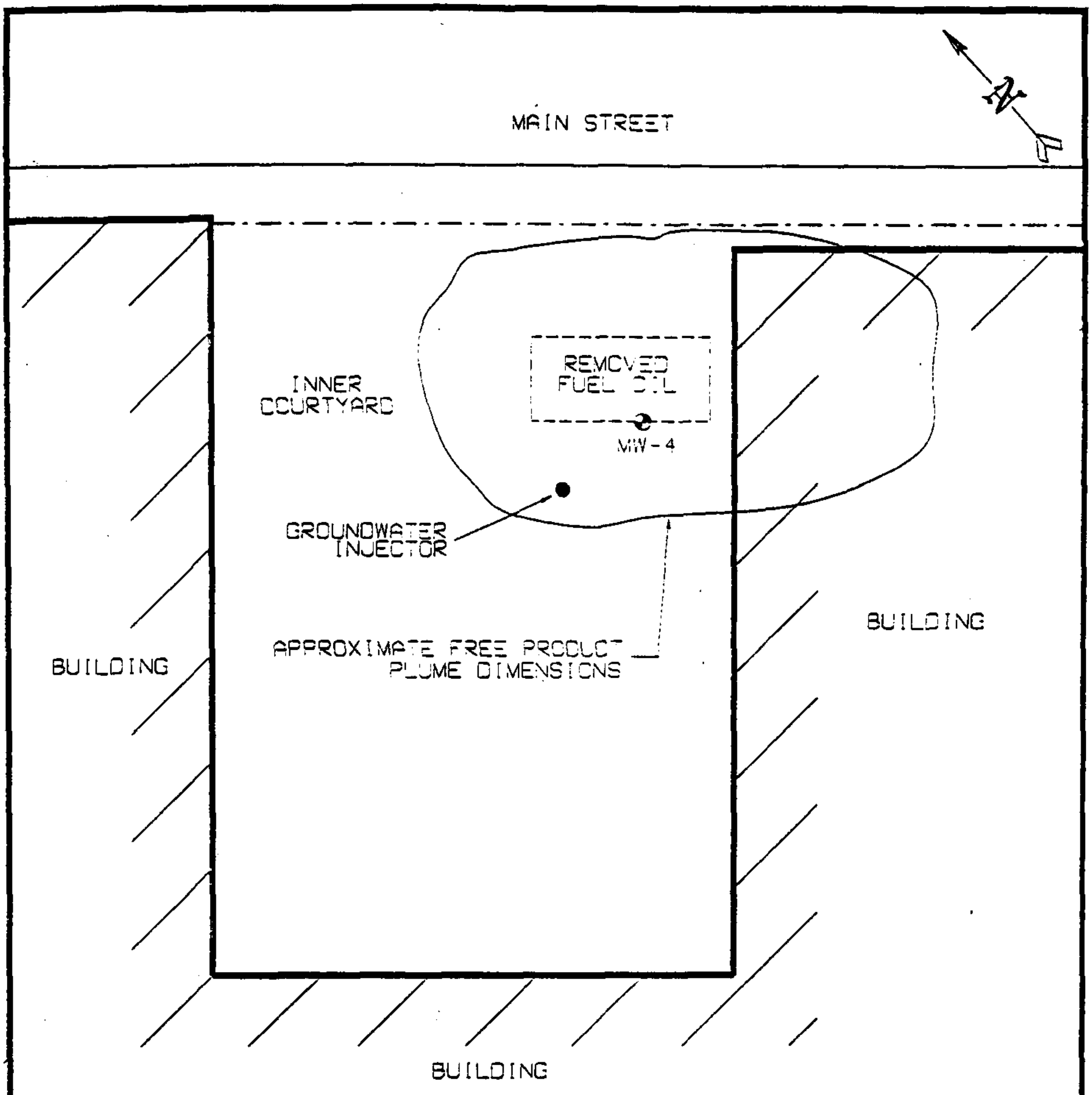
The chemical compounds discharged to the subsurface environment are considered a hazardous waste in accordance with New Jersey Statutes. The contaminant caused approximately 45,000 gallons of groundwater to be contaminated, including free phase contamination floating on groundwater.

In addition, the residual soil contamination below the buildings were inaccessible and would require a deed restriction on the property, thus limiting the use of the site for only commercial uses and reducing the value of the property. The traditional program would typically require years and approximately $100,000.00 to implement.

Hudson Environmental Services, Inc. proposed **GEO-CLEANSE** to clean the soil and groundwater without the need to significantly disturb the site. The client agreed to the program and an NJDEPE Approval was secured for the in-situ chemical oxidation/remediation of the soil and groundwater.

The groundwater contained approximately 61,000 ppb of dissolved contamination (See Attached Site Map). This contamination was below both the surrounding buildings and the courtyard area. Special injectors were designed and installed into the groundwater and a mixture of oxidizers and non-hazardous amendments and reagents were injected into the effected areas over a period of several days. The results of the injection program, 72 hours after the final injection, reduced groundwater contamination to below NJDEPE Standards. The NJDEPE required 3 sampling events documenting acceptable groundwater conditions as a condition of no further action on the property. The attached analytical data, maps and tables provide before and after results of the remediation process for the referenced site. A listing of references from both the clients and Regulatory Agency involved in this project can be provided upon request.

The site remediation program is considered complete and the total program required approximately 2 months and $22,000.00 for permitting, design, treatment, and post remedial evaluation.



LEGEND

— · — PROPERTY LINE

┌┄┄┐ LIMITS OF UNDERGROUND STORAGE TANKS

● MONITORING WELL LOCATION

SCALE: 1"=10'

10 5 0 10

INJECTION SYSTEM LAYOUT

CASE STUDY 2

HUDSON ENVIRONMENTAL SERVICES, INC.
4 MARK ROAD, SUITE C, KENILWORTH, NJ 07033

DRAWN: DCD DATE: 3/2/94
REVISED: DCD DATE: 7/20/94

PRE-REMEDIAL
GROUNDWATER ANALYTICAL RESULTS SUMMARY

FOR

FUEL OIL IMPACTED GROUNDWATER

	FIELD SAMPLE IDENTIFICATION	MW-4	MW-4	MW-4
	SAMPLE DATE	May-90	Jan-92	Mar-94
	DEPTH OF WELL	19'	19'	19'
	INTERVAL OF SCREEN	4-19'	4-19'	4-19'
PARAMETER (UNITS)	NJDEPE GROUNDWATER QUALITY CRITERIA			
VOLATILE ORGANICS (ppb)				
DILUTION FACTOR				5
MDL LOWEST				5
MDL HIGHEST				500
Acetone		ND	240 B	
Vinyl Chloride	0.08	37	ND	36
1,1-Dichloroethane		36	ND	
1,2-Dichloroethane	0.3			16 J
1,2-Dichloroethene (total)		5200	1300	
2-Butanone	Not Published			6 J
Benzene	0.2	120	110	17
Toluene	1000	2500	2500	390
Chlorobenzene	4	180	110	61
Ethylbenzene	700	110	160	31
Methylene Chloride		ND	85	
Xylenes (total)	Not Available	760	560	135
1,3-Dichlorobenzene	600	18	ND	9 J
1,2-Dichlorobenzene	600	290	560	92
1,4-Dichlorobenzene	75	31	ND	11 J
VO TARGETED TOTAL		9282	5625	804
VO TICs TOTAL		ND	605	605
VO + 10 TOTAL		9282	6230	1409
BASE NEUTRALS (ppb)				
DILUTION FACTOR				1
MDL A - LOWEST				5
MDL B - HIGHEST				10
Acenaphthene		19	6	
Pyridine	Not Published			3 JB
1,3-Dichlorobenzene	600	8.4	3	4 J
1,4-Dichlorobenzene	75	15	6	5
1,2-Dichlorobenzene	600	140	45	41
1,2,4-Trichlorobenzene	9			2 J
Naphthalene (PAH)	Not Published	270	104	34
2-Metylnaphthalene	Not Published	610	ND	45
Dibenzofuran	Not Published			1 J
Fluorene (PAH)	300	29	8	4 J
Phenanthrene (PAH)	Not Available		16	6
Pyrene (PAH)	200	11	3	1 J
Bis(2-Ethylhexyl)Phthalate	3		3	72
BN TARGETED TOTAL		1102.4	194	218
BN TICs TOTAL		ND	2545	580
BN + 15 TOTAL		1102.4	2739	798

NOTE: RESULTS REPORTED IN ug/l (PARTS PER BILLION).

NA - NOT ANALYZED.

ND - INDICATES COMPOUND WAS ANALYZED FOR BUT NOT DETECTED ABOVE METHOD DETECTION LIMIT (MDL).

J - INDICATES ESTIMATED VALUE USED WHEN A COMPOUND IS DETECTED AT LESS THAN THE SPECIFIED DETECTION LIMIT.

B - INDICATES COMPOUND WAS ALSO PRESENT IN THE BLANK.

GROUNDWATER QUALITY CRITERIA AS PER NJAC 7:9-6.

ANALYTICAL METHOD:

VO + 10 = EPA METHOD 624.

BN + 15 = EPA METHOD 625.

Regulatory Approvals

State of New Jersey
Department of Environmental Protection and Energy
Division of Responsible Party Site Remediation
CN 028
Trenton, NJ 08625-0028

anne M. Fox
cting Commissioner

Karl J. Delaney
Director

DEC 27 1993

CERTIFIED MAIL
RETURN RECEIPT REQUESTED

RE: Chemos Corporation
Newark City, Essex County
Remedial Action Workplan Addendum Dated: September 17, 1993
ISRA Case #83216

Dear Mr. :

Pursuant to the Authority vested in the Commissioner of the New Jersey Department of Environmental Protection and Energy ("NJDEPE") by the Industrial Site Recovery Act (ISRA) and duly delegated to the Assistant Director of the Industrial Site Evaluation Element pursuant to N.J.S.A. 13:3-4, the above referenced Remedial Action Workplan Addendum, submitted on behalf of Chemos Corporation, is hereby approved by the NJDEPE as conditioned below:

GROUND WATER CONDITIONS

1. The proposal to treat the di-n-butyl-phthalate (DNBP) contaminated soil in the Wright Street Courtyard Area with hydrogen peroxide, by injecting the hydrogen peroxide into monitoring wells 2 and 6, and infiltration trenches, is conditionally acceptable. Prior to implementation, Chemos Corporation shall report the quantity and injection rate of hydrogen peroxide. Also, Chemos Corporation shall provide the location and specifications of the infiltration trenches.

2. The proposal for post remediation ground water monitoring using monitoring wells 5 and 10 (MW 10, proposed down gradient monitoring well) is acceptable. Chemos Corporation shall install MW 10 in the location depicted on the enclosed map. One additional round, for a total of three ground water sampling episodes, shall be required to evaluate the effectiveness of the proposed soil remediation.

3. The proposal to perform only two more rounds of ground water sampling in the Inner Courtyard Area (MWs 4 and 7) is unacceptable due to the presence of free product in monitoring well 4. No further action can only be proposed if free product is not detected for six consecutive months. Quarterly sampling of monitoring well 7 for benzene, toluene, ethylbenzene, xylene and base neutral organic compounds with a forward library search (BN+15) will be required while free product is detected.

Chemos Corporation may propose active remediation for the Inner Courtyard Area as an alternative to long term monitoring.

GENERAL CONDITIONS

1. Chemos Corporation shall comply with all federal, state, and local laws, regulations, and ordinances in implementing the approved Remedial Action Workplan Addendum.

2. Chemos Corporation shall submit applications for all required federal, state, and local permits to the appropriate regulatory authority within 30 days of the receipt of this Remedial Action Workplan Addendum Approval. Should any condition or limitation of said permits be more stringent than those in the approved Remedial Action Workplan Addendum, then said permit requirements shall supersede the terms of this approval. Chemos Corporation shall submit a copy of each application to BEECRA.

3. Upon the written request of the NJDEPE, Chemos Corporation shall submit for NJDEPE review and approval any additional Remedial Action Workplans deemed necessary by the NJDEPE during the implementation of a Remedial Action Workplan Addendum to fully delineate the nature and extent of environmental contamination associated with Chemos Corporation. Chemos Corporation shall implement and complete any such additional Remedial Action Workplans and submit the results in accordance with the time frames set forth in the approved additional Remedial Action Workplans. Furthermore, Chemos Corporation shall prepare and submit to the NJDEPE for approval any revisions to the Remedial Action Workplan Addendum necessary to remediate any additional environmental contamination associated with Chemos Corporation as identified during the Remedial Action Workplan Addendum implementation, by any additional sampling, or from any other source. Chemos Corporation shall revise and submit the required information within a reasonable time, not to exceed 30 calendar days, from receipt of written notification from the NJDEPE.

4. Chemos Corporation shall collect all samples in accordance with the sampling protocol outlined in the May, 1992 edition of the NJDEPE's "Field Sampling Procedures Manual".

5. The ISRA requirement for remediation of all environmental contamination associated with Chemos Corporation and the terms and conditions of the approved Remedial Action Workplan Addendum shall be binding upon Chemos Corporation, and its successors in interest, assigns and any trustee or receiver appointed pursuant to a proceeding law or equity. Any officer or management official who knowingly directs or authorizes the violation of any provision of ISRA or the regulations shall be personally liable for the penalty established pursuant to N.J.S.A. 13:1K-13 and N.J.A.C. 7:26B-9.3 as amended by P.L. 1993 c.139.

6. Pursuant to N.J.A.C. 7:26B-5.6 (a) and (b), Chemos Corporation shall submit to the NJDEPE quarterly written progress reports in accordance with the Technical Requirements For Site Remediation, N.J.A.C. 7:26E-6.5 (b) 1-8 detailing the implementation of the Remedial Action Workplan Addendum by the fifteenth day of each month.

If modifications to the remedial schedule are anticipated during implementation of the referenced Remedial Action Workplan Addendum, Chemos Corporation shall submit a revised remedial action schedule with the subsequent progress report. Based on a review of this schedule, the NJDEPE will approve or disapprove the revised remedial action schedule. If the revised remedial action schedule is disapproved, the NJDEPE will note the reasons for the disapproval.

7. Chemos Corporation shall submit a final and any interim remedial action report in accordance with N.J.A.C. 7:26E-6.6.

8. Chemos Corporation shall notify the assigned Case Manager at least 14 calendar days prior to the initiation of any and all investigation/ remediation activities at the site so that the Case Manager may be present.

9. Chemos Corporation shall initiate the Remedial Action Workplan Addendum, as conditioned in this Remedial Action Workplan Addendum Approval, within two weeks of receipt of this letter and, in accordance with N.J.A.C. 7:26B-5.5(c), begin implementation of this Remedial Action Workplan Addendum according to the proposed remedial action schedule. If any current or anticipated delay is caused by events beyond the control of Chemos Corporation, then Chemos Corporation shall notify the NJDEPE in writing within 10 calendar days of such event. Chemos Corporation shall precisely describe the cause of the delay and request an extension. Increases in the costs or expenses incurred in fulfilling the requirements outlined in this letter shall not be considered a basis for an extension and such extension requests will not be granted. If Chemos Corporation fails to implement the Remedial Action Workplan Addendum in accordance with the proposed remedial action schedule, the NJDEPE reserves the right to implement full enforcement measures and assess penalties pursuant to N.J.A.C. 7:26B-9.

The NJDEPE's approval, as conditioned above, is limited to the above referenced Remedial Action Workplan Addendum only and is based upon information provided by Chemos Corporation to the NJDEPE. This Remedial Action Workplan Addendum Approval shall not limit, restrict, or prohibit NJDEPE from directing on-site or off-site cleanup, if deemed necessary by NJDEPE, under any other statute, rule, or regulation. Chemos Corporation is hereby required to fully implement the referenced Remedial Action Workplan Addendum, as conditioned above, in accordance with the time schedule as set forth therein.

By issuing this Remedial Action Workplan Addendum Approval, the NJDEPE continues to reserve its right to pursue any penalties allowable under the law for violations of the ISRA statute or regulations associated with this transaction, in accordance with the ACO.

If you have any questions concerning the document, please contact the Case Manager, Richard Burgos, at (609) 633-7141.

Sincerely,

Wayne C. Howitz, Assistant Director
Industrial Site Evaluation Element

c: Christine Lacy, BEERA
Ted Zagorski, BGWPA

State of New Jersey
Department of Environmental Protection

Christine Todd Whitman
Governor

Robert C. Shinn, Jr.
Commissioner

CERTIFIED MAIL
RETURN RECEIPT REQUESTED

OCT 17 [redacted]

[redacted]
Bressler, Amery & Ross
P.O. Box 1980
Morristown, NJ 07962

Re: [redacted]
North Brunswick, Middlesex County
Case #92-09-16-1942
UST #0032708
OxyClean Proposal dated: October 7, 1994

Dear Mr. Nemeth:

The New Jersey Department of Environmental Protection and Energy (Department) has completed a review of the above referenced OxyClean proposal. [redacted] proposes to inject 50% hydrogen peroxide solution with [redacted] into the Passaic Formation. This pilot study is being performed to evaluate the treatment of BTEX compounds at the site. [redacted] will be monitoring groundwater for hydrogen peroxide, dissolved oxygen and millivolt potential during the study. One week after the solution has been injected, the groundwater will be analyzed for BTEX. The results will be presented in a Remedial Action Workplan.

Pursuant to the New Jersey Pollutant Discharge Elimination System (NJPDES) regulations, specifically, N.J.A.C. 7:14A-2.15(a)3, the Department is issuing a permit-by-rule authorizing a discharge to a Class V Underground Injection Control (UIC) system. This permit-by-rule allows a discharge from a pilot test being used to gather data for an evaluation of the effectiveness of a remedial alternative. Therefore, the Department hereby authorizes the pilot study as described above. This approval is valid only when all of the following conditions are met.

The duration of the discharge shall not exceed 2 days.

Pepsi shall also analyze the groundwater for iron along with the proposed BTEX analyses.

Pepsi is responsible for properly plugging and abandoning the reinjection device once the reinjection is complete, in accordance with N.J.A.C. 7:14A-5.10(a)6.

Information detailing the operation, including: exact dates during which the pilot study occurred, the number of gallons injected, the level of treatment and method of treatment utilized, and details of the plugging and abandonment shall be submitted with the Remedial Action Workplan.

If you have any questions, please contact Reneé Wright, of the Bureau of Underground Storage Tanks, at (609) 984-3156.

Sincerely,

Kevin F. Kratina, Chief
Bureau of Underground Storage Tanks

c: Reneé Wright, Case Manager, BUST
Health Department

STATE OF NEW JERSEY

DEPARTMENT OF ENVIRONMENTAL PROTECTION AND ENERGY

Certifies That

Hudson Environmental Services, Inc.
4 Mark Road, Suite C
Kenilworth, NJ 07033

having duly met the requirements of the

Underground Storage Tank Certification Program
N.J.S.A. 58:10A-24.1-8

is hereby approved to perform the following services:

Closure
Subsurface Evaluation

2000014
PERMANENT CERTIFICATION NUMBER

02/28/95
EXPIRATION DATE

COMMISSIONER, DEPARTMENT OF
ENVIRONMENTAL PROTECTION AND ENERGY

TO BE CONSPICUOUSLY DISPLAYED AT THE FACILITY.

Certifications And Insurance

ACORD CERTIFICATE OF INSURANCE

ISSUE DATE 05/01/94

PRODUCER INSURANCE KINGDOM AGCY INC 525 BOULEVARD KENILWORTH, N.J. 07033	THIS CERTIFICATE IS ISSUED AS A MATTER OF INFORMATION ONLY AND CONFERS NO RIGHTS UPON THE CERTIFICATE HOLDER. THIS CERTIFICATE DOES NOT AMEND, EXTEND OR ALTER THE COVERAGE AFFORDED BY THE POLICIES BELOW. COMPANIES AFFORDING COVERAGE
INSURED Hudson Environmental Services, Inc. 4 Mark Road Suite C Kenilworth, N.J. 07033	COMPANY LETTER A TRAVELERS INSURANCE COMPANY COMPANY LETTER B CALVERT INSURANCE COMPANY COMPANY LETTER C LIBERTY MUTUAL INSURANCE CO. COMPANY LETTER D COMPANY LETTER E

COVERAGES

THIS IS TO CERTIFY THAT THE POLICIES OF INSURANCE LISTED BELOW HAVE BEEN ISSUED TO THE INSURED NAMED ABOVE FOR THE POLICY PERIOD INDICATED. NOTWITHSTANDING ANY REQUIREMENT, TERM OR CONDITION OF ANY CONTRACT OR OTHER DOCUMENT WITH RESPECT TO WHICH THIS CERTIFICATE MAY BE ISSUED OR MAY PERTAIN, THE INSURANCE AFFORDED BY THE POLICIES DESCRIBED HEREIN IS SUBJECT TO ALL THE TERMS, EXCLUSIONS, AND CONDITIONS OF SUCH POLICIES.

CO LTR	TYPE OF INSURANCE	POLICY NUMBER	POLICY EFF.DATE	POLICY EXP.DATE	LIMITS	
	GENERAL LIABILITY				BODILY INJURY OCC.	$
	[ ] Comprehensive Form				BODILY INJURY AGG.	$
B	[X] Premises/Operations	MPP-3081445	12/19/93	12/19/94	PROPERTY DAMAGE OCC.	$
	[ ] Underground Explosion & Collapse Hazard				PROPERTY DAMAGE AGG.	$
					BI & PD COMBINED OCC.	$ 1,000,000
	[X] Products/Completed Oper.				BI & PD COMBINED AGG.	$ 2,000,000
	[ ] Contractual				PERSONAL INJURY AGG.	$
	[ ] Independent Contractors					
	[ ] Broad Form Property Damage					
	[ ] Personal Injury					
	AUTOMOBILE LIABILITY				BODILY INJURY	$
	[ ] Any Auto				(Per Person)	
	[ ] All Owned Autos (Priv. Pass)				BODILY INJURY	$
C	[ ] All Owned Autos (Other than	AS1-332-436510-043	12/27/93	12/27/94	(Per accident)	
	[ ] Hired Autos Priv. Pass)				PROPERTY DAMAGE	$
	[X] Non-Owned Autos					
	[ ] Garage Liability				BODILY INJURY &	$
	[ ]				PROPERTY DAMAGE COMBINED	
	EXCESS LIABILITY				EACH OCCURENCE	$
	[ ] Umbrella Form				AGGREGATE	$
	[ ] Other Than Umbrella Form					
	WORKER'S COMPENSATION				[X] STATUTORY LIMITS	
A	AND	6-UB-300K627-9-94	01/01/94	01/01/95	EACH ACCIDENT	$ 100,000
	EMPLOYERS' LIABILITY				DISEASE-POLICY LIMIT	$ 500,000
					DISEASE-EACH EMPLOYEE	$ 100,000
	OTHER					

DESCRIPTION OF OPERATIONS/LOCATIONS/VEHICLES/SPECIAL ITEMS

CERTIFICATE HOLDER	CANCELLATION
SEE ABOVE FOR ADDRESS:	SHOULD ANY OF THE ABOVE DESCRIBED POLICIES BE CANCELLED BEFORE THE EXPIRATION DATE THEREOF, THE ISSUING COMPANY WILL ENDEAVOR TO MAIL 10 DAYS WRITTEN NOTICE TO THE CERTIFICATE HOLDER NAMED TO THE LEFT, BUT FAILURE TO MAIL SUCH NOTICE SHALL IMPOSE NO OBLIGATION OR LIABILITY OF ANY KIND UPON THE COMPANY, ITS AGENTS OR REPRESENTATIVES. INS. KINGDOM AGENCY, INC. AUTHORIZED REPRESENTATIVE Patricia M. Plasschaert PATRICIA M. PLASSCHAERT PRESIDENT

ACORD 25 (7/90) ACORD CORPORATION 1990