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Evaluation of Ultraviolet Oxidation (UV/Ox) Methods for the Remediation of Explosives Contaminated Groundwater: Final Report

Task Order 6

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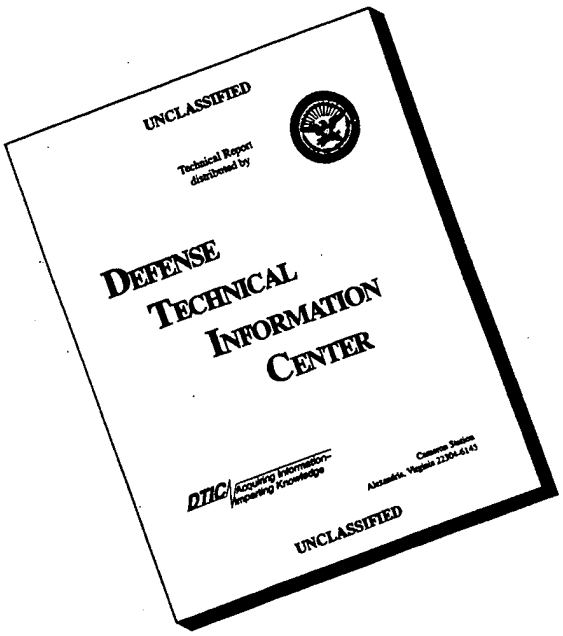

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13. ABSTRACT

The primary objective of this task was to evaluate the technical- and cost-effectiveness of advanced oxidation processes (AOP), specifically UV/Oxidation (UV/OX) in remediating groundwaters containing 2,4,6-trinitrotoluene (TNT) and other nitroaromatics by performing a pilot-scale demonstration. In addition to evaluating the effectiveness of UV/OX methods, USAEC wanted to identify the cost parameters associated with each of the commercially available processes for the treatment of explosives and assess the adequacy of bench-scale testing data for predicting full-scale equipment requirements. All four of the UV/OX processes evaluated achieved the treatment criteria for TNT and TNB on one or more days of the demonstration. There was considerable variation in the consistency with which the processes met these criteria. It was also concluded that, based on this demonstration, routine bench-scale testing is inadequate for providing sufficient data for accurate design, sizing, and costing for full-scale UV/OX systems for remediating explosives-contaminated groundwater.

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Advanced Oxidation Processes (AOP) Ultraviolet Oxidation (UV/OX); explosives; groundwater; bench scale testing; pilot plant; trinitrotoluene (TNT); 1,3,5-trinitrobenzene (1,3,5-TNB); 1,3-Dinitrobenzene (1,3-DNB); 2,4-dinitrotoluene (2,4-DNT), 2,6-dinitrotoluene (2,6-DNT) catalyst, present worth, life\cycle costs, capital costs, O&M costs.

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TASK ORDER 6

EVALUATION OF ULTRAVIOLET OXIDATION (UV/OX) METHODS FOR THE REMEDIATION OF EXPLOSIVES - CONTAMINATED GROUNDWATER

FINAL REPORT

U.S. ARMY ENVIRONMENTAL CENTER
Environmental Technology Division
SFIM-AEC-ETD
Aberdeen Proving Ground, MD 21010-5401

JUNE 1995

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EXECUTIVE SUMMARY

The U.S. Army Environmental Center (USAEC) has performed an evaluation of commercially available ultraviolet oxidation (UV/Ox) processes for the remediation of explosives-contaminated groundwater by conducting a pilot-scale demonstration at Savanna Army Depot Activity (SADA), located in Savanna, Illinois. This demonstration was performed to assess the technical and cost effectiveness of UV/Ox methods for the treatment of trinitrotoluene (TNT), trinitrobenzene (TNB), and other nitroaromatics found in groundwaters at Army installations nationwide. Roy F. Weston, Inc. (WESTON®), of West Chester, Pennsylvania was contracted to coordinate the demonstration and evaluate the results.

Currently, granular activated carbon (GAC) is the conventional technology for treating wastewaters and groundwaters containing explosives and nitroaromatics. Although the technique is simple and effective, the resulting spent-carbon containing the explosives is listed as a K045 hazardous waste and requires additional treatment and/or disposal. In contrast, the UV/Ox methods are destructive processes in which the target organic compounds are fully oxidized to innocuous end products of carbon dioxide, water, and salts. The residual-free nature of these processes makes them an attractive solution, if their effectiveness can be demonstrated for nitroaromatics.

In addition to evaluating the effectiveness of UV/Ox methods, USAEC hoped to identify the cost parameters associated with each of the commercially available processes for the treatment of explosives and nitroaromatics, and also hoped to assess the adequacy of bench-scale testing data for predicting full-scale equipment requirements. Pilot-scale studies are an inherent, but expensive, component of UV/Ox technology implementation. Significant savings could be realized by eliminating pilot-scale testing, but this is only feasible if full-scale systems could be accurately sized from bench-scale testing results.

Four commercial vendors were invited to operate UV/Ox processes at SADA. These vendors were selected based on their responses to a Request for Proposals (RFP) issued for

the demonstration. The selection criteria, in order of decreasing importance, included: technical merit of the proposals, followed by qualifications and experience, and cost. Based on the evaluations of the proposals, the four vendors selected for participation in the demonstration were Purifics Environmental Technologies (Purifics), Solarchem Environmental Systems (Solarchem), Ultrox International (Ultrox), and Vulcan Peroxidation Systems Incorporated (VPSI). Each of the participants conducted bench-scale testing using groundwater samples collected from SADA. Once the bench-scale testing was complete, the vendors mobilized pilot-scale systems to SADA for the performance of the demonstration.

The pilot-scale demonstration program was conducted under the coordination and supervision of USAEC. WESTON was under contract to USAEC for site preparation, health and safety protocols, independent evaluation, systems monitoring, and sampling and analysis. The focus of this demonstration was on the evaluation of performance of the various processes based on common input conditions. A common groundwater distribution system was installed to ensure that all four processes were receiving groundwater of identical quality. The participants were free to select a flowrate up to 10 gallons per minute that would be best for their individual process. Each participant's flowrate and electrical energy usage were logged hourly. For each day of the demonstration, an influent sample and an effluent sample from each vendor were collected three times a day at random intervals and submitted for explosives and nitroaromatics analysis by EPA Method 8330. The primary target compounds were 2,4,6-TNT and 1,3,5-TNB, which were present in the highest concentrations in the influent groundwater. Secondary target compounds detected in the influent groundwater included 1,3-dinitrobenzene (1,3-DNB), 2,4-dinitrotoluene (2,4-DNT), 2,6-dinitrotoluene (2,6-DNT), and amino dinitrotoluenes (amino DNTs). Daily average effluent concentrations of each of the target compounds were calculated by averaging the results of the three random daily samples collected from each participant's process effluent. These averages were then compared with the daily average treatment criteria established for each compound by the Illinois Environmental Protection Agency (IEPA).

The results of the demonstration showed that all four of the UV/Ox processes achieved the treatment criteria for both 2,4,6-TNT and 1,3,5-TNB on one or more days of the

demonstration. There was considerable variation in the consistency with which each process met the criteria. The Ultrox process was the only one to achieve the treatment criteria for all target compounds on all 14 days of the demonstration. The Solarchem process met all criteria on three of the days, as difficulties were experienced reaching the criteria for 2,4,6-TNT. The VPSI process met all criteria on one day, as it had difficulty meeting the criteria for 1,3,5-TNB. The Purifics process achieved the criteria for 2,4,6-TNT and 1,3,5-TNB on four days; however, it never achieved all the criteria because of the presence of 1,3-DNB at concentrations slightly above the discharge limits.

The following table presents the attainment of SADA discharge criteria in days by each process:

PROCESS	NUMBER OF DAYS OF SUCCESSFUL TREATMENT				
	TNT	TNB	DNB	All Other ECOCs	All ECOCs
Purifics	11	4	0	14	0
Solarchem	4	9	14	14	3
Ultrox	14	14	14	14	14
VPSI	12	1	14	14	1

*ECOC - Explosive Compounds of Concern

The DTECH test kits provided the participants with an inexpensive method to optimize treatment by semi-quantitatively assessing the disappearance of 2,4,6-TNT and 1,3,5-TNB. Rapid turnaround laboratory analyses, however, are still necessary for the quantification of 2,4,6-TNT and 1,3,5-TNB and for the detection of the other explosive compounds of concern. One participant relied solely on the DTECH method for process optimization and did not realize that the process effluent still contained 1,3-DNB until after the demonstration was completed.

The participating vendors were required to prepare cost estimates for a full-scale system both after the initial bench-scale testing and after the pilot-scale demonstration. This was done to evaluate whether the initial cost estimate provided after bench-scale testing was accurate, if the relative costs of the processes could be determined, and whether the data collected during the pilot-demonstration resulted in significant modifications to the prescribed full-scale system. From the results of the demonstration, it does not appear that the bench-scale testing is completely adequate for providing data for full-scale system designs. This is evidenced by the fact that only one of the four participants was able to prescribe a pilot-scale system based on the bench-scale testing that could consistently achieve the discharge criteria for both 2,4,6-TNT and 1,3,5-TNB on all 14 days of the demonstration. In addition, the full-scale capital and annual operations and maintenance (O&M) cost estimates made after bench-scale testing and after pilot-scale testing were significantly different, indicating that the pilot-scale testing provided important data necessary for the accurate sizing of the full-scale system.

Nonetheless, the bench-scale cost estimates were of the same order of magnitude as the revised costs based on the pilot-scale testing. Additionally, the relative costs of the four individual processes with respect to each other remained the same between the bench-scale and revised pilot-scale cost estimates. As a result, it appears that competitive pilot-scale studies could potentially be replaced with less costly competitive bench-scale testing. A single pilot-scale test would then be performed with the selected process to determine design parameters for a full-scale system. This approach could result in considerable economic savings.

The revised cost estimates provided by each of the participants following completion of the pilot-scale demonstration were based on a hypothetical groundwater remediation with a design flow of 50 gallons per minute and a groundwater quality similar to that of the water treated during the demonstration at SADA. The discharge criteria were identical to those imposed during the demonstration. Based on the capital costs and the annual O&M costs provided by each of the vendors, the 30-year present worth values were calculated. These calculations applied a 5.25% interest rate, a 3.5% inflation rate, and a 6.8% salvage value.

These costs are for the treatment of groundwater only and do not include the associated costs for pumping, conveyance piping, well installation, and effluent monitoring that would be associated with any groundwater remediation regardless of which pump and treat technology is selected. The resulting present worth values for each process are as follows:

Process	Present Worth
Purifics	$3,300,000
Solarchem	$6,080,000
Ultrox	$2,650,000
VPSI	$11,100,000

Because all the participants developed their full-scale cost estimates based on data gathered during the pilot-scale demonstration, there is more confidence in the present worth values of the processes that met the treatment criteria more frequently. It is important to note that the results of this pilot-scale demonstration, including the calculated present worth values, are specific to the quality and quantity of nitroaromatics and other constituents in the SADA groundwater. Consequently, extrapolation of these results or their use for evaluating the application of the processes at other sites may not be appropriate. The results, however, do provide an indication of how effective the UV/Ox technology can be. The discharge criteria may be different at sites other than SADA. The following table presents the process effluent explosive concentrations for the day that each process was most effective during the SADA demonstration.

PROCESS EFFLUENT CONCENTRATIONS (ug/L)*

Process	TNT	TNB	1,3 DNB	2,4 DNT	2,6 DNT	A-DNT	Tetryl	HMX	RDX	NB
Purifics (14 Oct 94)	1.6U	2.6C	4.9C	1.6U	1.6U	5.6C	4.7U	14U	6.7U	1.6U
Solarchem (30 Sep 94)	0.79C	4.1C	1.4C	1.4C	0.78U	1.5U	2.3U	6.6U	3.2U	0.78U
Ultrox (03 Oct 94)	0.49U	0.49U	0.49U	0.49U	0.51U	0.99U	1.5U	4.3U	2.1U	0.51U
VPSI (04 Oct 94)	1.9U	6.9	1.9U	1.9U	2.0U	3.8U	5.7U	17U	8.2U	2.0U

* Averaged data from the three effluent samples obtained on the dates indicated.

C Denotes that one or two of the samples were below the detection limit. detection limit values were used for averaging of nondetect sample data.

U Denotes that all three samples were below he detection limit. Values listed provide an indication of the detection limits.

The above data indicate the capability of all four processes to achieve low parts per billion (ppb) level treatment of the influent explosives found at SADA.

SECTION 1
INTRODUCTION

1.1 BACKGROUND INFORMATION

1.1.1 Nature of the Problem

The manufacture, storage, testing, and disposal of munitions at numerous U.S. Army installations has resulted in the contamination of groundwater with explosives compounds. This occurred as a result of past practices that were considered standard and acceptable at the time of operation. Under its Installation Restoration Program (IRP), the U.S. Army has established procedures for evaluating the nature and extent of contamination at these installations and, where appropriate, for implementing remedial actions to mitigate or eliminate the environmental and health risks associated with such sites.

The conventional technology for remediation of explosives and nitroaromatics in groundwater is granular activated carbon (GAC) adsorption. This technique provides a simple and effective method for removing these compounds from large volumes of groundwater by separating and concentrating them within a significantly smaller volume of GAC. Although this volume reduction is beneficial, the contaminants are not destroyed, and the resulting explosives-laden GAC requires additional treatment and/or disposal. Due to the reactive and explosive nature of the nitroaromatic compounds, management of this GAC residual has been problematic for the U.S. Army (A.D. Little, 1992).

The Army has investigated numerous waste management strategies for explosives-laden GAC including on-site regeneration, off-site regeneration, thermal deactivation, and incineration. Of these four options, off-site regeneration has proven to be the most economical for most of the Army installations that are currently generating this spent GAC. However, this option is not without difficulties. The spent GAC must be managed as a K045 hazardous waste [defined under the Resource Conservation and Recovery Act (RCRA) as spent GAC from the treatment of wastewater containing explosives]. Kansas Army Ammunition Plant (KAAP) has negotiated with state and federal regulators to have

individual batches of its GAC delisted by demonstrating its lack of explosive reactivity. All other installations have been handling spent GAC in compliance with hazardous waste regulations.

Currently, Envirotrol, Inc. of Sewickley, Pennsylvania is the only commercial regenerator willing to accept explosives-laden GAC. As a result, the Army does not have the flexibility to competitively contract the regeneration. Additionally, the very strict regulatory requirements for importing the K045 waste into Pennsylvania result in extensive documentation that some of the installations have found frustrating. Finally, some of the installations implementing this regeneration have experienced performance problems with the regenerated GAC including increased total suspended solids (TSS) in the effluent and loss of the structural integrity of the GAC. An emerging alternative which has shown promise for residual GAC management at two Army installations is the use of the explosives-laden GAC as a supplemental fuel in cement kilns. However, to be considered for such disposal, the spent GAC must be shown to be explosively non-reactive, while at the same time containing a minimum energy content to make the waste an attractive fuel source. As a result, the management of explosives-laden spent GAC from Army installations requires site-specific evaluations of factors such as the location of the installation, the nature of the site-related explosives contaminants, the characteristics of the spent GAC, and the proximity of either a cement kiln or off-site regenerator. (A.D. Little, 1992)

Based on these considerations, it is clear that the management of explosives-laden spent GAC presents a formidable chore at the numerous Army installations where it is generated. Consequently, the Army is interested in identifying promising treatment alternatives which could provide for the destruction of explosives and nitroaromatics in wastewaters and contaminated groundwaters without generating a residual requiring management or disposal.

In response to this need to identify alternatives to GAC for the treatment of explosives-contaminated groundwater, the U.S. Army Environmental Center (USAEC) initiated an evaluation of advanced oxidation processes (AOPs) which are also referred to as ultraviolet

light catalyzed oxidation (UV/Ox) processes. Roy F. Weston, Inc. (WESTON) was contracted to perform an initial assessment of the applicability of the technology to explosives and nitroaromatics. The results of this preliminary assessment are presented in Subsection 2.1. The scope of work was later expanded to include the performance of a pilot-scale demonstration of the technology at a representative Army installation. This report summarizes the effort under this contract, including the results and lessons learned from the pilot demonstration.

1.1.2 Introduction to Advanced Oxidation Processes (AOPs)

AOPs may provide an effective alternative to GAC for the remediation of explosives and nitroaromatics in groundwater. Unlike the GAC process in which the contaminants are separated and concentrated within the carbon, AOPs achieve destruction of the contaminants without generating residual wastes requiring treatment or disposal. AOPs are chemical oxidation processes in which highly reactive hydroxyl radicals are generated which subsequently react with, and destroy, most organic chemical compounds. UV/Ox processes are a set of special AOPs in which the hydroxyl radicals are created from hydrogen peroxide and/or ozone by photochemical reactions with ultraviolet light. The primary mechanisms of destruction of these UV/Ox processes include the following reactions:

- Oxidation by free radical molecules, primarily hydroxyl radicals.
- Direct oxidation by chemical oxidants such as hydrogen peroxide or ozone.
- Direct photolysis (cleavage) of the contaminant molecules by ultraviolet light.

Typically, all of the above mechanisms occur concurrently and there may also be a synergistic effect because of their combination. The dominant mechanism for AOPs is normally oxidation by free radicals, but this can vary depending on the process and on the characteristics of the waste stream being treated. Certain processes use hydrogen peroxide as an oxidant, while others use ozone. For some processes, the selection of oxidant is based on site-specific and contaminant-specific constraints. Similarly, there is variation in the types

of lamps implemented. Some processes use conventional "off-the-shelf" low-pressure lamps. Others use proprietary medium-pressure, higher intensity lamps. The destruction of different compounds occurs via various oxidative pathways in which initial oxidation reactions result in the formation of intermediate products that are subsequently oxidized to smaller intermediates. Ultimately, complete treatment by AOP processes results in relatively innocuous end products of simple carboxylic acids, carbon dioxide, water, nitrates, and other salts. However, special care must be taken during design to ensure that complete treatment is provided, otherwise, the treated effluent could potentially contain intermediate products that are more toxic or environmentally detrimental than the original contaminants (A.D. Little, 1993).

The potential elimination of post-treatment residuals by these processes could be a major advantage, particularly for explosives and nitroaromatics which create the waste management difficulties summarized in Subsection 1.1.1. Elimination of a residual waste stream further reduces the operation and maintenance (O&M) requirements of treating a specific wastewater or groundwater.

1.2 PROJECT OBJECTIVES AND APPROACH

The USAEC retained WESTON to perform a pilot-scale demonstration of four commercially available AOPs at the Savanna Army Depot Activity (SADA) in Savanna, Illinois in September and October of 1994. The overall project objective, as well as the specific goals of the demonstration are presented below.

1.2.1 Primary Objective

The primary project objective was to evaluate the technical and cost effectiveness of AOP technologies in remediating groundwaters containing 2,4,6-trinitrotoluene (TNT) and other nitroaromatics by performing a pilot-scale demonstration. The results of this evaluation would then be presented in the form of a technology transfer package consisting of this report, a Technical Application Analysis (TAA), implementation procedures, and the

associated photographs and video taken during the demonstration. This technology transfer package would then be used to facilitate the Remedial Investigation/ Feasibility Study (RI/FS) process at Army installations by providing decision makers with a tool for assessing the potential application of AOPs to the remediation of explosives-contaminated groundwater and comparing their effectiveness and cost parameters with conventional GAC systems. To ensure the usefulness of the evaluation and results, the demonstration was performed at an Army installation where the groundwater was determined to be representative of conditions existing at other Army depots and ammunition plants. As a result, the data collected and lessons learned from the demonstration may potentially eliminate the need to perform competitive pilot-scale studies at other sites with similar characteristics.

1.2.2 Specific Goals

To ensure that the technology transfer package would be useful and contain the appropriate information required by the RI/FS decision makers, the following specific goals were developed for the project:

- Evaluate the effectiveness of AOPs in remediating groundwater contaminated with TNT and other nitroaromatics.
- Evaluate various readily available commercial processes in terms of effectiveness and cost.
- Determine the reliability of using AOP bench-scale testing data for determining relative technical and cost effectiveness and for developing full-scale system designs.

Although the UV/Ox processes are applicable to a wide range of organic compounds, this project focused on the treatment of nitroaromatics in groundwater. An initial review of past treatment experience with nitroaromatics demonstrated that limited performance data existed and that competitive pilot-scale demonstrations of the technology were required to determine which commercial process was most effective. This pilot-scale demonstration was intended to assess the effectiveness of the competing commercial processes by allowing

several vendors to simultaneously treat a common groundwater. The data obtained from the demonstration would then facilitate the development of reliable life-cycle costs for comparing the technical cost-effectiveness of each of the participating commercial AOP processes. Another intent of the pilot-demonstration was to assess the accuracy of bench-scale testing, to evaluate whether any or all of the AOP technologies are mature enough to proceed directly from bench-scale tests to full-scale design without the need for costly pilot-scale testing, and whether relative costs could be determined. The ability to eliminate competitive pilot-scale testing could result in considerable savings in the implementation of AOP technologies.

1.3 APPROACH

The strategy implemented by USAEC in meeting the project objectives included the chronological performance of the following tasks:

- A background literature review of AOP technologies.
- Determination of the feasibility of using AOP technologies for the treatment of explosives and nitroaromatics.
- Identification of experienced, commercially available AOP process vendors.
- Selection of a representative Army installation to host the pilot-scale demonstration.
- Solicitation of proposals/bids from competent commercial vendors.
- Evaluation of proposals and selection of the most promising commercial processes for participation in the demonstration.
- Bench-scale testing.
- Pilot-scale testing at the selected installation.
- Evaluation of each participant's performance.
- Preparation of the technology transfer report.

SECTION 2

PRE-DEMONSTRATION ACTIVITIES

2.1 LITERATURE REVIEW/TECHNOLOGY SCREENING

Prior to initiating the pilot-scale demonstration of AOP technologies, USAEC conducted a background literature review and technology screening to determine the status of the technology and to assess its potential for application to TNT and nitroaromatics. Sources of information consulted during this review included technical journals, meetings and discussions with commercial vendors of AOP equipment, and personal communications with experts at the U.S. Army Waterways Experiment Station (WES) in Vicksburg, Mississippi.

Technical journals provided an initial, unbiased perspective of the current state of the technology, including current advancements, and process limitations. A review of the literature indicated that although the application of AOP technologies to groundwater cleanup projects is increasing, their application for the remediation of TNT and other nitroaromatic contamination is still in the developmental stages.

In addition to the technical journals, several meetings were conducted with technical sales representatives from four different commercial vendors of AOP systems. As expected, the vendors were very optimistic about the application of their individual processes for the treatment of TNT and nitroaromatics. Several vendors indicated that their previous bench-scale and/or pilot-scale testing on such compounds had produced encouraging results.

A meeting was held at WES to facilitate the transfer of technical knowledge to USAEC. Conversations with personnel at WES further supported the contention that AOPs could be effective for the treatment of TNT and nitroaromatics. WES had conducted numerous bench-scale tests using treatment strategies analogous to the systems available from three major commercial AOP vendors and had found them all to be effective.

2.1.1 Technology Background

The first commercial AOP processes emerged on the water treatment scene in the early 1980s (Rapaport, 1993). These so-called "first generation" units relied on the same basic chemical reactions used by the current AOP systems; however, there were mechanical and operational difficulties with these initial units. Although the concept of complete contaminant destruction and elimination of residuals management was enticing, the capital and operating costs of these first generation units prevented their widespread acceptance. As the technology progressed, improvements in both the efficiency of the units and the mechanical operation of the systems led to "second generation" units that were more competitive with conventional processes, such as GAC adsorption for treatment of organic contaminants. Currently, research is continuing to provide advancements in the development of AOPs. The evolution of the AOP technology, including the current advancements in the field, are presented in the following subsections.

2.1.1.1 First Generation Units

The first AOPs consisted of simple reactors in which the ultraviolet lamps were mounted within transparent quartz sleeves. This design was similar to the existing ultraviolet radiation disinfection systems that were sometimes used as an alternative to chlorination in water and wastewater treatment systems (Barnes and Wilson, 1983). Water to be treated was passed over the outside of the quartz sleeves where the reaction between the ultraviolet light and chemical oxidants such as ozone or hydrogen peroxide created highly reactive hydroxyl radicals which subsequently oxidized the organic contaminants. The economics of these early systems were not encouraging. The capital costs were very high relative to competing technologies such as GAC. In addition, lamp efficiencies had not yet been optimized and, as a result, the electrical costs for generating the ultraviolet light contributed to substantial operating costs.

Cost was not the only disadvantage of the early AOP systems. As field experience with the commercial units increased, operational problems with the systems became evident. The

most significant of these was the formation of precipitates, such as calcium carbonate and iron oxides within the reaction chambers which ultimately deposited on the surface of the quartz sleeves as a scale. Scale formation causes a significant decrease in ultraviolet light transmission, and subsequent decrease in process efficiency. Often, these scaling problems were not predicted by bench-scale studies or short-term pilot studies, which resulted in unreasonably optimistic full-scale design estimates. As a result of this scale formation and the reduced UV light output with bulb aging, many of the early systems had to be designed with extra capacity to accommodate this eventual reduction in ultraviolet light transmission and process efficiency. Manual cleaning of the quartz sleeves was required on a regular basis to restore the systems to their optimal operating condition. This cleaning requirement resulted in higher maintenance costs, and was detrimental to an emerging technology that was attempting to promote itself as low-maintenance (Rapaport, 1993).

The effects of scaling were evaluated in a study conducted at the Lawrence Livermore National Laboratory (LLNL). An AOP system employing a five-micron pre-filter and hydrogen peroxide injection prior to the ultraviolet light reaction chamber was used to treat an assortment of volatile organic compounds (VOCs) at an average flowrate of 50 gallons per minute. Effluent samples were analyzed for VOCs immediately after quartz sleeve cleaning events to assess the process performance achievable with freshly cleaned quartz sleeves. Additional samples were taken periodically between these cleaning events to assess the deterioration of performance caused by scaling. The sampling results consistently demonstrated a decrease in reactor efficiency with effluent concentrations of perchloroethylene (PCE), the indicator compound, increasing by factors of 10 to 100 within one to two weeks between cleaning events. (Camp, 1991)

2.1.1.2 Second Generation Units

The vendors of the commercial systems responded to the need for improvements to their first generation units with significant research and development efforts to address the specific shortcomings of their systems. One of the major improvements in these second generation systems was the installation of wiper mechanisms to provide automatic cleaning

of the quartz sleeves. These mechanisms provided intermittent cleaning of the outer surfaces of the quartz sleeves without interruption of the treatment process.

Another area of research and development in support of enhanced system performance was the ultraviolet light sources. Optimization of lamp efficiencies became a focus of many of the vendors. The conventional low-pressure mercury vapor lamps emitted ultraviolet light with a narrow bandwidth and a peak energy at a wavelength of approximately 254 nanometers (nm). Some vendors developed proprietary lamps designed to emit light with shorter wavelengths than the standard 254 nm light. Others developed lamps that emitted the ultraviolet light over a broader range of wavelengths in an attempt to destroy a larger number of organic contaminants. Finally, since all the systems rely on substantial electrical energy to power the lamps, optimizing the conversion of the electricity to ultraviolet light represented an area of research and development promising major improvements in system efficiencies (Roy, 1990a).

2.1.1.3 Current State-of-the-Art

One of the primary obstacles that the proponents of AOPs have had to address is the lingering negative perception of the technology created by the costs and operational problems with the first-generation units. Information concerning the level of reliability and effectiveness and the cost competitiveness of second generation AOPs with other treatment alternatives has not been widely known. While advancements in the basic chemistry and reactor designs of the systems are ongoing, many of the AOP vendors have focused on making user-friendly systems that are easier to implement. As a result, the commercial systems available today are equipped with extensive instrumentation and monitoring devices, and are much less susceptible to upsets than the first generation systems. Quartz sleeve cleaning mechanisms are standard on these systems, and virtually all the commercial systems are available with programmable logic controllers (PLCs) which allow for remote system monitoring and control.

Research continues to develop new applications for the technology and to further optimize the oxidation process through advances in reactor designs, lamp efficiencies, and the development of specialty catalysts. One developing system, for instance, uses ultrasonic sound, or "ultrasound" [acoustic frequencies between 20 and 120 kilohertz (kHz)] in addition to ultraviolet light and ozone. The mechanical action of the ultrasound is thought to prevent scaling on the surface of the quartz sleeves and to increase the mass transfer of ozone gas into the contaminated liquid (Roy, 1990b). A second company has developed a process which, in addition to UV light and chemical catalysts, uses hydrodynamic cavitation to generate hydroxyl radicals. According to the manufacturer, the cavitation process is more efficient than standard AOPs for generating hydroxyl radicals. This results in potentially lower operating costs relative to other AOPs. Another company is seeking to optimize the direct photolysis of organics with the development of pulsed flashlamps. These lamps emit ultraviolet light over a very broad band of wavelengths which encompasses all the frequencies absorbed by different toxic organics. The lamps provide bursts of high intensity ultraviolet light with enough energy to break apart organic molecules. Ozone and peroxide can also be added to improve the efficiency by encouraging oxidation reactions as well. These high intensity pulses can occur up to 100 times per second, but because the ultraviolet light is not generated continuously, the overall efficiency of the lamps is expected to be greater than conventional mercury vapor lamps (Wekhof, 1992).

2.1.1.4 Titanium Dioxide-Based AOPs

One recent development in the advanced oxidation field which has attracted much attention is the use of titanium dioxide semi-conductor as a catalyst. Much of the work with titanium dioxide has been limited to laboratory studies; however, there are currently at least two vendors who market commercial AOP systems that use the titanium dioxide catalyst as the basis of their design.

Unlike the conventional AOP systems that focus on oxidative reactions by encouraging direct photolysis and/or direct oxidation of the target organics, titanium dioxide-based systems can create both oxidizing and reducing environments through a process referred to

as "photocatalysis." In the photocatalytic process, the primary objective of the ultraviolet light is not the direct photolysis of the target molecules or reaction with the ozone and hydrogen peroxide oxidants to form free radicals. Rather, the titanium dioxide catalyst is activated by the ultraviolet light, and, as a result, an electron is promoted from the valence band to the conduction band within the semiconductor. This charge separation creates a highly reactive environment in which the negatively charged electron is available for reduction reactions and the complementary positively charged "hole" left behind by the electron becomes an oxidation site. The resulting independent reactions that occur with both the hole and the electron result in the formation of the highly reactive hydroxyl radicals which then become the dominant mechanism for destruction of the target compounds. To increase the efficiency of the photocatalytic process, irreversible electron acceptors can be introduced to prevent the recombination of electrons and holes. Potential advantages of photocatalytic reactions include more efficient and/or complete destruction of the target organic compounds (Schmelling and Gray, 1993).

2.1.2 Application to Explosives and Nitroaromatics

As stated previously, the application of the AOPs to explosives and nitroaromatics has been limited, primarily because the majority of the commercial AOPs in operation are addressing the treatment of VOCs and petroleum-based compounds. Most of the experience that vendors have had with nitroaromatics is associated with bench-scale and pilot-scale studies conducted as part of RI/FS activities at other Department of Defense (DOD) sites. For example, pilot studies investigating the application of AOPs to explosives and nitroaromatics have been conducted at the Milan Army Ammunition Plant (MAAP) in Tennessee and the Umatilla Depot Activity (UMDA) in Oregon. The results of these pilot studies have shown that the AOPs can be effective for the treatment of TNT and other nitroaromatics. However, the life-cycle cost estimates for AOPs have not always been among the most competitive alternatives. At MAAP, for instance, the compound 1,3,5-trinitrobenzene (TNB) proved to be very resistant to destruction by ultraviolet oxidation. Rather than proposing an AOP system alone, a hybrid treatment system consisting of an AOP to destroy

the less refractory nitroaromatics followed by GAC polishing to remove the TNB appeared to be most applicable. (ICF, 1993)

The difficulties encountered with the destruction of 1,3,5-TNB appear to be related to the use of hydrogen peroxide as an oxidant. During a bench-scale evaluation of a UV/peroxide process for treatment of TNT processing wastewater, 1,3,5-TNB was identified as a refractory byproduct of the TNT decomposition. This compound was not formed when ozone was used in place of the hydrogen peroxide (McPhee et. al., 1993).

2.2 SITE SELECTION

2.2.1 Review of IRDMIS Data

Prior to selecting an installation to host the AOP pilot-scale demonstration program, groundwater data obtained from the Army's Installation Restoration Data Management Information System (IRDMIS) was tabulated for the 18 Army facilities known to have TNT and other nitroaromatic compounds in groundwater. For each installation, the maximum, minimum, and average concentrations of TNT, cyclotrimethylenetrinitramine (RDX), iron, manganese, and alkalinity were calculated. The objective of this data manipulation was to reduce the number of potential sites to those which showed promise of providing a representative groundwater which would allow the results and lessons learned from the demonstration to be applied at other locations.

The review of the IRDMIS data showed that the groundwater concentrations of explosives varied considerably across the installations and also among sampling locations within individual installations. Concentrations of TNT varied from a minimum of 21 micrograms per liter (μg/L) to a maximum of 26,000 μg/L. Overall, the average TNT concentration that appeared to be representative for a pilot-scale demonstration was 1,000 μg/L.

Explosives concentrations were not the only factors considered during the pilot-scale demonstration site selection. Other criteria, including base location and accessibility, base activity, and anticipated regulatory acceptance also played a role in the selection process.

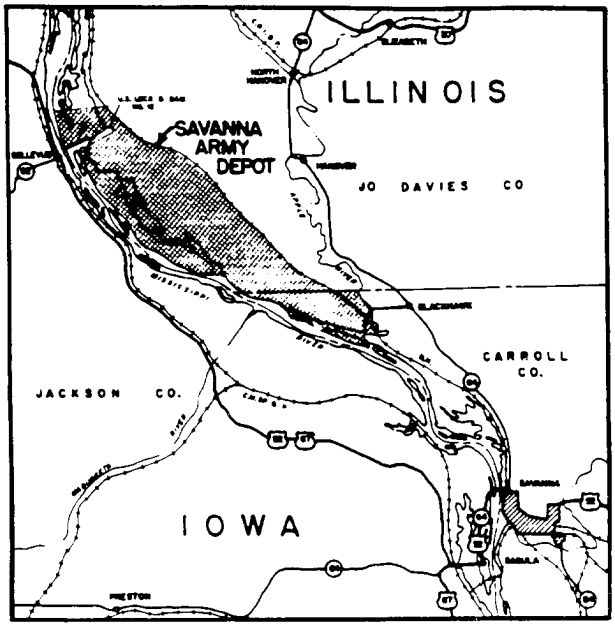
For example, although UMDA satisfied the concentration criteria and would likely have been an acceptable location for the demonstration, one of the anticipated potential participants had previously conducted treatability studies on the groundwater at this installation. Additionally, UMDA had already selected GAC for the remedial action (RA) and further testing would not have benefitted the installation. Iowa Army Ammunition Plant was another installation which showed promise for hosting the demonstration, but the hydraulic conductivity of the aquifer was insufficient to provide the anticipated 40 to 50 gallons per minute (gpm) flow required for the demonstration.

After a thorough evaluation of the candidate sites, the Savanna Army Depot Activity (SADA) in Illinois was selected to host the pilot-scale demonstration. Reasons for conducting the demonstration at SADA included:

- Representative explosives concentrations.
- Sufficient iron and manganese concentrations to assess the effects of scaling.
- Adequate hydraulic conductivity to allow the withdrawal of the maximum anticipated flow.
- Availability of an existing shelter near the contaminated wells in which to conduct the demonstration.

2.2.2 Background of Savanna Army Depot Activity (SADA)

SADA is located in northwestern Illinois (see Figure 2-1) and covers 13,172 acres on the eastern bank of the Mississippi River, approximately 12 miles north of Savanna, Illinois. SADA's current mission is receipt, storage, issue, and demilitarization of conventional ammunition, general supply, and strategic war material. SADA also has a mission of manufacturing, procuring, and maintaining ammunition peculiar equipment and repair for world-wide DOD support. In addition, the depot conducts ammunition function testing and special tests for the U.S. Army Armament, Munitions, and Chemical Command and the Marine Corps.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JACKSON CO.
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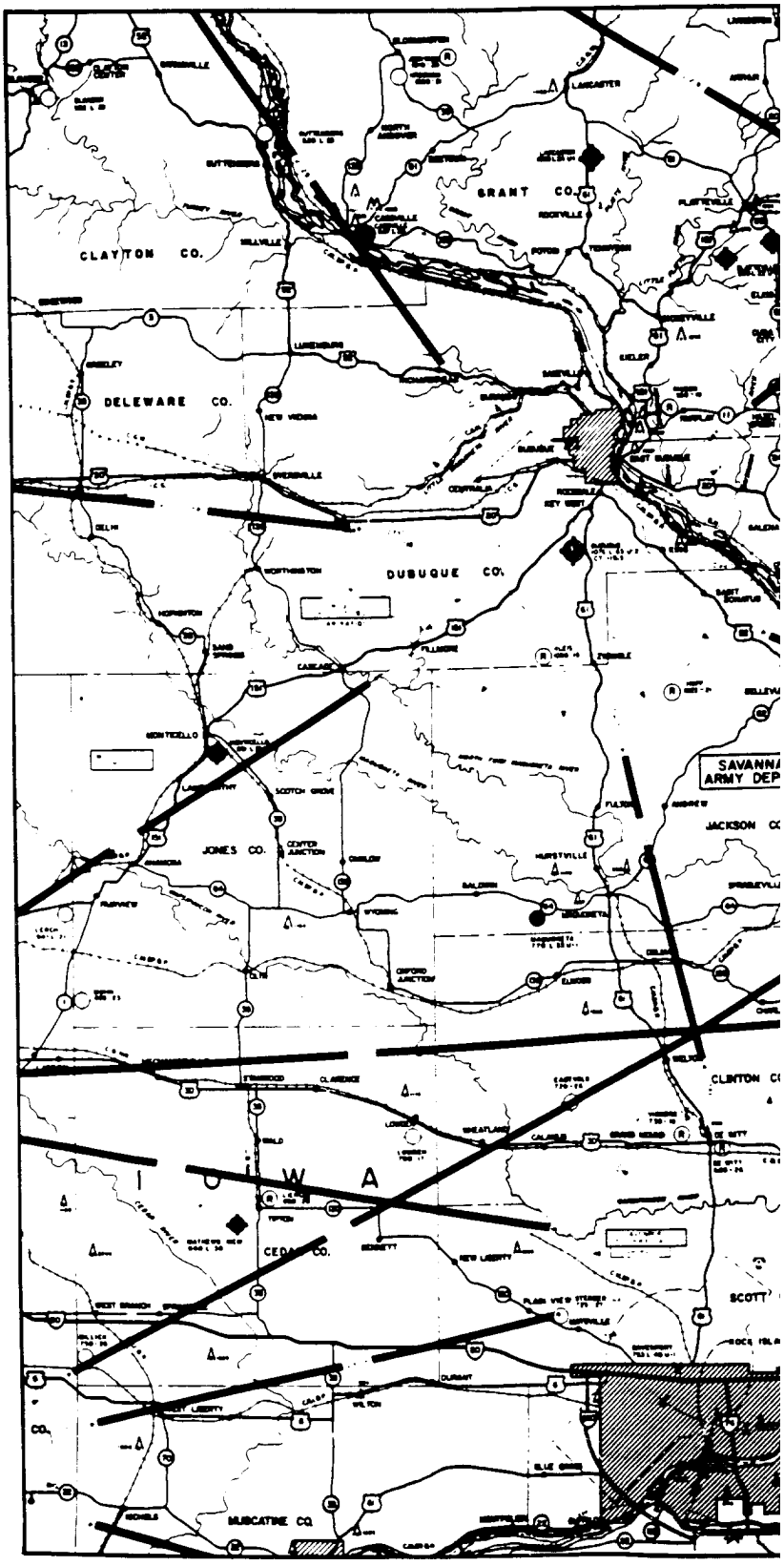
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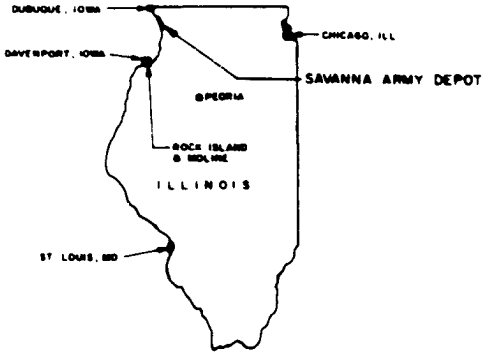
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CHICAGO, ILL
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@PEORIA
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ILLINOIS
ST LOUIS, MO

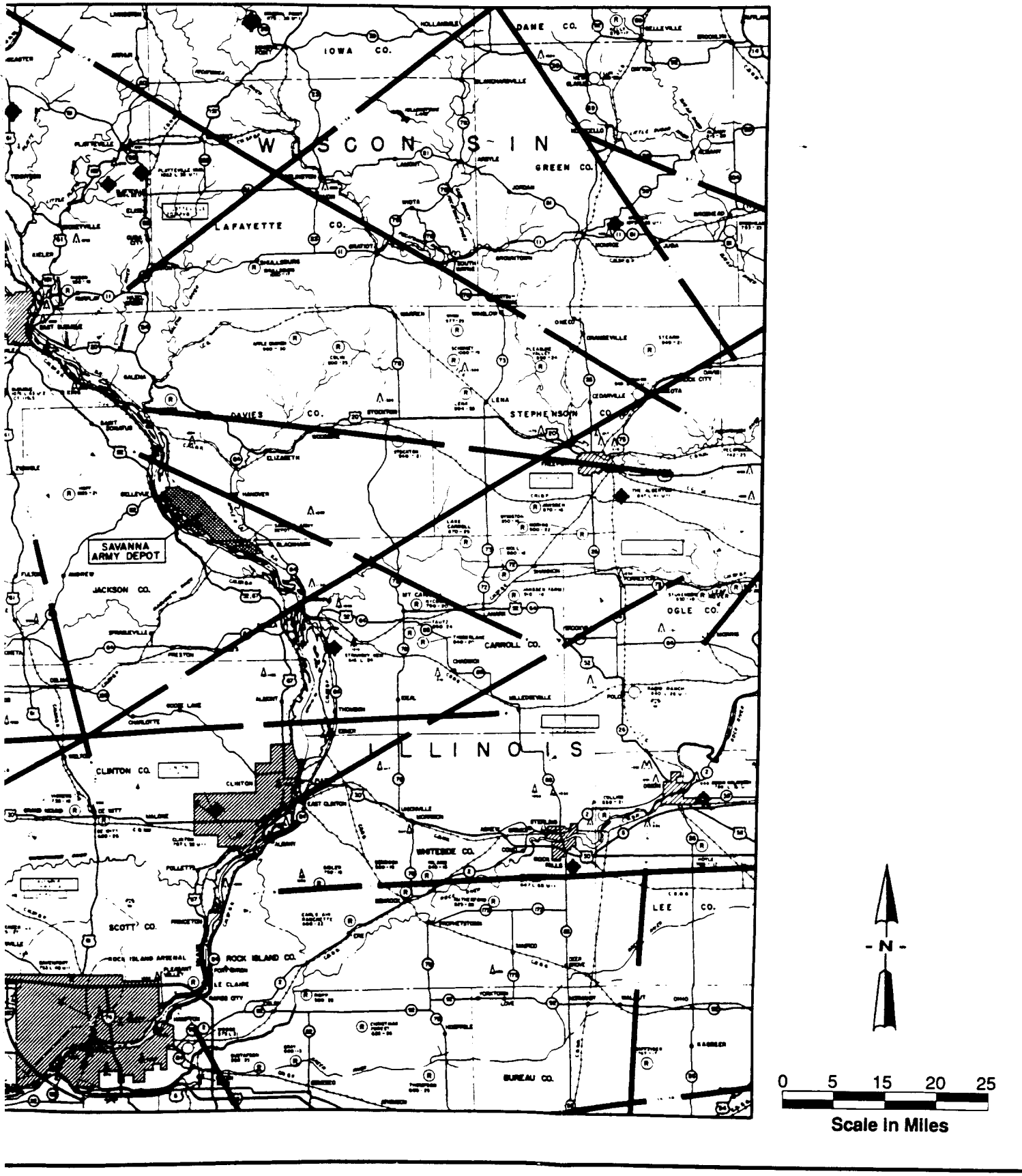


FIGURE 2-1 SADA LOCATION MAP

The specific site selected for the pilot demonstration was the location of the former TNT washout facility, where ammunition washout operations began in 1943. This area is located in the northern end of SADA as shown in Figure 2-2. Wastewater from the washout operation was discharged to four leaching lagoons, where it either evaporated, or percolated into the ground. The four leaching lagoons were inactivated in 1961 and two new leaching lagoons were used until operations were discontinued at the TNT Washout Facility in 1969.

Since that time, numerous environmental assessments and investigations of soil, sediment, surface water, and groundwater have been conducted at this site including studies by Environmental Science and Engineering (ESE) in 1982, Roy F. Weston Inc. (WESTON) in 1984, Hunter/ESE in 1989, and Dames and Moore in 1990 and 1991. A Remedial Investigation (RI) report on the TNT Washout Facility Lagoons was completed in 1991 (Dames & Moore, 1991). The RI summarized the nature and extent of groundwater contamination from data obtained during previous ESE and Hunter/ESE investigations.

The Feasibility Study (FS) for the TNT Washout Facility identified that a removal action, including the excavation of the old lagoons, the overflow ditch, and the drain trough, should be performed (WESTON, 1991). A Record of Decision (ROD) for the site was approved by EPA and the Illinois Environmental Protection Agency (IEPA) which defined the explosives-contaminated soils associated with the TNT Washout Facility as an Operable Unit and indicated rotary kiln incineration as the approved treatment technology. Approximately 25,000 cubic yards (yd^3) of contaminated soils were subsequently excavated and treated by incineration. Remediation of the contaminated soils at the former TNT Washout Facility was completed in 1993.

The RI report on the former TNT Washout Facility identified the distribution of contaminated groundwater in the vicinity of the Old and New Leaching Lagoons (Areas 21 and 22, respectively). Figure 2-3 shows the isoconcentration contours of total explosives in the shallow groundwater based on the 1989 Hunter/ESE data. Well 302102, located downgradient of the four Old Leaching Lagoons (Area 21), had the highest concentrations

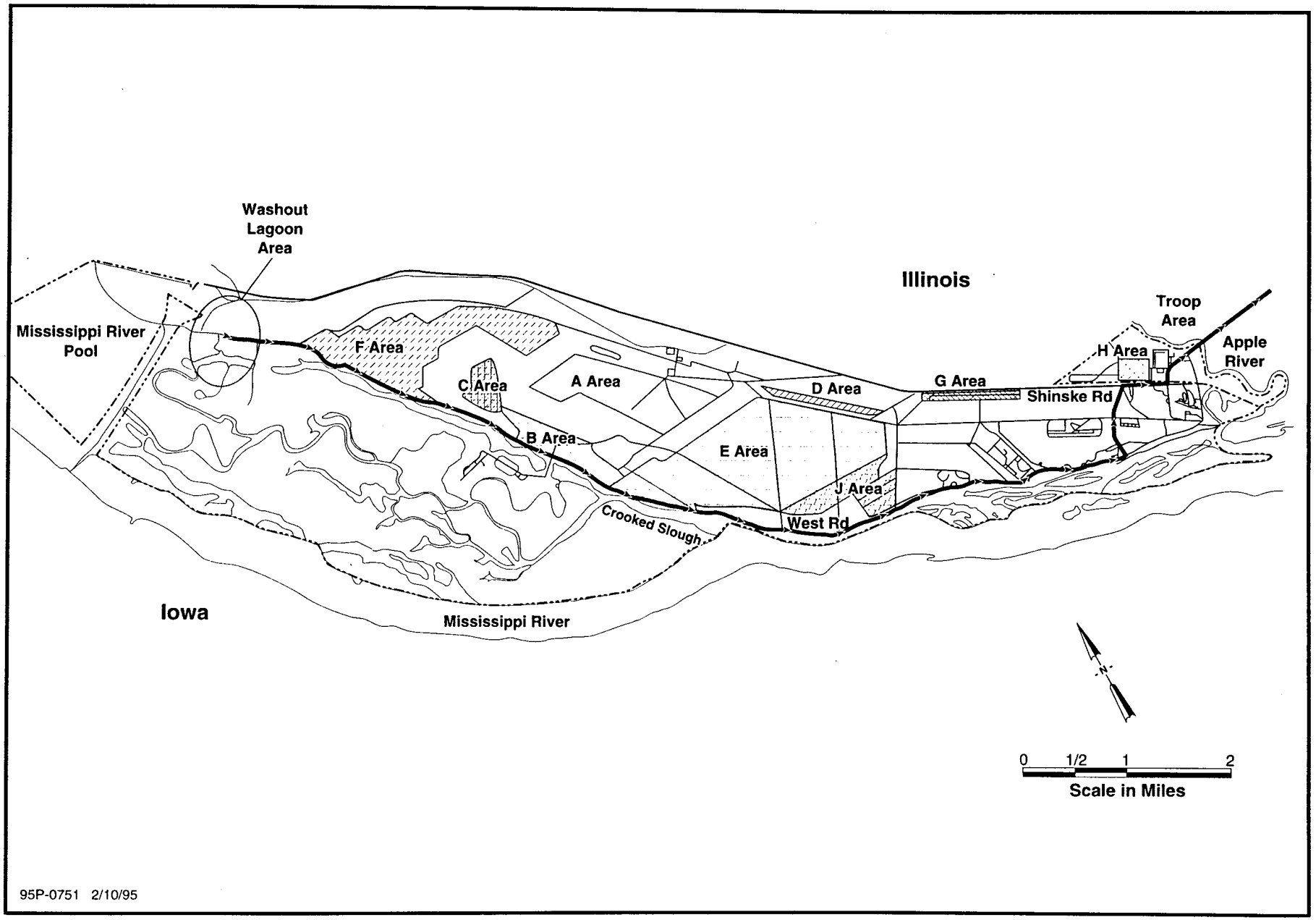
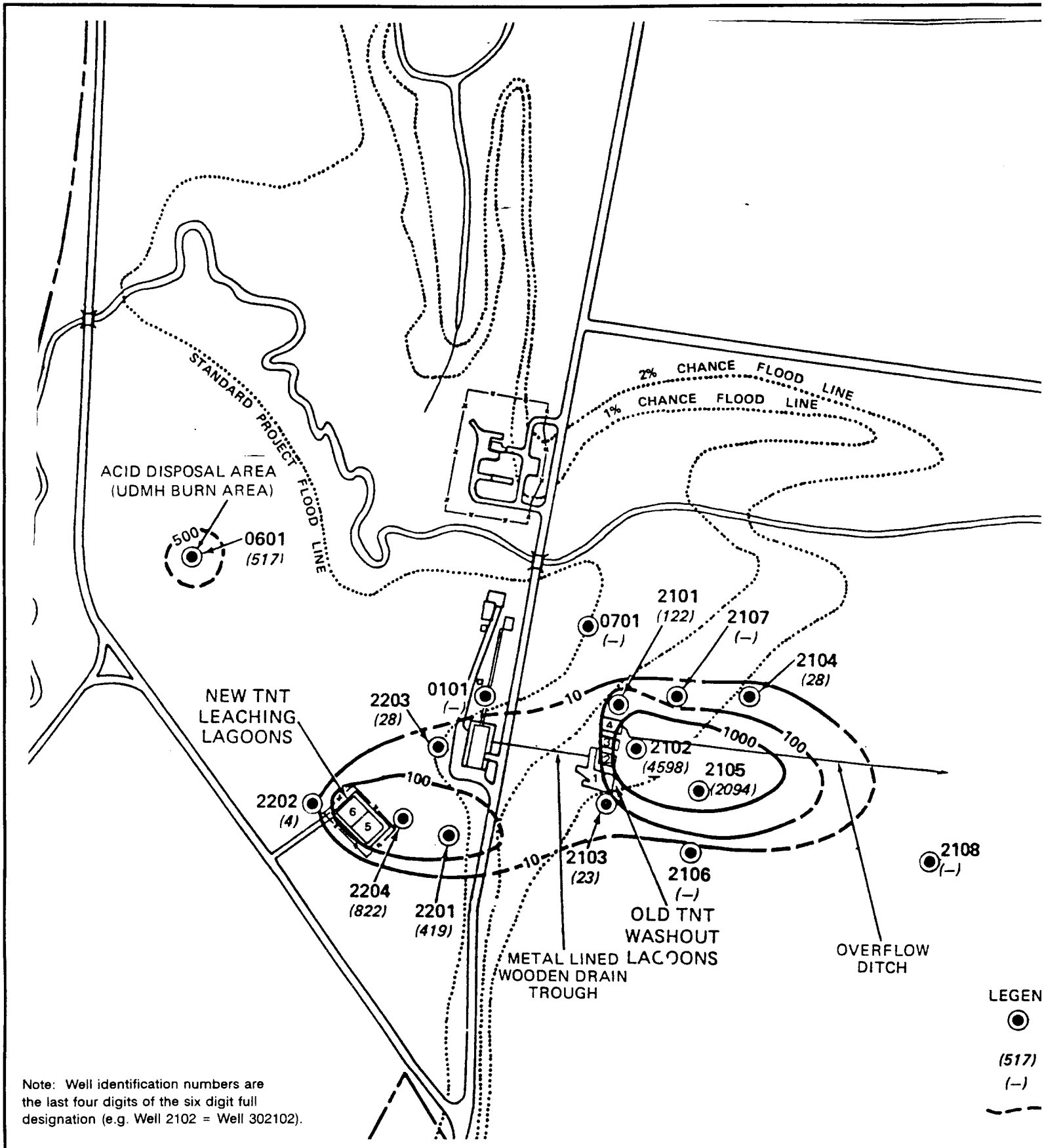


FIGURE 2-2 SADA FACILITY MAP



Note: Well identification numbers are the last four digits of the six digit full designation (e.g. Well 2102 = Well 302102).

SOURCE: Dames & Moore, 1991

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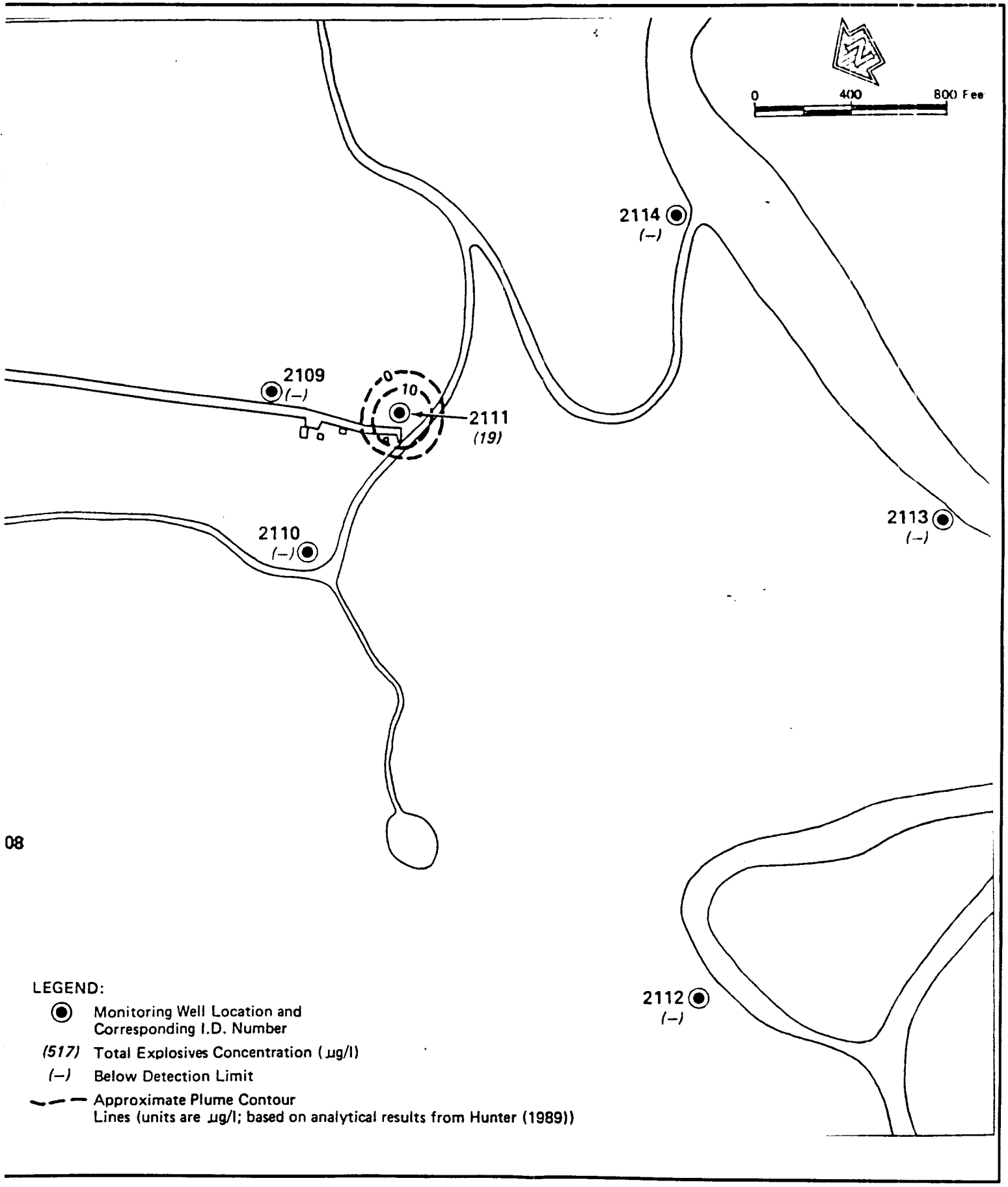

FIGURE 2-3 GROUNDWATER CONCENTRATIONS OF TOTAL EXPLOSIVES IN THE VICINITY OF THE OLD AND NEW LEACHING LAGOONS AT SADA

of TNT (3,420 μg/L), 2,4-DNT (246 μg/L), 2,6-DNT (49.4 μg/L), cyclotetramethylenetetranitramine (HMX; reported as > 28.6 μg/L), and tetryl (226 μg/L) of the wells sampled in the 1989 Hunter/ESE and earlier ESE studies (1982). The highest concentrations of the explosive compound RDX were obtained from wells 302102 and 302105 (reported as > 43.6 μg/L). Well 302102 also contained additional breakdown products: 1,3,5-trinitrobenzene (1,3,5-TNB; 490 μg/L), 1,3-dinitrobenzene (1,3-DNB; 86 μg/L) and nitrobenzene (NB; 7.35 μg/L). In general, concentrations of explosives and breakdown products were lower in the groundwater in the vicinity of the two New Leaching Lagoons (Area 22) than in the groundwater in the vicinity of the four Old Leaching Lagoons (Area 21).

Since the completion of the TNT Washout Facility Lagoons RI report, additional wells were installed in the vicinity of the lagoons and additional chemical characterization and slug tests were performed by Dames & Moore in support of the facility-wide RI/FS (Eaton, personal communication, 1994). Locations of the additional monitoring wells and the previously installed monitoring wells in Areas 21 (Old Leaching Lagoon) and 22 (New Leaching Lagoon) are shown in Figure 2-4. Chemical analysis of groundwater samples collected from wells in the vicinity of the Old Leaching Lagoons in March and May 1993 indicated the following concentration ranges of explosive and propellant compounds and their breakdown products:

- 2,4,6-TNT Non-detect (<0.426) to 830 μg/L.
- 2,4-DNT 0.356 to 79 μg/L.
- 2,6-DNT Non-detect (<0.6) to 79 μg/L.
- 1,3,5-TNB Non-detect (<0.21) to 870 μg/L.
- 1,3-DNB Non-detect (<0.458) to 12.9 μg/L.
- NB Non-detect (<0.645) to 58 μg/L.
- RDX Non-detect (<0.416) to 5.42 μg/L.

With the exception of 2,4-DNT which was not detected (< 0.90 μg/L) in the most recent round of RI sampling, Well 302124 contained the highest concentrations of the target analytes and their breakdown products. Consequently, Well 302124 was selected to supply contaminated groundwater for the UV/Ox demonstration.

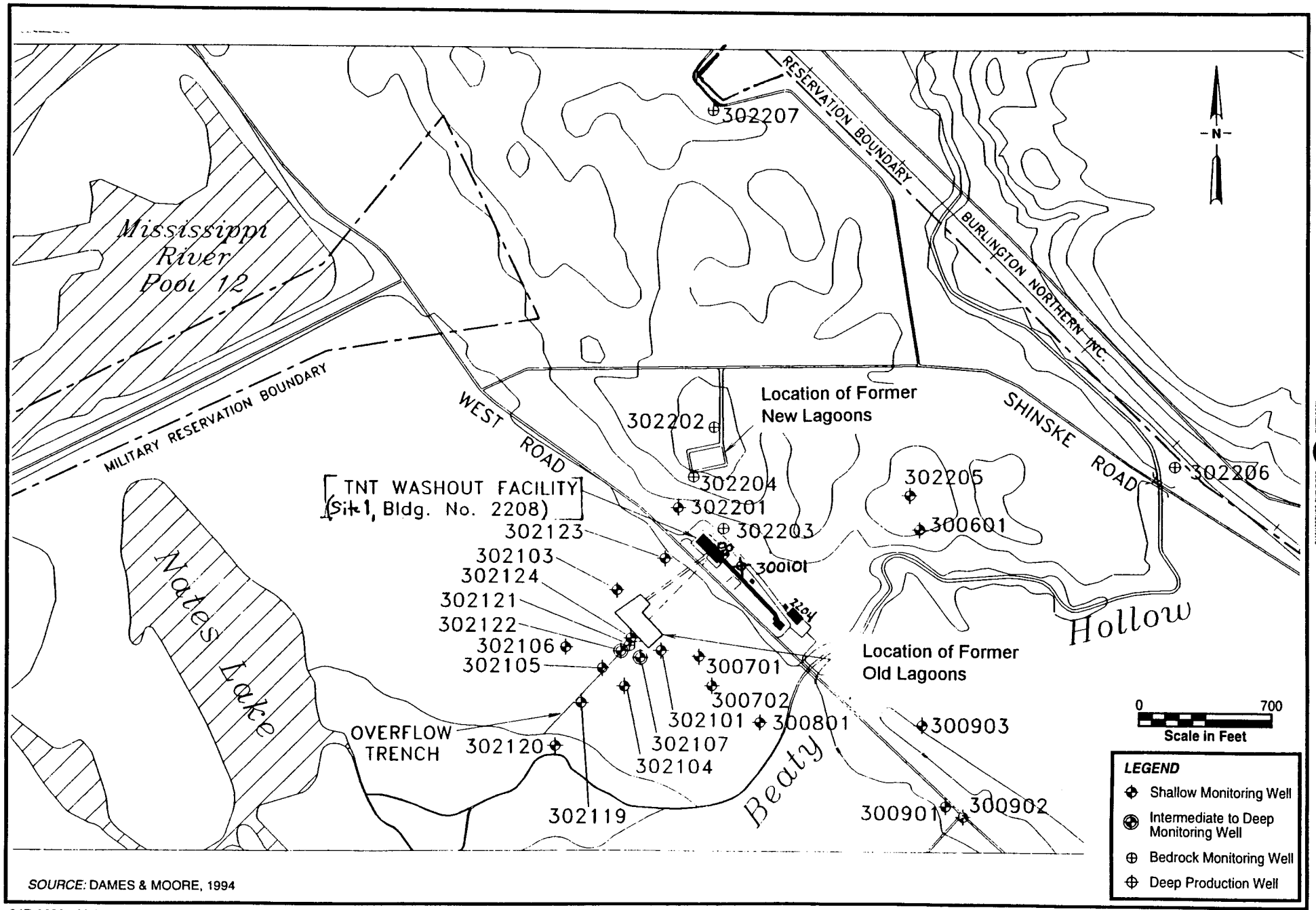

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FIGURE 2-4 LOCATIONS OF ADDITIONAL MONITORING WELLS

2.3 SELECTION OF PARTICIPANTS

2.3.1 Preparation of the Request For Proposals (RFP)

Based on information obtained during the literature review and the technology screening, seven commercial vendors of AOPs were identified for potential inclusion in the pilot demonstration at SADA. Although USAEC hoped to include as many of the vendors as possible, the project budget limited the participation to four commercial systems. Participation was procured as subcontracted efforts from each of the vendors.

A Request for Proposals (RFP) was prepared which summarized the purpose and objectives of the demonstration, as well as the scope of work that each participant would be responsible for completing including:

- Conducting bench-scale testing.
- Preparing bench-scale reports.
- Mobilization of equipment to SADA.
- Performance of the pilot-scale testing at SADA.
- Demobilization of equipment from SADA.
- Completion of a pilot-scale summary report.
- Estimation of life cycle costs for full-scale implementation.

In addition to the scope of work items listed above, the RFP also provided the vendors with the most up-to-date groundwater characterization data available for SADA. Vendors were also given the option of receiving a 250-mL sample of the SADA groundwater with the RFP to assist in the preparation of their proposals. The discharge criteria that each participant would be expected to achieve were also defined in the RFP, along with the details of WESTON's role in providing oversight on the pilot-demonstration program. In the end, responses to the RFP were received from each of the seven vendors who were included in the distribution.

2.3.2 Selection of Participants

After receiving commercial vendors' proposals, WESTON, at the direction of USAEC, initiated a selection process to determine which of the commercially available systems would be included in the demonstration. The three criteria used in the evaluation of the proposals were 1) technical merit, 2) qualifications and experience, and 3) cost.

Because the objective of the demonstration was to include the most promising technologies in a side-by-side comparison, the technical merit of the proposals, rather than the specified cost to perform the demonstration, was considered the primary evaluation criteria in the selection process and was given a weighing factor of 3. Because technical merit is a subjective determination, four separate reviewers, including two project engineers and two technical managers, ranked the seven proposals to ensure an unbiased assessment. Each reviewer ranked the proposals by technical merit in order with 1 representing the best proposal and 7 representing the least impressive proposal. Judgment of technical merit was based on the degree to which each proposal demonstrated an understanding of the ultraviolet oxidation processes relative to the treatment of explosives. Proposals that showed an understanding of the underlying chemistry of TNT oxidation, even if limited in experience or data, were ranked better than "cookie cutter" proposals which presented general system descriptions and treatment results for compounds such as VOCs which were not constituents of concern for the pilot-scale demonstration. The individual scores determined by each of the four reviewers were averaged and then multiplied by 3 to determine the overall technical merit score for each proposal.

After technical merit, qualifications and experience was the next criterion used in the selection process. As a minimum requirement, USAEC determined that all processes considered for inclusion in the pilot-demonstration at SADA should be commercially available at the time of the selection. The seven respondents to the RFP all had commercial units available and were eligible for inclusion in the demonstration. However, there was a broad range of experience among the respondents, evidenced best by the number of full-scale units each had in operation. As a result, respondents with more than

50 process units in operation were given a score of 1, those with fewer than 50 but more than three process units were scored at 2, and those with three or fewer process units were scored at 3. A weighing factor of 2 was then applied to each of these values to determine each proposal's overall qualifications and experience score.

The cost estimates to conduct the scope of work detailed in the RFP was the third and final evaluation criteria. The proposals were ranked from 1 to 7 in order of increasing cost. A weighing factor of 1 was applied to these cost rankings.

Finally, the overall rankings of the seven proposals were determined by summing the weighted scores for technical merit, qualifications and experience, and cost. The proposal with the lowest total score was ranked number 1 and the proposal with the highest score was ranked number 7. A meeting was held to discuss this selection methodology and it was determined that the evaluation strategy was appropriate. This selection methodology was later officially approved by the Defense Logistics Agency. Once this final ranking had been determined, the top four proposals (based on score) were selected for inclusion in the demonstration at SADA. Based on this evaluation method, the four companies invited to demonstrate their AOPs at SADA were (in alphabetical order):

- Purifics Environmental Technologies (Purifics).
- Solarchem Environmental Systems (Solarchem).
- Ultrox International (Ultrox).
- Vulcan Peroxidation Systems Incorporated (VPSI).

WESTON awarded subcontracts to each of these vendors for participation in the pilot-scale demonstration program.

2.4 BENCH-SCALE TESTING

2.4.1 Bench-Scale Sample Collection

Upon the selection of the four AOP processes for the pilot-scale demonstration at SADA, the individual vendors were contacted to determine their sample volume requirements to

perform bench-scale testing. Bulk samples of the groundwater were obtained on 05 August 1994 from monitoring well 302124 at SADA and shipped to the participants. The vendors were given four weeks from receipt of the groundwater samples to conduct the bench-scale testing and prepare their summary reports. The primary objectives of the bench-scale testing were to assist the vendors in the configuration and operation of the pilot-scale systems to be used during the demonstration and to provide operating data to the individual vendors for use in developing a preliminary full-scale system design. Each vendor was permitted to develop its own bench-scale testing protocol to achieve these objectives. USAEC did not impose any specific constraints or requirements on the bench-scale testing. The performance of the bench-scale testing was not observed, but the bench-scale testing reports provided by the vendors were reviewed extensively. The following subsections contain brief descriptions of the results of the bench-scale testing and the proposed pilot-scale treatment systems as reported by the vendors. Full-scale system sizing and estimated costs developed by the vendors using the bench-scale testing data are discussed later in Subsection 4.4.

2.4.2 Bench-Scale Test Summaries

2.4.2.1 Purifics

The Purifics bench-scale system consisted of one rack of 16 photocatalytic cells, each containing a single 73-watt low-pressure ultraviolet lamp. Pretreatment of the raw groundwater was performed prior to the testing by acidification of the sample to approximately pH 4 to remove alkalinity and thereby eliminates the competition of the alkalinity for hydroxyl radicals. Purifics designed its bench-scale testing to evaluate the effectiveness of the following treatment strategies, all of which included the use of the titanium dioxide (TiO_2) slurry:

- Direct photocatalysis without chemical additives.
- Hydrogen peroxide addition throughout the treatment process.
- Direct photocatalysis followed by hydrogen peroxide addition.
- Proprietary additive followed by hydrogen peroxide addition.

The results of the eight initial bench-scale test runs indicated little differences in the destruction of TNT and TNB with different additives. Direct photocatalysis without additives, photocatalysis with hydrogen peroxide, and photocatalysis with an organic acid additive provided post-treatment effluent TNT concentrations ranging from 94 to 164 μg/L and effluent TNB concentrations ranging from 37 to 112 μg/L. In several of the tests, post-treatment effluent was recycled to the rack to evaluate the effect of increased residence time and/or additives. Purifics concluded from the eight initial bench-scale test runs that adsorption and subsequent desorption of TNT and TNB from plastic components of the bench-scale system resulted in contamination of the post-treatment effluent. A ninth bench-test run performed using an all stainless steel system indicated that the Purifics system was capable of meeting the 7 μg/L criteria value for TNT.

Because of the contamination problems experienced during these bench-scale tests, Purifics indicated that it would continue to evaluate its treatment strategies during the optimization period at SADA. Based on the bench-scale results, Purifics determined that the following pilot-scale equipment would be required for the demonstration at SADA:

- Pretreatment consisting of filtration with a 5 micron (μm) bag filter and acidification to pH 4 by sulfuric acid addition for removal of alkalinity.
- Two photocatalytic racks in series with a combined power requirement of 2.25 kW and flow rate of 1.59 gpm (6 liters per minute).
- Post-treatment consisting of neutralization by sodium hydroxide (caustic) addition.

2.4.2.2 Solarchem

The Solarchem bench-scale test equipment consisted of two separate systems. The first system used for testing hydrogen peroxide as the primary oxidant used a 27-liter batch tank, a recycle pump, and a 1-kW bench-scale Rayox® reactor equipped with a medium-pressure, high-intensity lamp identical in UV spectra output to the standard 30-kW full-scale lamps. Total volume of the system was 33 liters. The system included a transmittance controller to clean deposits from the quartz sleeve surrounding the UV lamp. Each of the bench-test

runs was performed by adding 29 liters of the SADA groundwater to the batch tank and circulating the water through the reactor at a rate of 18 gpm. Tests conducted with this system were performed by adding hydrogen peroxide to the holding tank and lighting the UV lamp. Samples were collected periodically and analyzed for TNT and TNB.

A second bench-scale system was used for evaluating ozone as the primary oxidant. This system consisted of a 100-liter stainless steel reaction vessel with a sparger for introducing ozone. Ozone was generated as a 2%-by-weight mixture in air. Bench-scale tests were conducted for the following treatment strategies:

- Ozone only.
- Ozone and UV light.

Solarchem concluded from the bench-scale testing that direct photolysis and UV/peroxide treatments were ineffective for treating TNT and TNB. Ozonation under high pH (pH 8.5 to 9) was determined to be the most effective process for treating the SADA groundwater. Based on the bench-scale results, Solarchem determined that the following pilot-scale equipment would be required for the demonstration at SADA:

- Pretreatment consisting of addition of caustic to increase pH.
- 21 pound per day ozone generator.
- UV/Ozone reactor with three 1-kW UV lamps and a flow rate of 1.25 gpm.
- Post-treatment neutralization consisting of addition of sulfuric acid.

2.4.2.3 Ultrox

The Ultrox bench-scale system consisted of a 2.4 liter glass reaction vessel with a magnetic stirrer, an ozone sparger, and a UV lamp mounted within a quartz sheath. Nine bench test runs were performed by adding 2 liters of the SADA groundwater to the reaction vessel prior to each run. Tests were performed using varying combinations of UV light, ozone addition, hydrogen peroxide addition, pH adjustment, and reaction time. Bench-scale test results indicated that the UV/ozone treatment provided the best destruction of TNT and TNB. In addition, Ultrox concluded that pH adjustment to pH 4 improved the oxidation

of the explosives compounds by removing the carbonates and bicarbonates in the raw SADA groundwater.

Based on the bench-scale results, Ultrox determined that a pilot-scale system using pretreatment consisting of pH adjustment to pH 4 followed by UV irradiation and ozone addition would meet the treatment criteria for the demonstration at SADA. The bench-scale report did not provide specific information on the size of the system which would be deployed during pilot-scale testing.

2.4.2.4 VPSI

The VPSI bench-scale testing was performed using a closed-system bench-scale perox-pure™ test unit with a recycle reservoir. Bench-test runs were conducted by placing an aliquot of the SADA groundwater into the reservoir, starting a pump to continuously circulate the water, and starting the UV lamp. Catalysts and hydrogen peroxide were added as required by the individual runs. A total of 10 test runs were performed under varying hydrogen peroxide and catalyst dosages and pH regimes. VPSI concluded from the bench-scale testing that optimal treatment occurred when the groundwater was pretreated for removal of solids and turbidity by adding hydrogen peroxide followed by filtration with a 3-μm cartridge filter, pH adjustment to pH 4, a hydrogen peroxide dosage of 100 mg/L, and the addition of Catalyst Formula I at a dosage of 12 mg/L. The bench-scale report did not provide specific information on the size of the system that would by deployed during pilot-scale testing.

SECTION 3

DEMONSTRATION ACTIVITIES

3.1 DEMONSTRATION PLANNING

3.1.1 Work Plan Preparation

Prior to commencing field activities at SADA, a Work Plan, which included a Quality Assurance Project Plan (QAPP), was prepared (WESTON, 1994 - see Appendix A). The Work Plan documented the objectives of the demonstration, summarized existing conditions at SADA, and described the design of the electrical supply, the groundwater extraction, storage, delivery, and post-treatment systems, and other ancillary facilities. In addition, the Work Plan specified sampling, sample handling and shipping, and field and laboratory quality assurance and quality control (QA/QC) procedures for the demonstration. Field and laboratory QA/QC procedures specified in the QAPP for this study included the collection of duplicate and matrix spike/matrix spike duplicate (MS/MSD) samples. During demonstration planning, the Illinois Environmental Protection Agency (IEPA) indicated that the discharge criteria previously applied to treated water from the TNT Washout Lagoon remediation project should be adopted as the treatment criteria for the pilot-scale program. The treatment criteria are shown in Table 3-1. For the purposes of this study, the daily average process effluent concentration values were calculated as the average of the three daily grab samples obtained for each of the processes. Because the pilot-scale treatment systems were not expected to always achieve complete treatment of the explosives compounds during start-up, optimization, and pilot-scale periods, additional post-treatment polishing of the AOP system's effluents with GAC was necessary to ensure that the discharge limits were not exceeded.

As mentioned above, design and planning requirements addressed in the Work Plan included the design and sizing of the groundwater extraction, storage, and delivery systems. Conservative estimates of the pilot system's flow rates and groundwater yield were used to

Table 3-1

SADA Demonstration Effluent Treatment Criteria

Parameter	Monthly Average (mg/L)	Daily Average (mg/L)
2,4,6-Trinitrotoluene	-	0.007
2,4-Dinitrotoluene	0.003	0.006
2,6-Dinitrotoluene	-	0.009
1,3,5-Trinitrobenzene	-	0.007
Tetryl	-	0.044
HMX	-	0.013
1,3-Dinitrobenzene	-	0.004
2-Amino-4,6-Dinitrotoluene	-	0.036
Nitrobenzene	-	0.010
RDX	-	0.014
pH	-	6 - 9

size the extraction and distribution pumps, the influent and effluent equalization tanks, piping, and the post-treatment system. This approach was intended to minimize the potential for interruptions of the pilot-scale treatment schedule caused by equipment failure and to provide each of the processes with a constant pressure supply of groundwater for treatment. Further information on the configuration of the pilot-scale testing system is provided in Subsection 3.2.

Other issues addressed in the Work Plan included mobilization, demobilization, site restoration activities, the collection and recordkeeping of electrical and chemical consumption data for each of the vendor systems, operating and analytical data management procedures, and the analysis and reporting of the bench-scale testing and pilot-scale demonstration results.

3.1.2 Health and Safety Plan

A site-specific Health and Safety Plan (HASP) was prepared prior to performing any sampling or construction activities at the SADA site. The HASP contained an overview of the field program, a summary of historical analytical data on the groundwater at the site, emergency response procedures, and general and specific field safety requirements and procedures including personal protective equipment, lockout/tagout provisions, and decontamination procedures.

A site health and safety coordinator (SHSC) was present throughout the demonstration to ensure compliance with the provisions of the HASP and to provide additional guidance for the safe conduct of construction, testing, and demobilization activities. The HASP was applicable to all personnel entering or visiting the site during the demonstration activities. No site health and safety incidents or accidents occurred during the performance of the pilot-scale study.

3.1.3 Preconstruction Meeting

A preconstruction meeting was held at SADA with members of the SADA environmental, electrical, fire, and safety departments, WESTON, and USAEC personnel prior to mobilization. Issues such as base security, site access, health and safety procedures, installation of the electrical components, regulatory agency interface, project schedule, mobilization and demobilization, and site restoration were discussed at the meeting.

3.2 MOBILIZATION/SITE PREPARATION

The washout lagoon site at SADA was convenient for hosting the pilot demonstration because of the proximity of the following required features:

- An adequate and representative supply of contaminated groundwater.
- A sheltered structure to accommodate the four AOP systems and all ancillary equipment.
- An electrical substation with sufficient capacity to provide the combined power demand of the four AOP systems.
- An accessible hydrant to provide pressurized clean water for cooling and eye wash stations.
- An acceptable surface water (Beaty Hollow Creek) for discharge of the treated effluent from the demonstration.

Despite the availability of these utilities, a considerable amount of site preparation was required to ready the site for the performance of the pilot demonstration. Specifically, there were three major tasks that needed to be completed prior to the arrival of the four AOP participants:

- Installation of the electrical equipment (including transformers, switches, circuit breakers, kilowatt-hour meters, etc.) necessary to meet each of the participant's specific requirements.
- Construction of the groundwater collection and distribution system.

- Installation of the effluent treatment and discharge system.

Figure 3-1 is a plan view of the layout of the washout lagoon site showing the relative locations of the major components of the AOP pilot demonstration. Specific details of the major tasks performed during the site preparation are presented in the following subsections.

3.2.1 Electrical Power

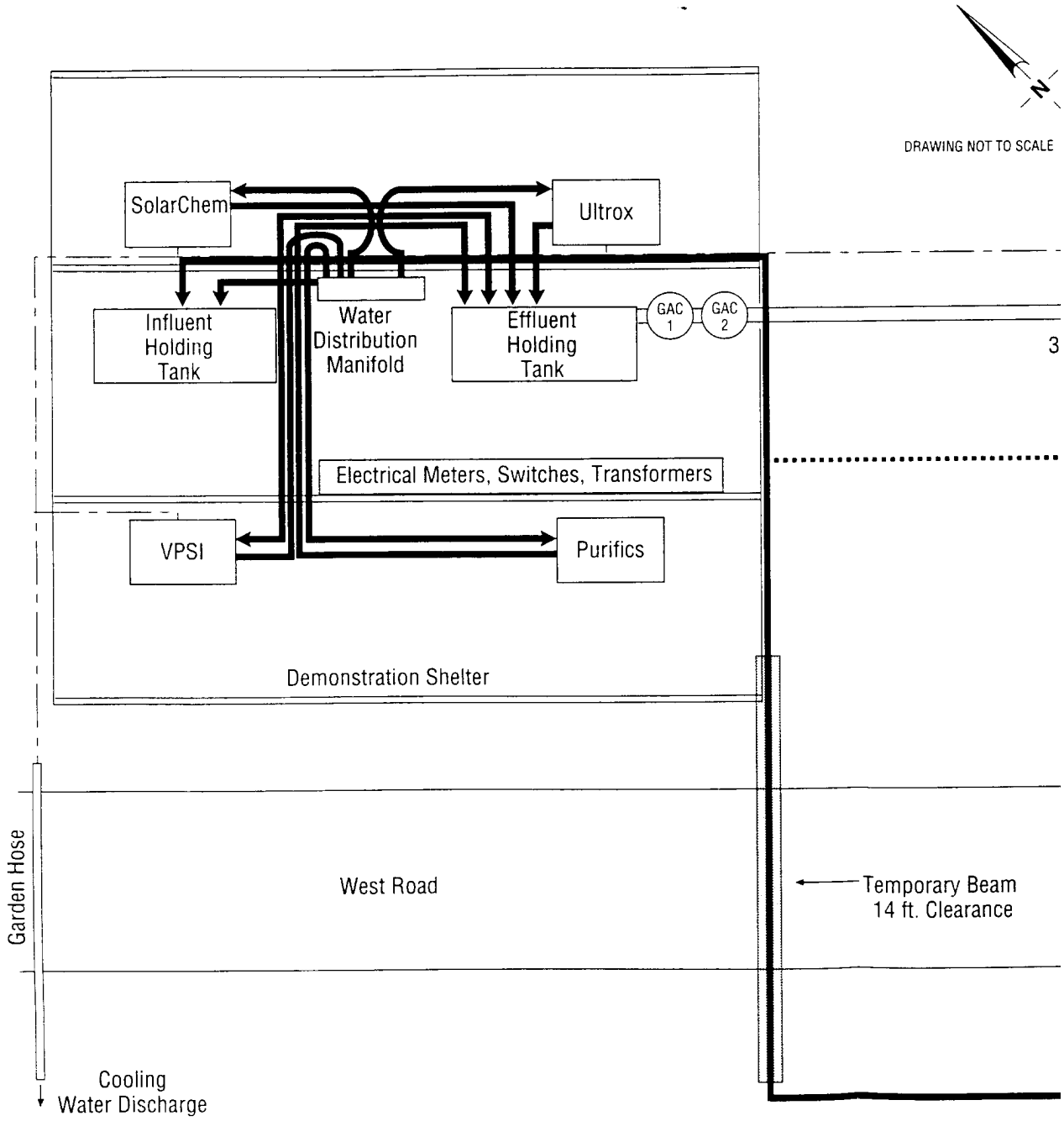
The most critical service necessary for the performance of the pilot demonstration was the electrical power supply. Prior to the commencement of site preparation, each participant was questioned about its process electrical requirements, including an estimate of the overall power requirements, preference for single- or three-phase power, reactor operating voltages, and requirements for standard 120-volt AC supplies.

Once the participants had responded with their electrical requirements, an electrical single line drawing/wiring diagram was developed. The installation of the electrical equipment was then performed in accordance with the wiring diagram by SADA's own electricians. Figure 3-2 is a wiring diagram for the pilot-demonstration. The primary components of this system included:

- Separate electrical usage meters for each of the participants.
- A 480-volt AC, 3-phase transformer to provide power to Solarchem, Ultrox, and VPSI.
- Fused disconnect switches for each of the four AOP systems.
- A 240-volt, single-phase transformer to provide power to Purifics.
- A 120-volt, single-phase transformer to provide power to the field office trailer and to numerous convenience outlets within the demonstration shelter.
- A fused disconnect switch and starter motor for the groundwater pump.

Figure 3-1

Plan View Layout of Demonstration Site at SADA



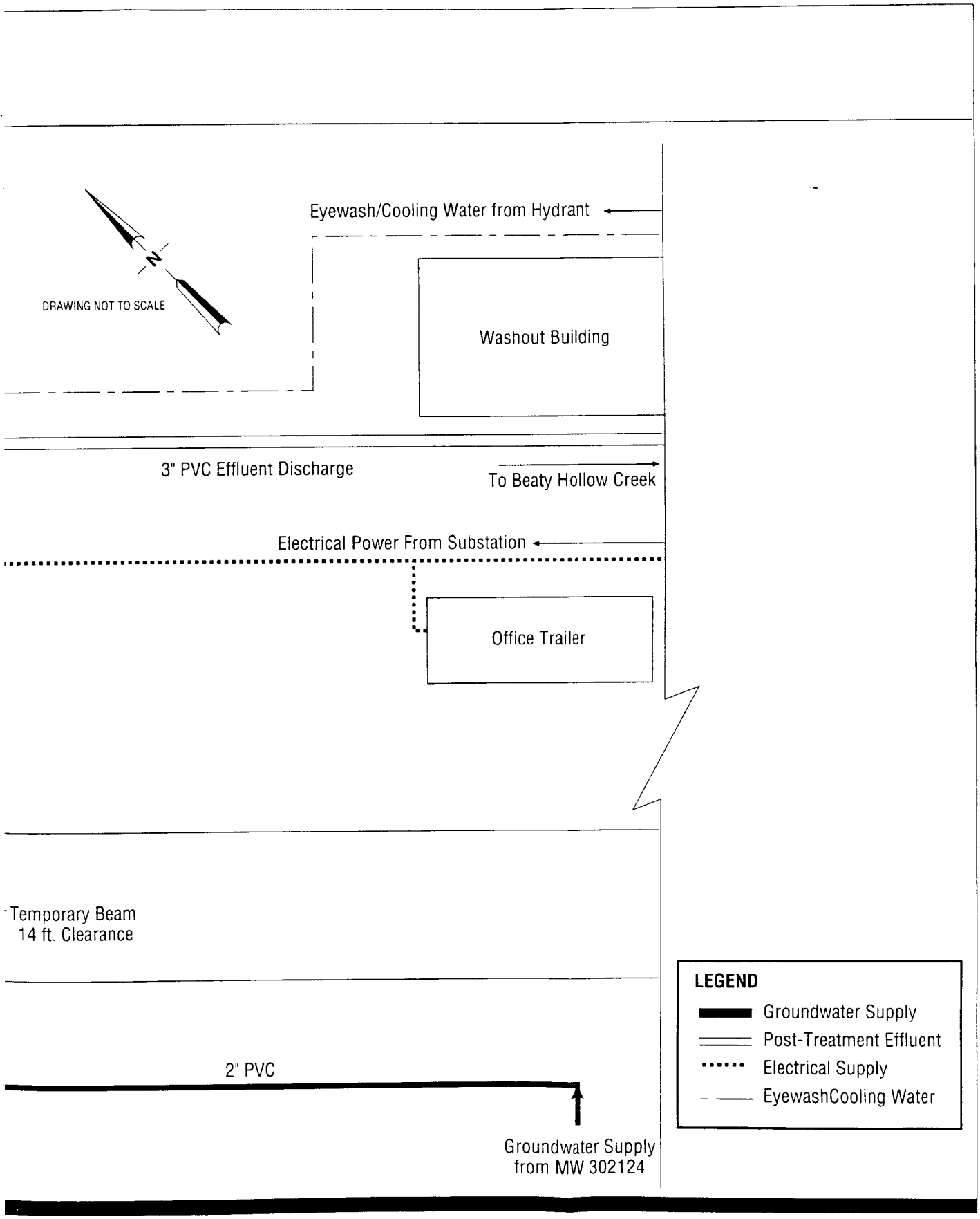
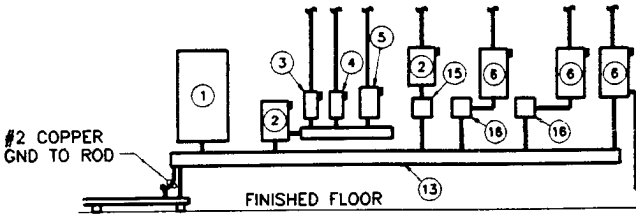
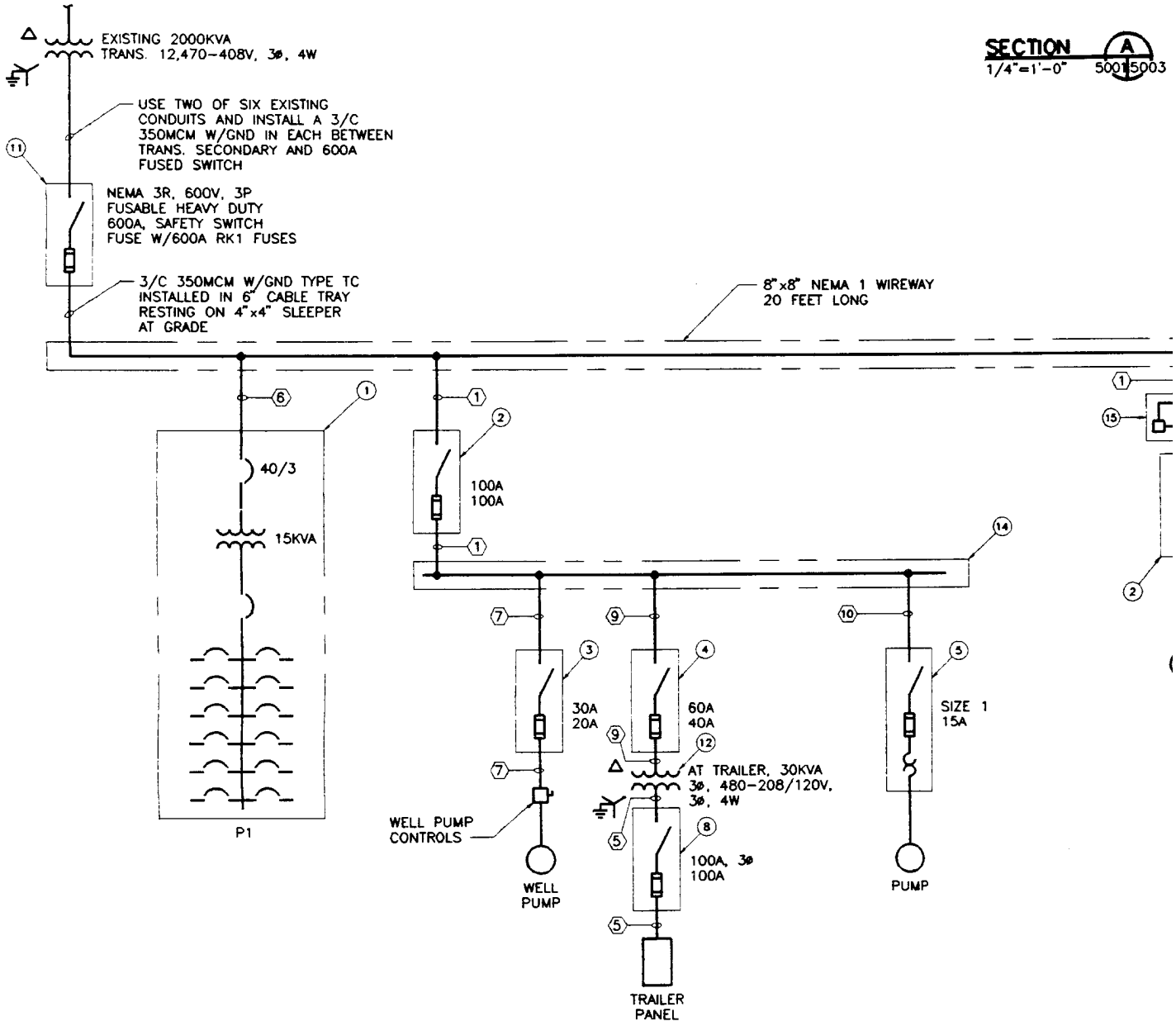


FIGURE 3-1 PLAN VIEW LAYOUT OF DEMONSTRATION SITE AT SADA

1 of 3



SECTION A
1/4"=1'-0" 50015003



SINGLE LINE

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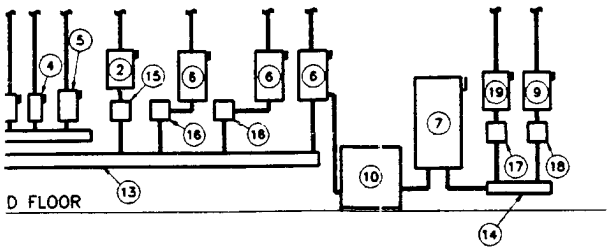
PLT. SC. 1=1
FILE NO. 12065005

SAVANN



2 4 3

SECTION A
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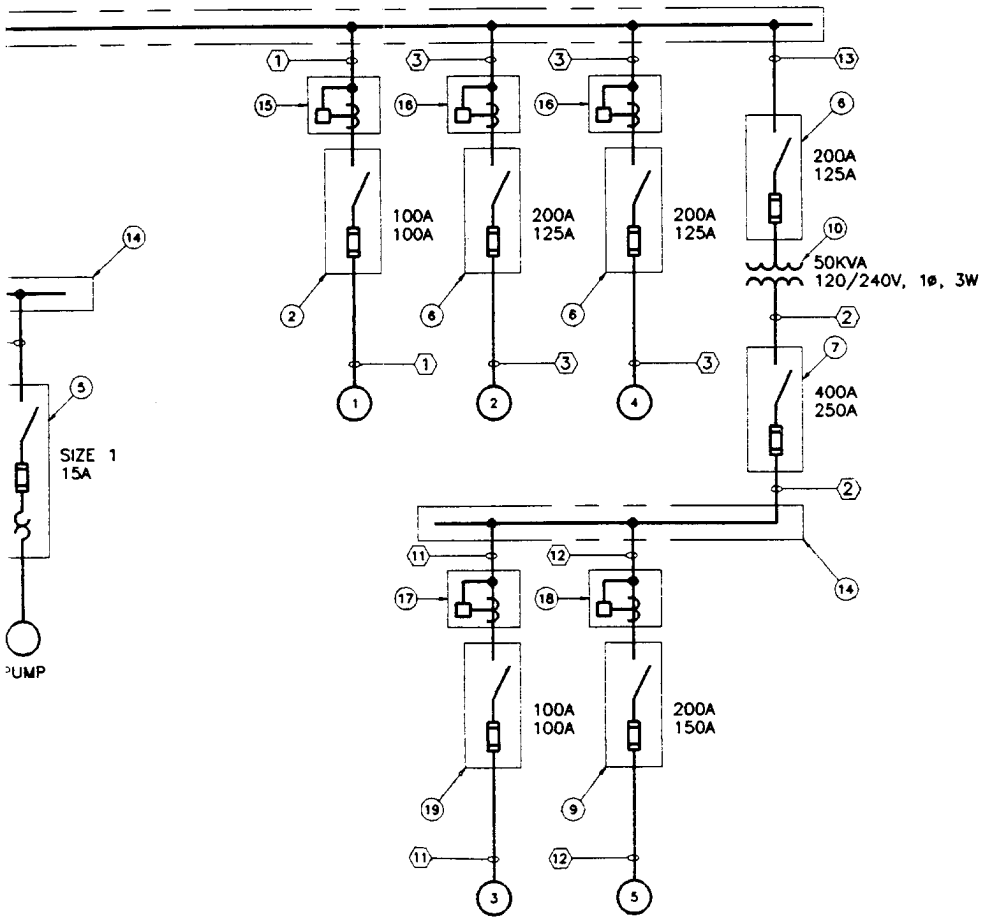
EWAY



LINE

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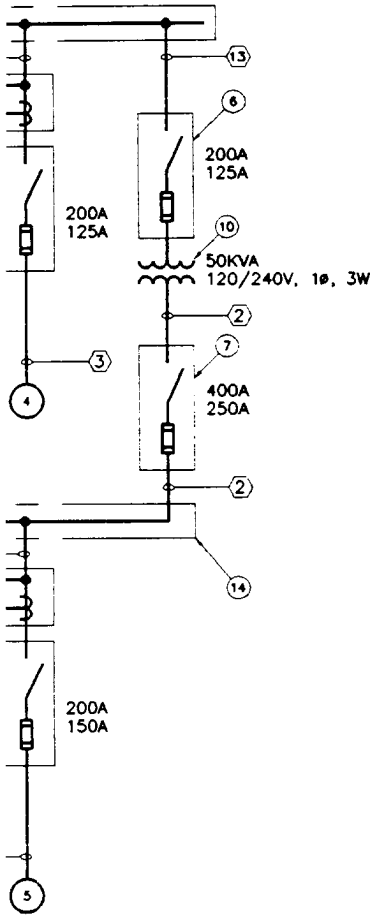
FIGURE 3-2 P

QUANTITY		DESCRIPTION
1	①	MINI POWER ZONE, 15KVA, 3ø, 480-208Y/120V, 3ø, 4W 40A MAIN CIRCUIT BREAKER, 12 1P, 20A FEEDER BREAKERS SQUARE-D CAT. NO. MPZ15T2F.
2	②	SAFETY SWITCH HEAVY DUTY, 600V, FUSIBLE, 3W, 100A, NEMA 3R, SQUARE-D CAT. NO. H363RB.
1	③	SAFETY SWITCH HEAVY DUTY, 600V, FUSIBLE, 3W, 30A, NEMA 3R, SQUARE-D CAT. NO. H361RB.
1	④	SAFETY SWITCH HEAVY DUTY, 600V, FUSIBLE, 3W, 60A, NEMA 3R, SQUARE-D CAT. NO. H362RB.
1	⑤	COMBINATION MOTOR STARTER, FUSIBLE TYPE, NEMA SIZE 1, NEMA 12 ENCLOSURE WITH 120V CONTROL CIRCUIT AND TRANSFORMER FOR 480V, 3ø MOTOR.
3	⑥	SAFETY SWITCH HEAVY DUTY, 600V, FUSIBLE, 3W, 200A, NEMA 3R, SQUARE-D CAT. NO. H364RB.
1	⑦	SAFETY SWITCH HEAVY DUTY, 240V, FUSIBLE, 1ø, 3W, SOLID NETURAL, 400A, NEMA 3R, SQUARE-D CAT. NO. H225NR.
1	⑧	SAFETY SWITCH HEAVY DUTY, 240V, FUSIBLE, 3ø, 4W, SOLID NETURAL, 100A, NEMA 3R, SQUARE-D CAT. NO. H323NRB.
1	⑨	SAFETY SWITCH HEAVY DUTY, 240V, FUSIBLE, 2ø, 3W, SOLID NETURAL, 200A, NEMA 3R, SQUARE-D CAT. NO. H224NRB.
1	⑩	TRANSFORMER 50KVA, 120/240, 1ø, 3W, WITH RAIN SHIELD SQUARE-D CAT. NO. 50S3HWS363.
1	⑪	SAFETY SWITCH HEAVY DUTY, 600V, 3P, FUSIBLE, 600A, NEMA 3R, SQUARE-D CAT. NO. H366R.
1	⑫	TRANSFORMER 30KVA, 480-208Y/120V, 3±, 4W, WITH RAIN SHIELD SQUARE-D CAT. NO. 30T3HWS363
1	⑬	8" x 8" WIREWAY, NEMA 1, 20'-0" TOTAL: STRAIGHT PIECE SQUARE-D CAT. NO. LD85 4 @ 5'-0" EACH CLOSING PLATES SQUARE-D CAT. NO. LD885
1	⑭	6"x6" WIREWAY NEMA 1, 10'-0"
1	⑮	Kwh METER-FOR 480V, 3ø, 100A SERVICE
2	⑯	Kwh METER-FOR 480V, 3ø, 200A SERVICE
1	⑰	Kwh METER-FOR 240/120V, 1ø, 3W, 100A SERVICE
2	⑱	Kwh METER-FOR 240/120V, 1ø, 3W, 200A SERVICE
1	⑲	SAFETY SWITCH HEAVY DUTY 240V FUSIBLE 1ø, 3R, 3W, 100A, NEMA 3R, SQUARE-D CAT. NO. H223NRB



CONDUIT KEY

①	1-1/2"C-3#2 W/GND
②	3"C-(2)500MCM, (1)500MCM NEUT W/GND
③	2"C-3#3/0 W/GND
④	2-1/2"C-4#3/0 W/GND
⑤	2"C-4#2 W/GND
⑥	3/4"C-3#10 W/GND
⑦	2"C-3/C #10 W/GND, 3/C #14
⑧	1"C-3/C #10 W/GND
⑨	1-1/2"C-3/C #6 W/GND
⑩	3/4"C-3#12 W/GND
⑪	1-1/2"C-2#2, 1#2 NEUT W/GND
⑫	2"C-2#3/0, #3/0 NEUT W/GND
⑬	2"C-2#3/0 W/GND

A
ICAL
LINE
ILLINOIS

ROY F. WESTON, INC.
WESTON
MANAGERS DESIGNERS/CONSULTANTS

DRAWN	DATE	DES. ENG.	DATE	W. O. NO.
SCB	6/29/94			02281012006
CHECKED	DATE	APPROVED	DATE	DWG. NO.
				5001

FIGURE 3-2 PILOT DEMONSTRATION ELECTRICAL WIRING DIAGRAM

- Level control circuits and high-level warning light for the groundwater influent tank.

3.2.2 Groundwater Collection and Distribution System

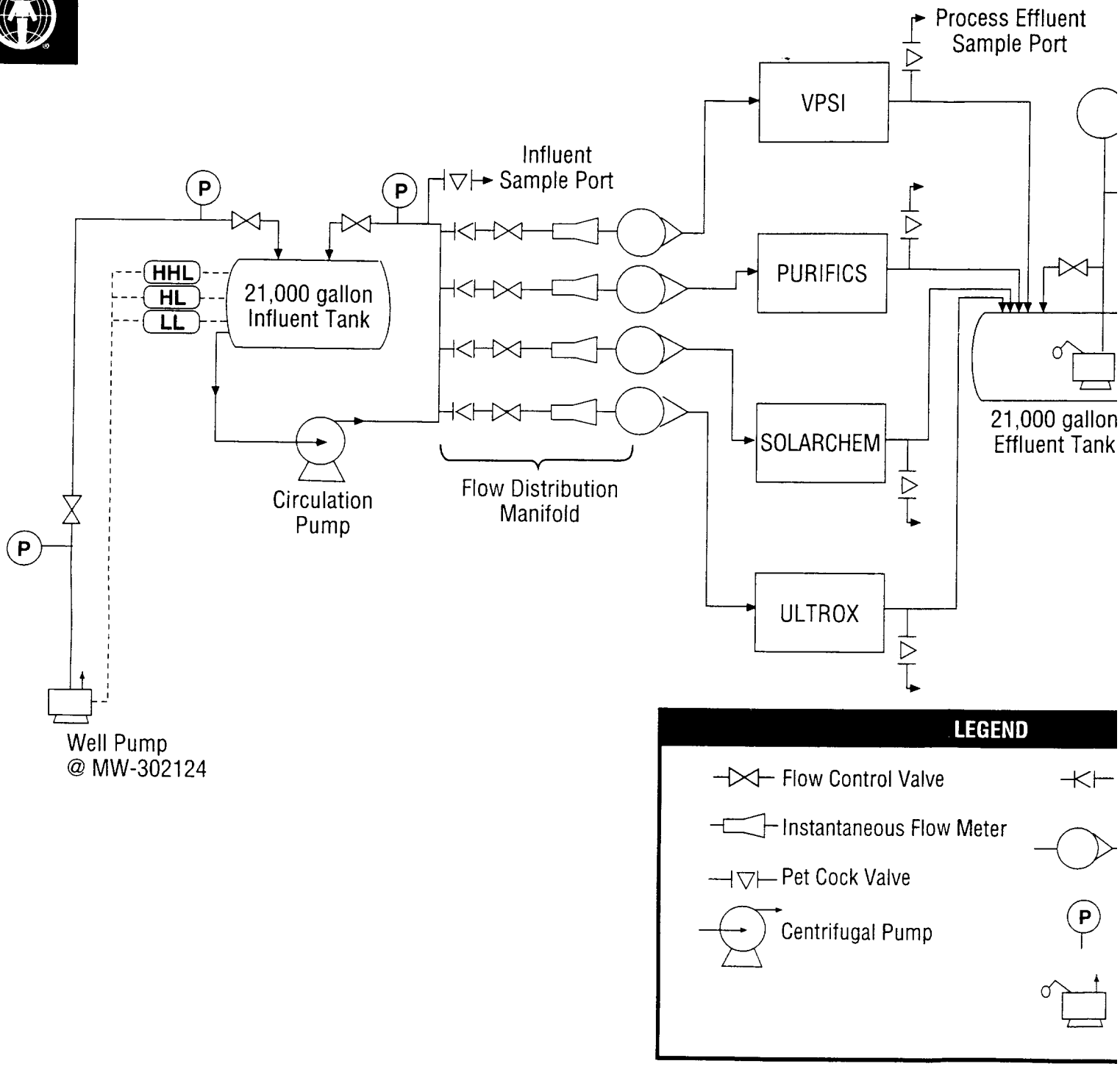
While the electrical service was being installed by SADA, work was concurrently performed on the installation of the groundwater collection and distribution system. The primary components of this system included:

- One 4-inch-diameter, 3-horsepower, 3-phase, 480-volt AC, submersible stainless steel well pump to pump groundwater from monitoring well No. 302124.
- Approximately 1,000 feet of 2-inch Schedule 40 PVC conveyance pipe to deliver the groundwater from the well to the influent holding tank.
- One 21,000-gallon influent holding tank with level controls.
- One 5-horsepower, 480-volt, 3-phase AC, 3-phase centrifugal pump to supply the groundwater to the AOP processes.
- A PVC distribution manifold with float-type instantaneous flow indicators and cast iron flow totalizers to monitor the flow of groundwater to the individual processes.

Figure 3-3 is a schematic process flow diagram (PFD) of the groundwater distribution system implemented during the demonstration. Prior to installing the well pump, Well 302124 was developed by pumping several thousand gallons of groundwater to the influent holding tank with a temporary pump. After installation and testing of the permanent extraction pump, it was determined that the valves provided in the conveyance piping would need to be throttled back to avoid excessive drawdown. Through manual adjustments to the valves, it was determined that the maximum sustainable pumping rate for the supply well was approximately 40 gpm. From the extraction well, the groundwater was conveyed by nearly 1,000 feet of 2-inch Schedule 40 PVC pipe to the influent equalization and holding tank. A temporary beam with a vertical clearance of 14 feet was constructed across West Road

Figure 3-3

UV/Ox Pilot Study at SADA: Schematic Process Flow Diagram



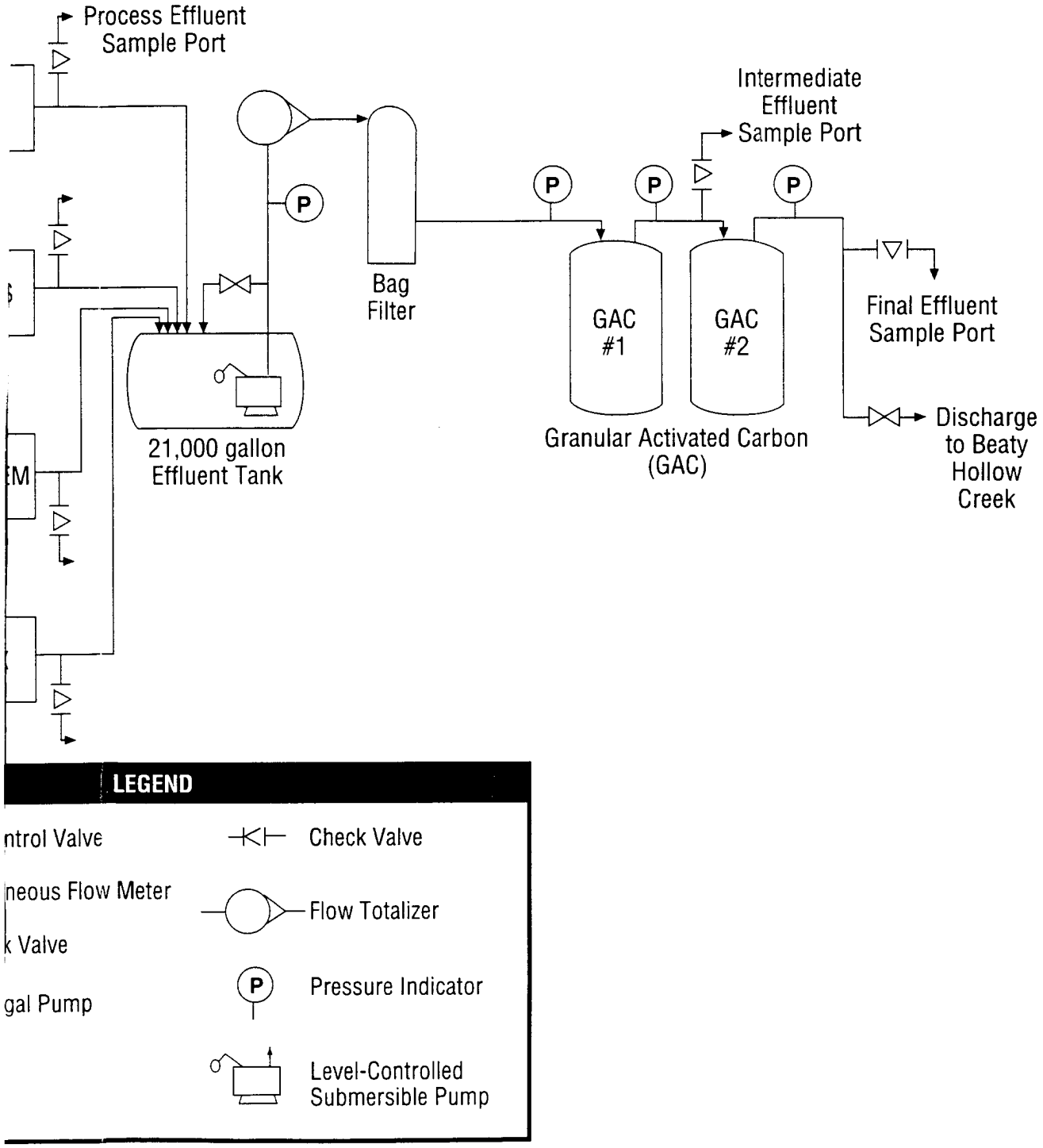


FIGURE 3-3 SCHEMATIC PROCESS FLOW DIAGRAM

to allow for the crossing of both the PVC conveyance piping and the well pump power cable without obstructing depot traffic.

The influent tank installed at the site was a transportable 21,000-gallon steel tank with two manhole access ports on top and two standard threaded pipe fittings for drainage on the bottom. The purpose of this tank was to serve as an equalization tank for both flow and contaminant concentrations. Throughout the demonstration, the groundwater volume in the influent tank was managed near capacity through the use of electronic level control circuitry. When the level of water in the tank reached the low level (LL) set point, the well pump was automatically energized to bring the water level up to the high level (HL) set point, where the pump was automatically shut off. A third high level (HHL) set point, served as a safety backup to turn off the well pump and activate a warning light if the level in the tank were to exceed the high level set point. In the event that the participating processes were cumulatively treating more than the 40 gpm supplied by the well pump, this automatic level control would have allowed refilling of the influent tank after hours without the need for manual operation of the well pump to avoid overflow.

By maintaining the influent tank volume near capacity, any short-term fluctuations in groundwater quality that may have occurred during the demonstration should have been minimized by equalization with the larger volume of water already in the tank. More importantly, even at the upper treatment rate of 10 gpm per participant, the 21,000 gallon capacity would have provided enough groundwater for 8 hours of continuous operation in the event of a well pump failure, conveyance system leak, or any other system upset which might have interrupted the groundwater supply.

Groundwater from the influent tank was provided to each of the participating AOP vendors through a common distribution manifold. This common manifold ensured that each participant was receiving the same groundwater at any given time. A sampling labcock installed in this common manifold minimized the number of influent samples collected during the test period by allowing the collection of a single influent sample, as opposed to collecting four separate influent samples. A five-horsepower centrifugal pump, referred to

as the "loop pump", provided the pressure for distribution of the groundwater to each of the AOP units. As shown in Figure 3-3, water from the distribution loop that was not routed to one of the four AOP units was cycled to the influent tank. The purpose of this recirculation was to allow for control of the manifold supply pressure and to minimize influent variability by mixing the tank contents. By adjusting the valve on the discharge end of the distribution loop, the desired supply pressure of 30-35 psi was maintained.

From the common distribution manifold, each vendor was provided with a 1-inch Schedule 40 PVC supply line which included a check valve to prevent backflow, a valve to control flow, a flow indicator for measuring instantaneous flowrate, and a flow totalizer for tracking cumulative flows. Connections to each vendor's AOP system influent port were made after their equipment was delivered and set in place.

3.2.3 Effluent Treatment and Discharge

As shown in Figure 3-3, the primary components of the effluent treatment and discharge system included:

- One 21,000-gallon effluent holding tank.
- Flow totalizer.
- 100-micron bag filter.
- Two 1,800-pound GAC beds connected in series.
- Approximately 1,200 feet of 3-inch diameter Schedule 40 PVC discharge pipe.

Effluent from each of the four AOP systems was conveyed by 1-inch PVC pipes to the 21,000-gallon effluent storage tank. A sump pump placed in the bottom of the tank was used to pump the effluent through the bag filter and the GAC units. A valved recycle line back to the effluent storage tank was installed to allow the flow rate through the GAC to be controlled. Throughout most of the demonstration, the valve was maintained in a position that resulted in a flow rate through the GAC of approximately 10 gpm. This provided more than ample retention time for contaminant removal in the carbon beds while preventing a net accumulation of treated water within the effluent tank. The total amount

of water pumped through the GAC units during the demonstration was recorded by a flow totalizer. The purpose of this totalizer was to track the cumulative volume of effluent treated by the carbon beds so that the total amount of extracted groundwater could be documented and estimates of the spent GAC explosives concentrations could be made at the end of the demonstration. The bag filter was installed to remove any solids from the effluent that could potentially clog the GAC beds.

3.3 OPTIMIZATION PERIOD

An optimization period of the pilot-scale demonstration was provided to allow the vendors to install their process equipment, correct any damages caused by shipping, and to operate and adjust their processes to treat the contaminated groundwater while obtaining analytical data on pilot-scale system performance. During this period, DTECH field TNT test kits were provided to the vendors to provide rapid semiquantitative analyses of residual TNT in the pilot-system effluent (see Appendix A, the QAPP, for summary of DTECH Method). The optimization period was extended from the one-week period described in the Work Plan (WESTON, 1994) to a two-week period. Participation during both weeks of the optimization period was optional for the vendors. With the exception of Ultrox, which arrived in the first week of optimization testing, the vendors elected to use the additional time for in-house preparation and shipment of their pilot-scale equipment. However, because of damage to its system during shipment, Ultrox was unable to operate its system during the first week of the optimization period.

During the second week of the optimization period, all vendors installed and operated their processes. After troubleshooting their systems, the vendors optimized their treatment processes by varying such parameters as pH adjustment, oxidant dosage, and flow while using the DTECH tests to evaluate their effluent. Several of the vendors also collected samples for off-site analysis for explosives by EPA Method 8330. Post-treatment effluent from the pilot systems over the optimization period was collected in the effluent storage tank for subsequent GAC polishing prior to discharge to Beaty Hollow Creek. The volume

of groundwater treated by each individual pilot system during the optimization period ranged from approximately 1,300 gallons to 7,300 gallons.

3.4 DEMONSTRATION PERIOD

Throughout the three-week demonstration, WESTON provided two project engineers and a site health and safety coordinator to oversee all activities at the SADA demonstration. Specifically, WESTON personnel were responsible for the following items:

- Implementation of the project Work Plan.
- Collection of influent and effluent samples in accordance with the sampling protocol, followed by proper labeling and shipment to the laboratory for analysis.
- Monitoring and documentation of each processes' flow, electrical power consumption, and chemical usage.
- Implementation and enforcement of the Site Health and Safety Plan.
- Documentation of all process adjustments and maintenance activities required to maintain operation.

3.4.1 Operating Schedule

The demonstration period commenced on 27 September 1994 and continued through 14 October 1994. The nominal operating schedule for the demonstration was 0830 hours CDT through 1630 hours CDT Monday through Friday. In order to avoid performance problems caused by a cold start, the vendors were allowed to start and balance the pilot-scale systems at 0800 hours.

3.4.2 Sampling and Monitoring Procedures

At the beginning of each operating day and at 1-hour intervals thereafter, the kilowatt hour (kWh) quantity displayed by the kWh meters and the volume displayed by the flow totalizer

was logged for each of the pilot-scale systems. In addition to recording electrical usage and flow, data on chemical additive consumption by the pilot-scale systems were recorded at hourly intervals, where possible.

Chemical characterization samples of the influent (groundwater supply) and each individual pilot system effluent were collected three times daily. Sample collection times were varied and no notification was provided to the vendors regarding the sampling schedule. Samples of the influent groundwater and the post-treatment pilot-scale systems' effluent were collected directly into sample containers from petcocks installed in the supply and discharge lines. Sample containers were labeled, logged, and packed for shipment to the WESTON analytical laboratory in accordance with the procedures contained in the Work Plan (WESTON, 1994). The influent and pilot-scale system effluent samples were analyzed for explosives by EPA Method 8330. Field measurements of pH and temperature were also recorded during each of the chemical sampling events. In addition, one influent sample per day was analyzed at the WESTON analytical laboratory for hardness, alkalinity, iron, and manganese. Quality assurance/quality control (QA/QC) samples included a minimum of one duplicate and one matrix spike/matrix spike duplicate (MS/MSD) sample per day.

In order to determine whether the AOP systems produced other toxic organic compounds not included in the EPA Method 8330 analyses, two random samples of each of the vendor system's effluent were analyzed for volatile and semivolatile organic compounds by SW 846 Methods 8240 and 8270, respectively.

In addition to monitoring explosives concentrations in the influent groundwater and the pilot-scale system effluents, the final effluent (after GAC polishing) was monitored daily with the DTECH field TNT test kits and weekly by analysis by EPA Method 8330. Analytical results from the demonstration are presented in Subsection 4-2.

3.4.3 Maintenance Activities

Monitoring and oversight of the pilot demonstration also included documentation of any maintenance activities performed by the participants during the demonstration. The nature of these maintenance activities varied among the participants as summarized in the following paragraphs.

Purifics' primary maintenance activity was limited to the daily changeout of its TiO_2 slurry. Each day, Purifics disposed of its slurry in the effluent tank and prepared a fresh batch with 40 grams of TiO_2. Purifics performed this daily slurry replacement for all but the last four days of the demonstration. During the last four days, Purifics operated with the same slurry to demonstrate that effective treatment could be achieved without the need to replace the slurry. Purifics also used a prefilter to remove solids from its influent groundwater. This filter did not require replacement during the three-week demonstration.

Solarchem's maintenance was limited to troubleshooting activities and minor equipment repairs. For example, on Saturday, 01 October 1994, Solarchem repaired its leaking discharge pump and also installed an acid metering pump to control the pH of its effluent. On this same day, Solarchem also experimented with its ozone generator to determine the maximum output it could achieve. On two other occasions, Solarchem spent 1.5 hours after the end of the daily operating period to drain its reactor and perform an acid wash of the system. This was done to restore the flowrate through the ozone diffusers in the reactor which appeared to have become clogged, resulting in reduced ozone flow. On two days of the demonstration, Solarchem experienced freezing of its NaOH feed lines because of low overnight temperatures, which required additional maintenance to thaw the lines and resulted in delayed start-up of its system.

Ultrox conducted minimal maintenance on its system during the demonstration. The maintenance was limited to the replacement of cartridge filters used to remove the precipitates from the influent groundwater. Initially, Ultrox alternately used one of two 25-μm filters to remove these solids. It later modified the filtering scheme by inserting a 100-

μm roughing filter prior to each of the 25-μm filters, thereby reducing its overall filter cartridge consumption. Ultrox experienced an ozone leak which took 5 minutes to locate and repair.

VPSI conducted daily maintenance on its quartz tubes. At the end of each day, VPSI drained its reactor to check for scaling on the tubes. Occasionally the tubes were clean, but more often they required cleaning, which resulted in approximately 1.5 hours of maintenance per day. On Saturday, 01 October 1994, two VPSI engineers spent nearly 9 hours troubleshooting the system. VPSI was having trouble with the lamp cleaning shuttles, which were not functioning properly at the low flow rates that the process engineers thought were necessary for effective treatment. The engineers modified these shuttle mechanisms and then operated their system to assess the effects on scaling. VPSI also experienced freezing of the NaOH lines. After the first occurrence, VPSI's process engineer insulated the NaOH tanks and installed an electric heater to prevent future problems.

3.5 DEMOBILIZATION

At the conclusion of the demonstration period, the influent supply and effluent discharge lines and the electrical supply lines were disconnected from the vendor systems. The vendors subsequently dismantled and/or prepared their systems for shipment, and shipped them from the demonstration site. A decontamination pad was constructed for steam-cleaning the PVC piping used to convey the contaminated groundwater and post-treatment effluent. The piping was subsequently cut into approximately 8-foot long sections and transported to the decontamination pad for steam cleaning. Rinsewater from the steam cleaning of piping and ancillary equipment in contact with contaminated water was pumped to the effluent holding tank for GAC polishing to remove any residual contamination. Field TNT test kits were used to confirm that the final rinsewater from steam cleaning of the piping, equipment, and the influent and effluent holding tanks contained less than 5 μ/L of TNT. Decontaminated piping was subsequently placed in a roll-off container for disposal in a landfill, and the rental holding tanks were decontaminated and removed from SADA.

Upon the completion of the decontamination of the piping, ancillary equipment, and holding tanks, a sample of the GAC from the leading GAC bed was shipped to Envirotrol of Beaver Falls, Pennsylvania for testing to determine the feasibility of carbon regeneration. Testing by Envirotrol indicated that the GAC was acceptable for regeneration. The GAC beds were subsequently shipped to Envirotrol for regeneration. Residual solid waste from the bag filter system and the glassware from the DTECH field TNT test kits were shipped to the WESTON Environmental Technology Laboratory for characterization to determine the appropriate disposal methods. No explosives compounds were present above their respective detection limits in the bag filter residual.

Other demobilization activities included the regrading, raking, and seeding of grassy areas damaged by vehicles, the demolition and removal of temporary wooden structures used for pipe supports, and the removal of the field office trailer. The electrical equipment, including the cable, transformers, and disconnect switches were left in place for disassembly and storage by the SADA electricians.

SECTION 4
RESULTS

In this section, the results of the pilot demonstration are presented for each of the four AOP processes. Subsection 4.1 contains a description of the process equipment used by each of the participants during the demonstration. These process equipment summaries are then followed in Subsection 4.2 by a summary of the analytical results obtained for the common influent samples and for the effluent samples from each of the participant processes. These analytical results include the following:

- Influent and process effluent concentrations of TNT and TNB.
- Influent alkalinity, hardness, iron, and manganese concentrations.
- Influent and process effluent temperatures and pH as measured in the field.

A full tabulation of the analytical results for the demonstration is contained in Appendix B. Subsection 4.3 contains information on the daily and total groundwater volumes and electrical energy consumed by each of the participants, an examination of which enables a relative comparison of pilot-scale process efficiencies. Finally, Subsection 4.4 contains a discussion of the full-scale cost estimates developed by each of the participants.

4.1 PROCESS EQUIPMENT SUMMARIES

The following process equipment summaries of the vendor systems were obtained from field observation by WESTON personnel and from information contained in the vendor bench-scale test reports (Appendix C) and the vendor pilot-scale test reports (Appendix D).

4.1.1 Purifics Pilot-Scale Process System

The Purifics pilot-scale process system consisted of a 4-rack continuous flow titanium dioxide slurry demonstration system (see Appendix D for process flow diagram). Each of the four racks was composed of 8 individual tubular reaction cells with one low-pressure UV lamp of 73 W capacity per cell for a total of 32 lamps. All the individual cells and the racks were

connected in series. Pretreatment of the influent groundwater to remove alkalinity was accomplished by adding sulfuric acid, under automatic pH control, to yield an influent with a pH 3 to pH 4. In addition, a small bag filter was used to remove particulates prior to treatment in the photocatalytic reactor, but because the Purifics process did not include a high pH step that would form a precipitate, no significant amount of solids was removed. Hydrogen peroxide and/or a proprietary additive was added to the pretreated groundwater as it entered the photocatalytic reactor where it was mixed with the TiO_2 slurry and exposed to the UV light. A titanium dioxide separation system recycled the titanium dioxide from the end of the photocatalytic system to the initial reaction cells to maintain a relatively constant titanium dioxide slurry concentration. Post-treatment pH adjustment was performed by caustic addition, under automatic pH control, prior to discharge of the groundwater to the effluent holding tank.

4.1.2 Solarchem Pilot-Scale Process System

The Solarchem pilot-scale process system used a 27-gallon capacity stainless steel reactor column equipped with three medium-pressure, high-intensity 1-kW UV lamps (see Appendix D for process flow diagram). Pretreatment of the groundwater consisted of pH adjustment to pH 12 by addition of a 50% caustic solution by a diaphragm metering pump to a chemical injection port followed by an in-line static mixer. This rise in pH was accompanied by the formation of a brownish, floc-like precipitate which was carried through the Solarchem process without being removed by filtration. Following this pretreatment, the groundwater entered the bottom of the reactor column. Ozone was injected into the groundwater through spargers in the bottom of the reactor and flowed concurrently with the groundwater toward the top of the reactor. The ozone generation system consisted of an air compressor and air dryer and a PCI Model G-21 ozone generator that was rated at 21 pounds of ozone per day. Residual ozone off-gas from the system was treated by a catalytic ozone destruction unit. Post-treatment pH adjustment of the treated effluent leaving the top of the reactor was performed by injecting sulfuric acid into an effluent holding tank that did not include a mixer.

4.1.3 Ultrox Pilot-Scale Process System

The Ultrox pilot-scale process system consisted of a 325-gallon capacity stainless steel reaction tank with 6 internal baffles with 6 low-pressure UV lamps of 65W capacity in each baffled area for a total of 36 lamps (see Appendix D for process flow diagram). An ozone generation system that included an air compressor, air filter, and air dryer and a 14 pound/day ozone generator provided ozone to the ozone diffusers in the reaction tank.

The groundwater was pretreated in a 30-gallon capacity tank with automatic pH controlled addition of caustic to pH 11. Influent flow to the adjustment tank was controlled by a level controller activating a solenoid valve on the influent line. Following adjustment to pH 11, the brownish, floc-like precipitate that was formed was removed by a 25-μm inline cartridge filter and the pH of the groundwater was readjusted to pH 4 in a 30-gallon capacity tank by pH controlled sulfuric acid addition. Flow through the reaction tank was by gravity to an effluent sump in which a caustic solution was added in a controlled manner to yield treated water with pH 7. Excess ozone that was discharged from the reactor unit as an off-gas was treated by a catalytic ozone destruction unit, prior to release to the atmosphere.

4.1.4 VPSI Pilot-Scale Process System

The VPSI pilot-scale process system consisted of a perox-pure^{tm} Model SX-30 treatment system with three medium-pressure, high-intensity 10-kW UV lamps (see Appendix D for process flow diagram). Pretreatment of the groundwater consisted of the addition of caustic to pH 11, addition of the primary oxidant, hydrogen peroxide, followed by filtration through a 1- or 3-μm cartridge filter to remove the precipitate, and subsequent addition of sulfuric acid to yield an influent with a pH 3 to pH 4. In addition, a proprietary catalyst (Catalyst Formula I) was added prior to the entry of the groundwater into the UV reaction chamber. Effluent from the UV reactor was treated by adding caustic to adjust the pH. Flow through the VPSI reactor varied from 2 to 5 gpm throughout the demonstration. For most of the demonstration, VPSI operated all three of its UV lamps, but on the final day, they operated only one lamp, in an attempt to obtain additional process information.

4.2 ANALYTICAL RESULTS

4.2.1 Explosives

The treatment criteria imposed on the participants in the pilot demonstration at SADA were expressed as daily average effluent limitations for several nitroaromatic compounds, as summarized previously in Table 3-1. These surface water discharge limitations, which were developed by the IEPA, were the same as those imposed previously during the remediation of the washout lagoons soils. Of the nitroaromatics included in the limitations, 2,4,6-TNT and 1,3,5-TNB were present at the highest concentrations in the supplied groundwater influent. As a result, these two compounds were the primary focus of the effluent analyses. Other nitroaromatic compounds such as the dinitrotoluenes, amino-dinitrotoluenes, and 1,3-dinitrobenzene were present in detectable concentrations in some of the influent samples. These same compounds were also occasionally detected in some of the process effluent samples, but were typically below the established treatment criteria. One exception to this is the consistent appearance of 1,3-dinitrobenzene (DNB) at concentrations slightly above the discharge criteria of 4 μg/L in the effluent from the Purifics process.

As indicated earlier, for each process, the daily average 2,4,6-TNT and 1,3,5-TNB effluent concentrations were calculated by taking the average of the analytical results for the three individual samples collected each day. Similarly, the average influent concentrations were calculated by averaging the three influent results for each day. These daily averages are presented in Table 4-1 for each of the participating processes. The values presented in bold type are those average effluent concentrations that exceeded the treatment criteria. Overall achievement, as presented in the bottom row of the table, is defined as the percentage of days during the demonstration that a process met the treatment criteria for all target compounds. In Figures 4-1 and 4-2, these same data are presented graphically for TNT and TNB respectively.

In addition to the effluent concentrations, the daily removal efficiencies for each participating AOP system vendor were calculated by the following equation:

$$\text{Removal Efficiency} = [(\text{Avg. Influent Conc.} - \text{Avg. Effluent Conc.})/\text{Avg. Influent Conc.}] \times 100$$

Table 4-1

Daily Average Effluent Concentrations of Target Compounds From Demonstrated AOPs

Target Compound	Date	Avg. Influent Conc. (µg/l)	Daily Average Effluent Concentrations				Treatment Criterion (µg/l)
			Purifics (µg/l)	Solarchem (µg/l)	Ultrox (µg/l)	VPSI (µg/l)	
2,4,6-TNT	27-Sep-94	860	**9.5**	1.0	0.70	**42**	7.0
	28-Sep-94	1090	6.0	**17**	0.77	2.4	7.0
	29-Sep-94	890	7.0	2.3	0.62	2.0	7.0
	30-Sep-94	887	5.4	0.79	0.67	1.7	7.0
	3-Oct-94	637	1.7	**37**	0.49	1.7	7.0
	4-Oct-94	760	**9.7**	**35**	0.67	1.9	7.0
	5-Oct-94	790	**20**	**24**	0.78	2.3	7.0
	6-Oct-94	793	5.2	**14**	0.81	1.6	7.0
	7-Oct-94	690	6.8	3.5	0.80	1.6	7.0
	10-Oct-94	703	1.6	**43**	0.95	1.6	7.0
	11-Oct-94	687	1.6	**23**	0.79	5.0	7.0
	12-Oct-94	630	1.7	**10**	0.85	**9.1**	7.0
	13-Oct-94	680	1.6	**13**	0.78	1.8	7.0
	14-Oct-94	670	1.6	**19**	0.89	1.7	7.0
Average Concentration		769	5.7	17	0.75	5.4	7.0
Criterion Achievement (%)		NA	78.6%	28.6%	100.0%	85.7%	NA
1,3,5-TNB	27-Sep-94	655	**767**	**64**	0.70	**278**	7.0
	28-Sep-94	823	**693**	**9.8**	0.77	**124**	7.0
	29-Sep-94	713	**377**	5.0	0.62	**210**	7.0
	30-Sep-94	730	**323**	4.1	0.67	**367**	7.0
	3-Oct-94	523	**205**	**31**	0.49	**29**	7.0
	4-Oct-94	613	**457**	**7.6**	0.67	6.9	7.0
	5-Oct-94	647	**457**	2.2	0.78	**92**	7.0
	6-Oct-94	650	**600**	1.5	0.81	**31**	7.0
	7-Oct-94	590	**504**	3.6	0.80	**50**	7.0
	10-Oct-94	563	1.6	**9.9**	2.7	**126**	7.0
	11-Oct-94	570	1.6	1.3	0.79	**187**	7.0
	12-Oct-94	527	**26**	1.8	0.85	**130**	7.0
	13-Oct-94	563	1.6	0.84	0.78	**118**	7.0
	14-Oct-94	550	2.6	0.78	0.89	**12**	7.0
Average Concentration		623	315	10	0.88	126	7.0
Criterion Achievement (%)		NA	28.6%	64.3%	100.0%	7.1%	NA
Overall Achievement (%)		NA	0	21.4%	100.0%	7.1%	NA

NA = Value not applicable

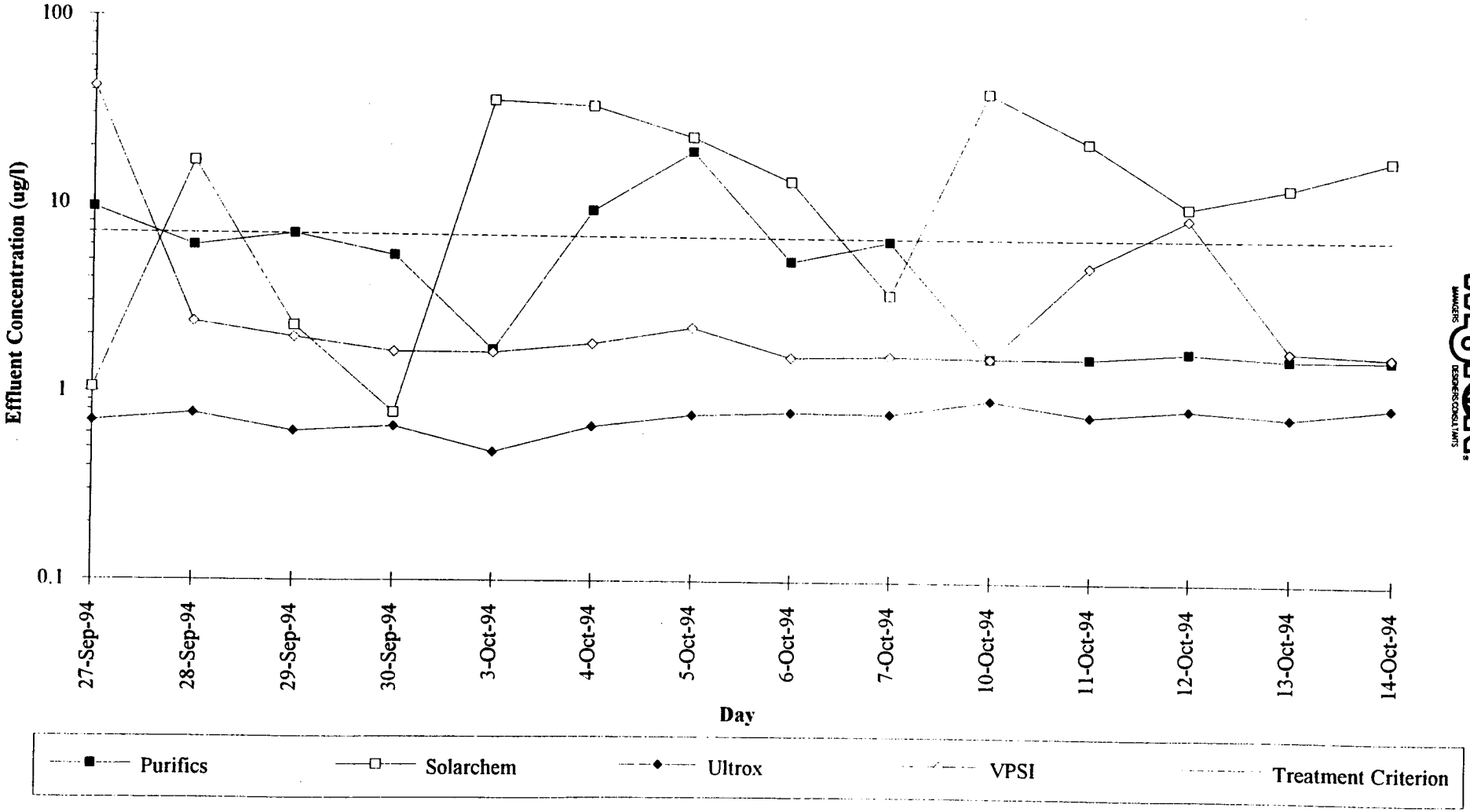


FIGURE 4-1 DAILY AVERAGE EFFLUENT CONCENTRATION OF 2,4,6-TNT

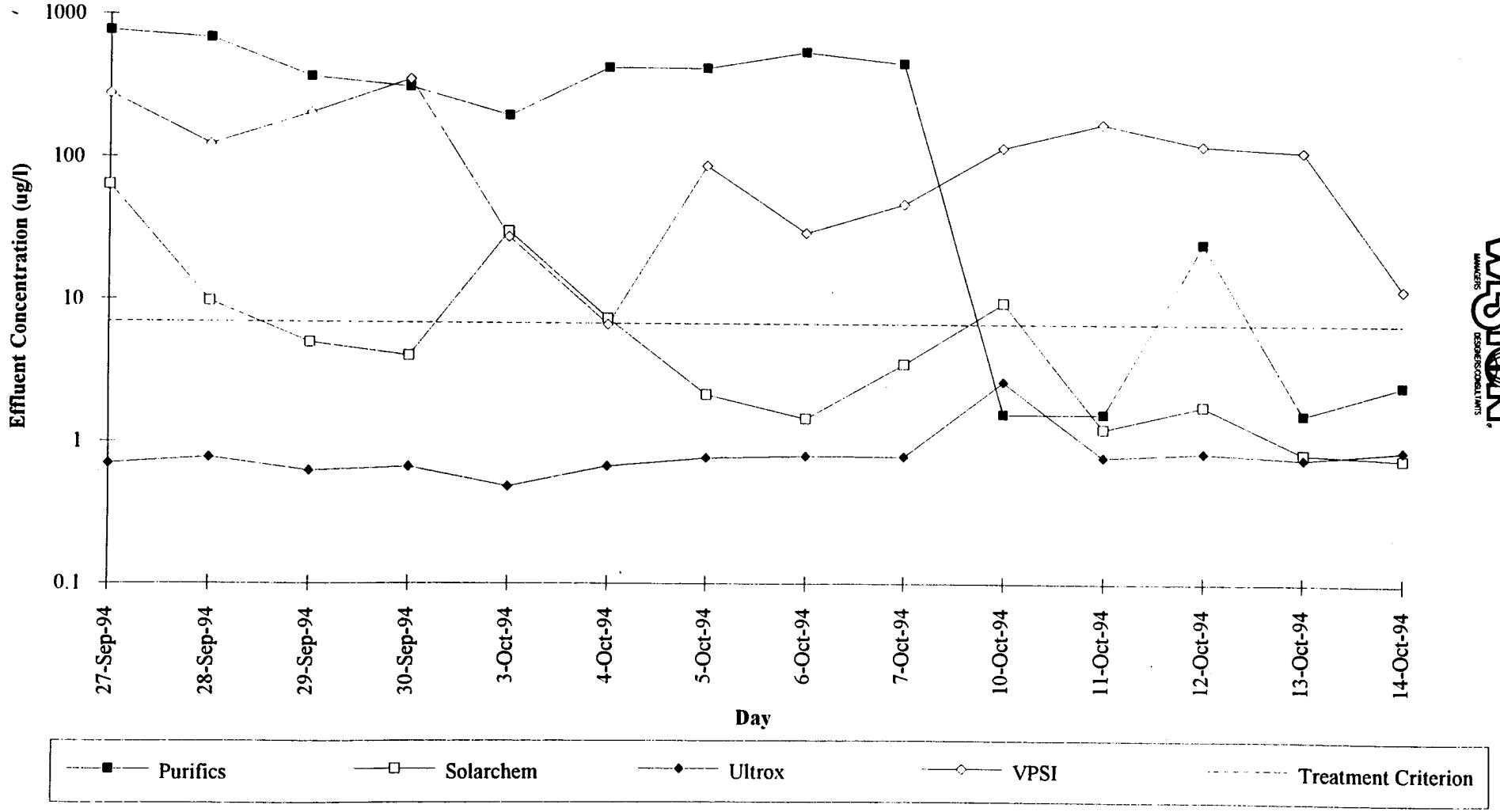


FIGURE 4-2 DAILY AVERAGE EFFLUENT CONCENTRATIONS OF 1,3,5-TNB

These calculated removal efficiencies are presented in Table 4-2. Because the influent concentrations varied slightly from day to day, there was no single removal efficiency that ensured achievement of the treatment criteria. Instead, the removal efficiencies have been presented as a relative measure of the individual processes' abilities to destroy the TNT and TNB. Because the minimum detection limits were used in the calculations for non-detect results, it was not possible to quantify the removal efficiency to greater than 99.9%.

Overall, all four processes demonstrated the ability to meet the treatment criteria for both 2,4,6-TNT and 1,3,5-TNB at one time or another. However, there was considerable variation in the consistency with which each process met the discharge limitations. Specific results for the individual processes are presented in the following subsections. For each process, a figure is provided that graphs the influent and effluent concentrations for TNT and TNB. Each figure depicts the analytical results for the individual samples collected during the demonstration rather than the daily average values. A total of 42 samples (14 days x 3 samples/day = 42 samples) were collected during the demonstration as indicated by the chronological sampling event legend for the x-axis in the graph. For some sampling events, two or more compounds had the same concentration, usually because of a non-detect value in which the lower detection limit has been plotted. In such cases, a data point marker for one target compound may obscure the data point marker for another compound in the graph.

In addition to the daily nitroaromatic analyses, a set of two effluent samples was collected from each process during the last two days of the study and analyzed for volatile and semi-volatile organic compounds.

4.2.1.1 Purifics

Explosives removal by the Purifics process varied over the course of the study. For the Purifics process, the pilot demonstration period can be divided into two separate operating phases: one for the first nine days, and one for the final five days. During the first nine days of the demonstration period, the process operated at times with hydrogen peroxide being

Table 4-2

Daily Average Removal Efficiency of Target Compounds From Demonstrated AOPs

Target Compound	Date	Purifics (% Removal)	Solarchem (% Removal)	Ultrox (% Removal)	VPSI (% Removal)
2,4,6-TNT	27-Sep-94	98.9	99.9	99.9	95.1
	28-Sep-94	99.4	98.4	99.9	99.8
	29-Sep-94	99.2	99.7	99.9	99.8
	30-Sep-94	99.4	99.9	99.9	99.8
	3-Oct-94	99.7	94.2	99.9	99.7
	4-Oct-94	98.7	95.4	99.9	99.8
	5-Oct-94	97.4	96.9	99.9	99.7
	6-Oct-94	99.3	98.2	99.9	99.8
	7-Oct-94	99.0	99.5	99.9	99.8
	10-Oct-94	99.8	93.8	99.9	99.8
	11-Oct-94	99.8	96.6	99.9	99.3
	12-Oct-94	99.7	98.3	99.9	98.6
	13-Oct-94	99.8	98.0	99.9	99.7
	14-Oct-94	99.8	97.2	99.9	99.8
	Average	**99.3**	**97.6**	**99.9**	**99.3**
1,3,5-TNB	27-Sep-94	-17.0	90.3	99.9	57.6
	28-Sep-94	15.8	98.8	99.9	85.0
	29-Sep-94	47.2	99.3	99.9	70.6
	30-Sep-94	55.7	99.4	99.9	49.8
	3-Oct-94	60.8	94.0	99.9	94.5
	4-Oct-94	25.5	98.8	99.9	98.9
	5-Oct-94	29.4	99.7	99.9	85.7
	6-Oct-94	7.7	99.8	99.9	95.2
	7-Oct-94	14.6	99.4	99.9	91.5
	10-Oct-94	99.7	98.2	99.5	77.6
	11-Oct-94	99.7	99.8	99.9	67.3
	12-Oct-94	95.1	99.7	99.8	75.3
	13-Oct-94	99.7	99.9	99.9	79.0
	14-Oct-94	99.5	99.9	99.8	97.8
	Average	**52.4**	**98.3**	**99.9**	**80.4**

fed and at other times without hydrogen peroxide. During this period, the effluent from the Purifics process system exhibited daily average TNT levels above the treatment criteria of 7 μg/L for three of the first nine days of the demonstration. During this same period, TNB concentrations in the reactor effluent exceeded the treatment criteria for all of the first nine days, ranging in concentration from 205 to 767 μg/L. In addition, 1,3-DNB was present in concentrations ranging from 10.0 to 62.0 μg/L, which were above the treatment criteria of 4 μg/L.

During the third week of the demonstration, the Purifics process was modified. It was determined through the DTECH field screening method that treatment using the hydrogen peroxide was not effective. A proprietary additive was used instead of hydrogen peroxide in the process, and the flowrate decreased slightly. Effluent quality improved immediately after these modifications, with TNT and TNB levels dropping to non-detectable levels. An examination of the effluent analytical data for the final 5 days showed that the Purifics process never exceeded the treatment criteria for TNT, and it exceeded the criteria for TNB on only one day. This excursion was the result of a single TNB concentration of 74 μg/L that was measured in the third sample collected on 12 October 1995. After this third sample was collected, Purifics' process engineer discovered that the metering pump supplying the additive to its reactor was not operating and he expressed concern that the sample may be affected by the upset to the process. Therefore, it is likely that this high TNB concentration was the result of this temporary loss of additive feed. Following the change from peroxide to the proprietary additive, the 1,3-DNB levels decreased considerably, as well; however, the effluent continued to contain levels slightly above the discharge criteria, ranging from 4.9 to 10.1 μg/L. The Purifics process results are shown graphically in Figure 4-3.

The results for the two samples analyzed for volatile and semivolatile organics indicated that the Purifics process exhibited effluent acetone concentrations of 3,700 and 3,400 μg/L, respectively. Since VOA analysis were not performed throughout the study, it is uncertain whether this acetone was present in Purifics' effluent throughout the demonstration or whether it was the result of the process modifications made during the final five days.

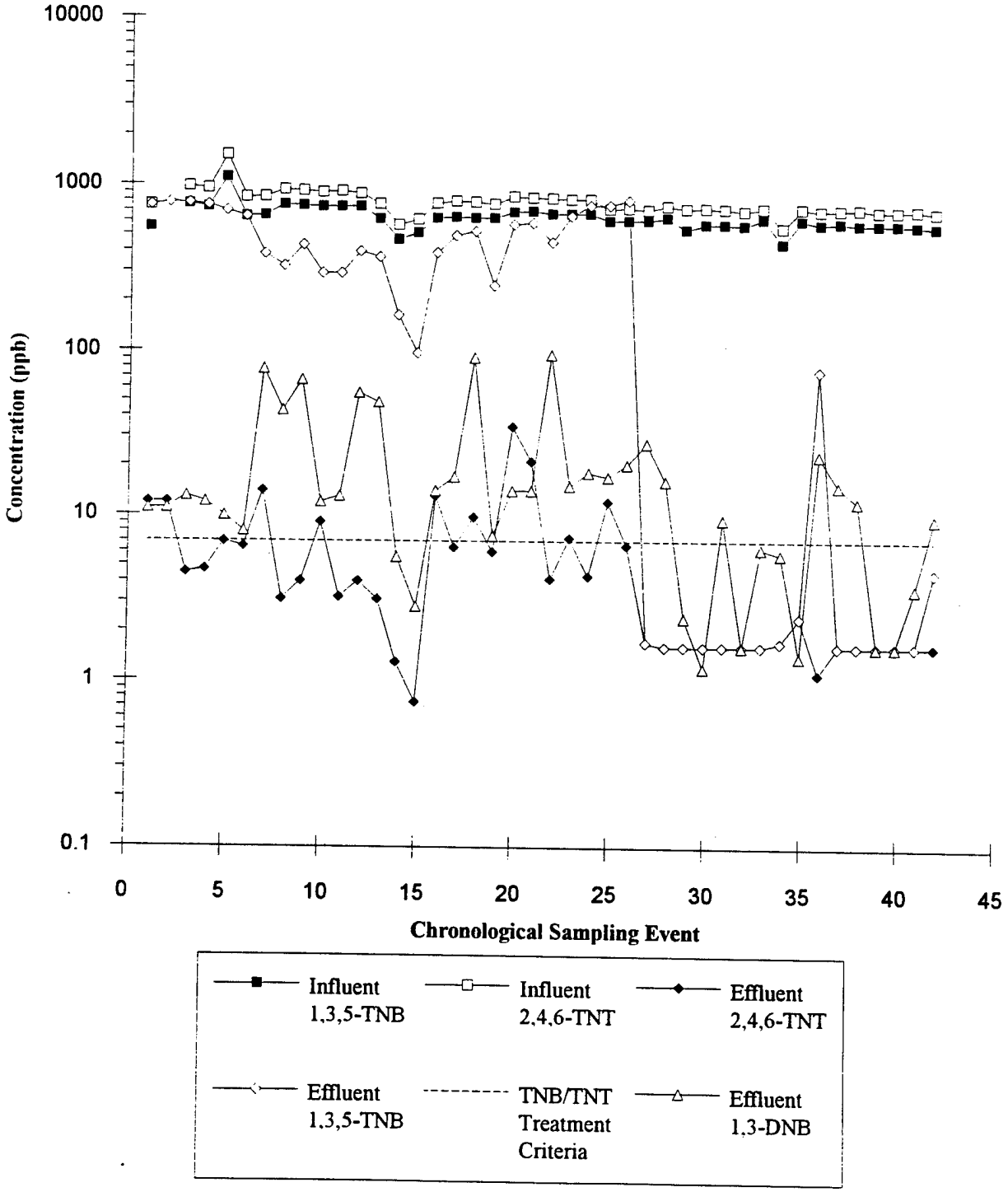


FIGURE 4-3 PURIFICS TREATMENT RESULTS

4.2.1.2 Solarchem

The explosives reduction achieved by the Solarchem process was variable throughout the project. However, the Solarchem process appears to have had more success in destroying TNB than TNT. An examination of the 14 daily average effluent concentrations shows that the Solarchem process effluent met the discharge criteria for TNB on 9 occasions (64.3% of the time) and met the discharge limit for TNT on 4 occasions (28.6% of the time). Overall, the Solarchem process achieved all the treatment criteria for 3 of the 14 days (21.4%). Although 1,3-DNB was detected in some of the Solarchem effluent samples, none of the daily average concentrations exceeded the treatment criteria of 4 μg/L. In Figure 4-4, these results are presented graphically. The results of the two volatile and semivolatile organic analyses performed on the Solarchem process effluent demonstrated non-detect concentrations for all the compounds analyzed.

4.2.1.3 VPSI

The VPSI process attained relatively consistent effluent quality throughout the study. Throughout most of the demonstration, the VPSI process was able to achieve the discharge criteria for TNT. It met the criteria for TNT on 12 of the 14 days (85.7%), but for TNB, the criterion was met on only one day. Overall, the VPSI process achieved the treatment criteria for all target compounds on only one of the 14 days (7.1%). Figure 4-5 is a graphical presentation of these results. The results of the two volatile and semivolatile organic analyses performed on the VPSI process effluent demonstrated non-detect concentrations for all the compounds analyzed.

4.2.1.4 Ultrox

The consistency of explosives removal criteria achievement by the Ultrox process was the best among the processes evaluated. The Ultrox process was able to achieve a discharge in which every nitroaromatic compound was not detected when analyzed by EPA Method 8330, with the exception of a single sample in which TNT and TNB were detected at

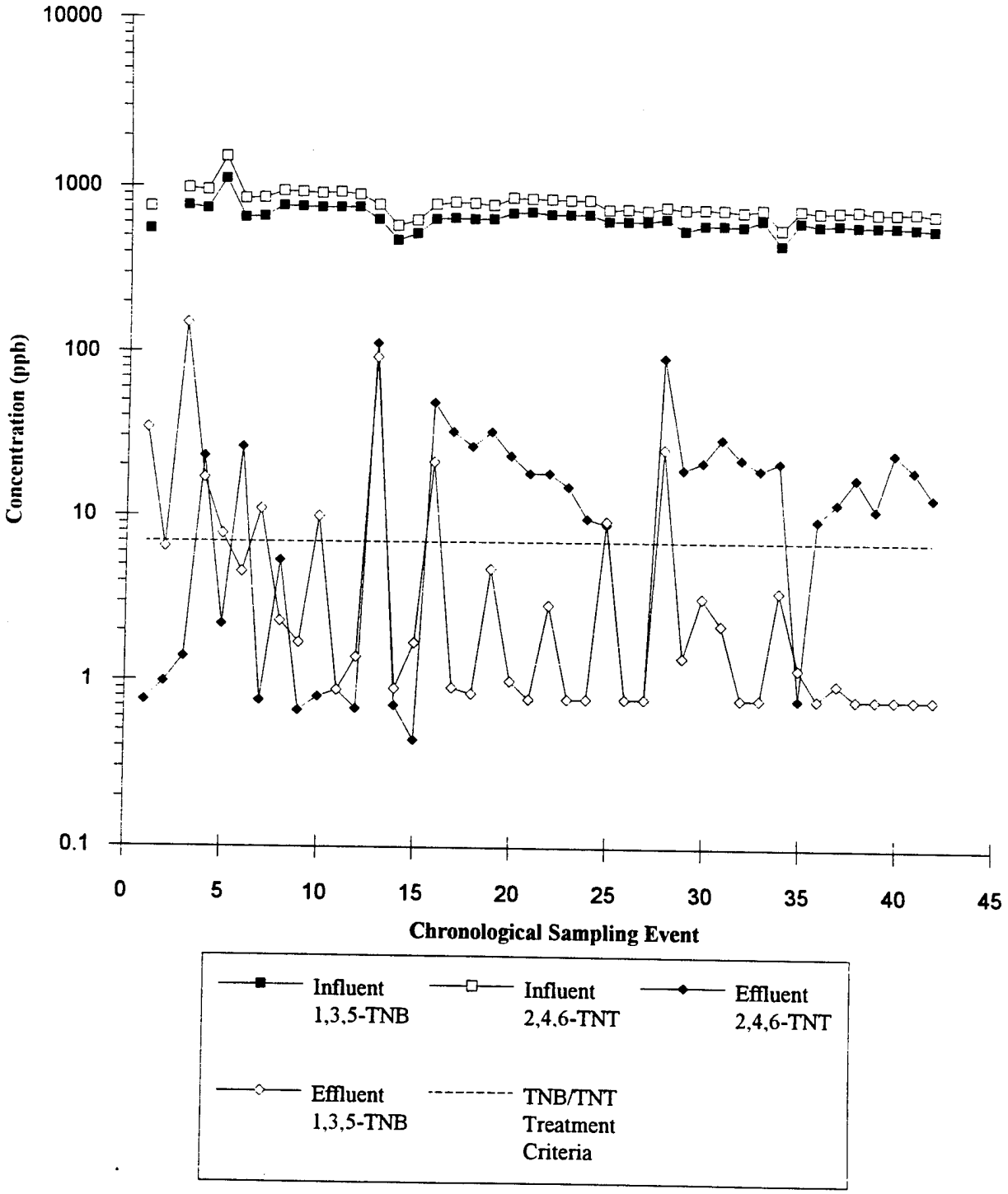


FIGURE 4-4 SOLARCHEM TREATMENT RESULTS

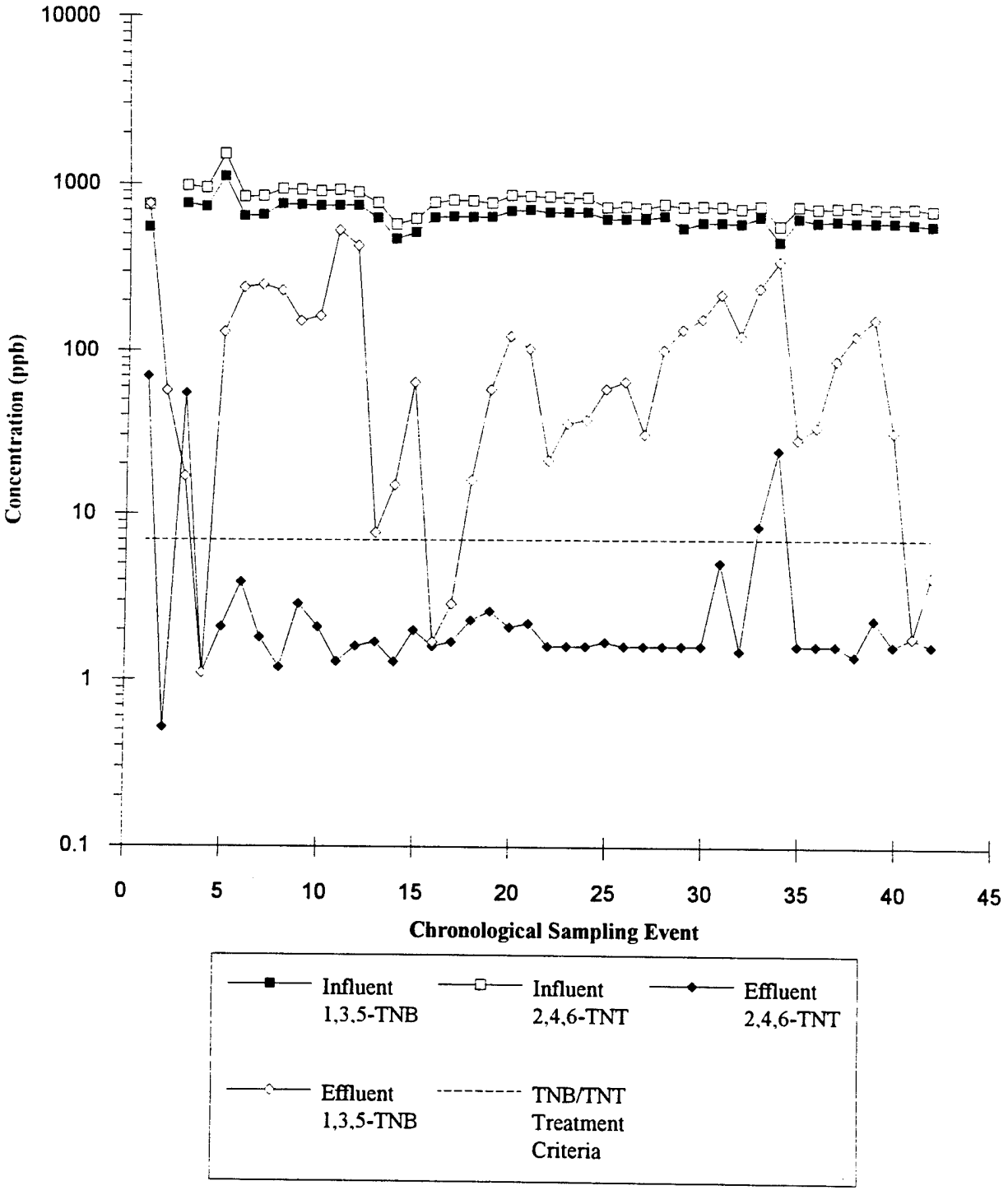


FIGURE 4-5 VPSI TREATMENT RESULTS

concentrations below the discharge criteria. Ultrox's process effluent discharge met the daily average discharge criteria for every compound monitored, for every sample (100%) collected. No volatile or semivolatile organics were detected in the Ultrox process effluent. Ultrox's process results are shown graphically in Figure 4-6. It is important to note that the analytical detection limits for both 1,3,5-TNB and 2,4,6-TNT were identical for any given sample. As a result, for all but one of the Ultrox process effluent samples, the 1,3,5-TNB and 2,4,6-TNT concentrations plot as a single point. In these situations the TNB data marker is "masking" the TNT data marker as illustrated in Figure 4-6.

4.2.1.5 Post-Treatment Effluent

Treated effluent from the polishing GAC units that was discharged to Beaty Hollow Creek during the demonstration was also monitored for explosives. Daily DTECH field screening tests were performed and weekly grab samples were collected for laboratory analyses by EPA Method 8330. The results for both methods showed non-detectable concentrations for all tested compounds. These results were provided to the IEPA for documentation.

4.2.2 Influent Parameters

In addition to explosives analyses, one influent sample per day was also submitted for analysis of iron, manganese, alkalinity, and hardness. These parameters can affect the effectiveness of the AOPs. Therefore, this daily sampling was performed to assess any changes in concentrations that might have occurred throughout the demonstration. These influent parameters remained relatively constant during the demonstration. Iron concentrations ranged from 124 to 563 μg/L during the demonstration with an average value of 319 μg/L. Manganese was present in concentrations ranging from 1,630 to 1,930 μg/L, and averaged 1,741 μg/L. Alkalinity measurements ranged from 168 to 226 mg/L, with an average value of 190 mg/L. Finally, hardness values ranged from 304 to 353 mg/L, and averaged 336 mg/L.

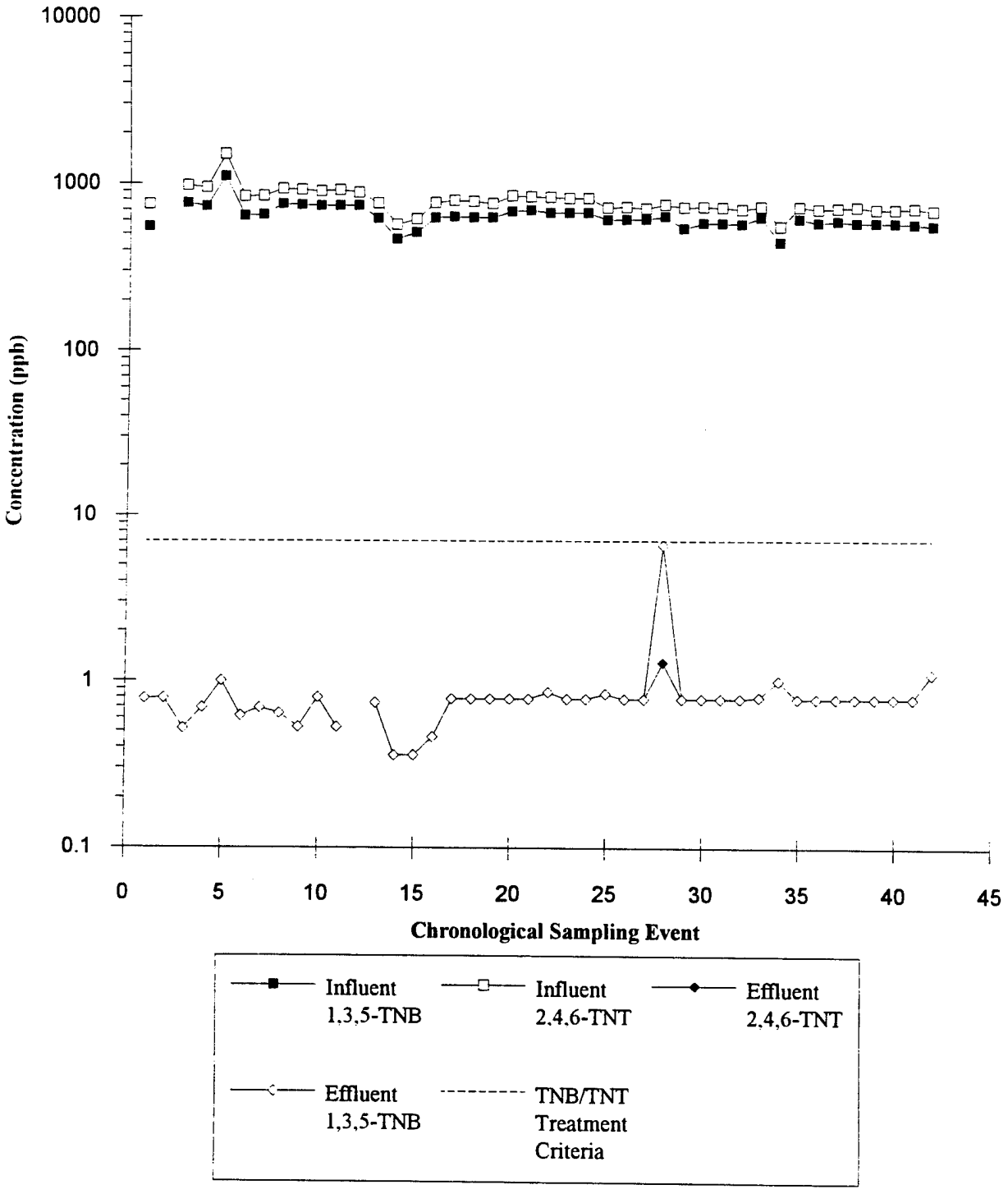


FIGURE 4-6 ULTROX TREATMENT RESULTS

Because of the temperature equalization provided by the large amount of water in the influent holding tank, there was very little change in the influent temperature throughout the demonstration. The average temperature was 12 °C, with a minimum of 10 °C and a maximum of 14 °C. Typically, the morning samples were one to two degrees cooler than the afternoon samples because of slight warming during the day. The pH values were also relatively constant throughout the demonstration. The influent ranged from pH 7.0 to pH 8.0, with an average of pH 7.4.

The various processes included different pretreatment strategies to address the alkalinity and manganese levels in the SADA groundwater. The Purifics process added sulfuric acid to remove alkalinity and used a bag filter to remove suspended solids. Solarchem's process pretreatment consisted of caustic addition without filtration or clarification. The Ultrox process added caustic and removed the resulting precipitate by an inline cartridge filter. Following filtration, the pH was readjusted to pH 4 prior to introducing the influent to the reaction chamber. The VPSI process pretreatment method consisted of the addition of caustic to pH 11, addition of hydrogen peroxide, filtration, and pH readjustment to a pH 3 to pH 4 prior to introducing the influent to the reaction chamber.

4.2.3 Other Effluent Parameters

For each of the three daily effluent samples collected, measurements of temperature and pH were made directly in the field using a thermometer, and either a portable pH meter or pH paper. The measurement of pH was necessary because the IEPA discharge criterion required the final post-treatment effluent discharged to Beaty Hollow Creek to be within pH 6 to pH 9. Collection of pH data from the AOP process systems allowed the evaluation of the effectiveness of the post-treatment pH adjustment systems and alerted WESTON staff to any pH excursions which could potentially affect the pH of the final effluent discharged to Beaty Hollow Creek. Temperature was monitored in order to assess potential problems associated with temperature rises. Although no temperature limit was applied by IEPA to the final discharge, many discharge permits contain maximum temperature limits which could result in post-treatment cooling requirements for AOP process systems.

Purifics' process system produced an effluent with a temperature varying from 12°C to 22°C, with an average effluent temperature of 19 °C. The pH of the discharge was controlled by automatic acid addition based on feedback from an inline pH meter. The calibration of this feedback control, however, appears to have been inaccurate, as their effluent averaged pH 5.7. Overall, Purifics' process effluent ranged between pH 3.6 and pH 7.0.

Solarchem's process effluent was discharged to a 200-gallon-capacity reservoir which was maintained at varying levels of fullness. During sampling, a pump was engaged to pump water from this reservoir into the central effluent holding tank. As a result, there was some equalization of temperature, and the values recorded may not necessarily be representative of the temperatures immediately after discharge from its reactor. The average temperature of the Solarchem process effluent was 16 °C, with a minimum of 9 °C and a maximum of 23 °C. For much of the demonstration, Solarchem's process engineer neutralized the effluent by manually adding acid to the discharge reservoir. A metering pump was subsequently installed which was manually adjusted to add acid to the effluent. Overall, Solarchem's average discharge pH was 7.6, but it ranged from a minimum of pH 1.8 to a maximum of pH 12.4.

Ultrox's process effluent temperature averaged 16 °C, and varied between 13 °C and 22 °C. The effluent pH was controlled through the use of a metering pump which fed caustic to the effluent to elevate the pH into the 6-9 range. Throughout much of the demonstration, the process system was able to maintain its pH within the required range, with an overall average of pH 6.7. Their fluctuations ranged from a low of pH 4.1 to a high of pH 8.7.

The VPSI process's average effluent temperature was 47 °C. There was considerable fluctuation in effluent temperature as VPSI modified the flowrate through its process system. During the higher flow periods when the retention time in the unit was the lowest, the effluent temperature was as low as 20 °C. However, at the lowest flow rates, its effluent temperature was measured as high as 70 °C. With respect to pH control, the VPSI process initially was not equipped to readjust pH prior to discharge. As a result, early VPSI values were as low as pH 1.7. When VPSI did eventually begin dosing caustic to the effluent, VPSI

was asked to discharge effluent at a slightly elevated pH to raise the pH of the water in the effluent holding tank. During this period, effluent pH values were as high as 12.2. Overall, its average effluent pH was 4.6.

4.2.4 Analytical Data Management

With the exception of Matrix Spike/Matrix Spike Duplicate (MS/MSD) values, all results from the explosives and inorganic analyses were entered into spreadsheets (Appendix B-2). The tabulated data included results from all duplicates, dilution, and repreparation analyses. The laboratory data reports and the tabulated data were reviewed by USAEC for QA/QC comment. Based on the USAEC review of the data set and matrix spike recoveries, a summary table of explosives and inorganic data from the pilot-scale demonstration was prepared (Appendix B-1).

4.2.5 QA/QC Summary

WESTON Analytics of Lionville, Pennsylvania, performed all analyses during the pilot-scale demonstration program in accordance with the procedures specified in the Work Plan and the QAPP (WESTON, 1994). With the exception of two samples broken in shipment, IN 09282 and ULT 09303, all samples were received intact and extracted and analyzed within their respective holding times. A minimum of one replicate (duplicate) and one MS/MSD sample were collected daily. As indicated above, laboratory data reports and tabulated data were reviewed by USAEC. The analytical data were considered usable with generally good agreement between primary samples and replicates (Appendix B-2). Although blank spike recoveries were initially low, recoveries increased with the use of improved extraction glassware obtained at the end of the second week of the pilot-scale testing.

4.3 ELECTRICAL CONSUMPTION

During the performance of the demonstration, the individual electrical energy usage was logged hourly through the use of kilowatt-hour (kWh) meters that were connected to the

supply line for each participant. Because individual processes were treating different flowrates, it was necessary to record the total gallons of water that had been treated during each hour. In this way, the electrical consumption by each participant for each hour of the demonstration could be determined.

The electrical meters were connected to each participant's reactor power supplies and did not measure the electricity consumed from the ancillary 120-volt outlets that were provided as a courtesy to each participant. To ensure that all process-related energy consumption was monitored, an ammeter was used by WESTON to measure the current being consumed by any process equipment powered from these 120-volt outlets.

The Ultrox process did not use the 120-volt courtesy outlets for any process-related equipment because their systems were equipped with built in transformers. At times, Purifics' process operated several overhead fluorescent lamps inside the trailer which were not process-related. These lamps were powered from main electrical supply and required 60 watts. This accounts for approximately 2.5% of the total electricity consumed throughout the demonstration by the Purifics process.

The Solarchem process operated two metering pumps and an air dryer from the 120-volt courtesy outlets which drew a total of approximately 0.8 amps. Although these were process-related equipment, their contribution to the overall energy consumption of the reactor and ozone generator is negligible. As a result, this usage was not considered in the calculation of overall electrical usage of the process. The Solarchem process also included an ozone monitor from the 120-volt outlets which drew approximately 3.0 amps. Solarchem's on-site engineer indicated that this equipment would not be included in a full-scale unit, and as a result, this electrical consumption was excluded from the calculation of electrical consumption.

Process-related equipment that the VPSI process powered from its 120-volt courtesy outlets included two metering pumps and an air compressor. The metering pumps together drew approximately 0.4 amps, which was negligible compared to the energy consumed by its

reactor. The air compressor drew 8.5 amps during operation, however, it operated only intermittently to recharge a pressurized reservoir. Consequently, this consumption was not considered in the process electrical consumption calculations.

Table 4-3 is the tabulation of the daily groundwater flow treated, daily electrical energy consumption, and kilowatt-hours per 1,000 gallons (kWh/kgal) for each of the participants throughout the demonstration. The last rows, labeled "Total" and "Average," show the total flow, total energy, average flow, and average energy consumed during the three-week demonstration, and the overall electrical consumption (expressed as kWh/kgal) based on these totals. If all the participants had met the discharge criteria for all the effluent samples collected throughout the demonstration, then direct comparison of the overall electrical consumption numbers would have provided an accurate assessment of the most energy-efficient processes. However, with the exception of Ultrox process, none of the participants consistently met the treatment criteria. As a result, these electrical consumption values should be considered carefully in light of the treatment results summarized in Subsection 4.2.

4.3.1 Purifics

Throughout the duration of the demonstration, the Purifics process's average energy consumption was 39.2 kWh/kgal of groundwater treated. Energy consumption during this period ranged from 34.8 to 46.5 kWh/kgal treated. However, during most of the first two weeks of the demonstration, the Purifics process did not meet the discharge criteria specified for the demonstration. During the last week of the demonstration, Purifics made several adjustments to its process, which included reducing its flowrate. Despite the decreased flow, the energy consumption remained the same. During this final week, the process generally met the discharge criteria for 2,4,6-TNT and 1,3,5-TNB. The average energy consumption over this last week dropped slightly to 43.8 kWh/kgal. The Purifics process met the TNT and TNB discharge criteria with an electrical energy consumption as low as 38.6 kWh/kgal.

Summary of Total Flow and Electrical Energy Consumption

Date	Purifics			Solarchem			Ultrox			VPSI		
	Daily Flow (gal.)	Electrical Energy (kwh)	Normalized Electrical Energy (kwh/kgal.)	Daily Flow (gal.)	Electrical Energy (kwh)	Normalized Electrical Energy (kwh/kgal.)	Daily Flow (gal.)	Electrical Energy (kwh)	Normalized Electrical Energy (kwh/kgal.)	Daily Flow (gal.)	Electrical Energy (kwh)	Normalized Electrical Energy (kwh/kgal.)
27-Sep-94	454	18	39.6	377	90	238.7	1,460	63	43.2	2238	200	89.4
28-Sep-94	537	19	35.4	953	104	109.1	1711	68	39.7	2001	198	99.0
29-Sep-94	543	20	36.8	979	101	103.2	1696	69	40.7	2288	228	99.7
30-Sep-94	533	20	37.5	1033	93	90.0	1720	69	40.1	2245	218	97.1
3-Oct-94	509	20	39.3	849	94	110.7	1695	68	40.1	830	223	268.7
4-Oct-94	494	19	38.5	824	96	116.5	1688	68	40.3	729	228	312.8
5-Oct-94	533	19	35.6	776	96	123.7	1663	66	39.7	1086	230	211.8
6-Oct-94	546	19	34.8	700	100	142.9	1673	68	40.6	1252	227	181.3
7-Oct-94	539	20	37.1	465	96	206.5	1638	67	40.9	1207	223	184.8
10-Oct-94	492	19	38.6	493	80	162.3	1590	67	42.1	1247	229	183.6
11-Oct-94	443	20	45.1	522	90	172.4	1576	67	42.5	1357	234	172.4
12-Oct-94	433	19	43.9	440	74	168.2	1661	68	40.9	1258	223	177.3
13-Oct-94	445	20	44.9	650	94	144.6	1668	69	41.4	1212	235	193.9
14-Oct-94	409	19	46.5	607	96	158.2	1615	68	42.1	798	158	198.0
Total	**6,910**	**271**	**NA**	**9,668**	**1,304**	**NA**	**23,054**	**945**	**NA**	**19,748**	**3,054**	**NA**
Average	**494**	**19**	**39.2**	**691**	**93**	**134.9**	**1,647**	**68**	**41.0**	**1,411**	**218**	**154.6**

NA = Value is not applicable

4.3.2 Solarchem

The Solarchem process's average energy consumption for the demonstration was 134.9 kWh/kgal. Throughout the demonstration, both its energy consumption and its flowrate varied. As a result, its daily energy consumption values ranged from 90.0 to 238.7 kWh/kgal. However, the Solarchem process never consistently met the 2,4,6-TNT discharge criteria of the demonstration and it is difficult to correlate a connection between its energy consumption and destruction efficiency. The lowest electrical energy consumption that met the discharge criteria for both 2,4,6-TNT and 1,3,5-TNB was 90 kWh/kgal.

4.3.3 VPSI

The VPSI process's average energy consumption for the demonstration was 154.6 kWh/kgal. During the first four days of the demonstration, it treated a flow of between 4 and 5 gpm. During this time, VPSI's on-site process engineers determined that they needed to cut the flow rate to approximately 2 to 2.5 gpm to achieve better destruction rates. As a result, the electrical energy consumption during the last two weeks of the demonstration averaged 208 kWh/kgal. The lowest electrical energy consumption that achieved the discharge criteria for both 2,4,6-TNT and 1,3,5-TNB was 312.8 kWh/kgal.

4.3.4 Ultrox

The Ultrox process's average energy consumption for the demonstration was 41.0 kWh/kgal. Because it operated under constant system settings throughout the demonstration, its energy consumption varied only slightly, ranging from 39.7 to 43.2 kWh/kgal. In addition, the Ultrox process met all the discharge criteria for every day of the demonstration. As a result, this electrical energy consumption is a reliable estimate of what a full-scale system could achieve. The lowest electrical energy consumption that achieved the discharge criteria was 39.7 kWh/kgal.

4.4 FULL-SCALE COSTS AND VENDOR-PRESCRIBED DESIGNS

At the conclusion of the bench-scale testing phase of this demonstration, the participants were required to provide a preliminary full-scale system design and cost estimates for treating explosives-contaminated groundwater. These estimates were for treatment only, and did not include any of the fixed costs associated with a full-scale groundwater remediation such as installation of extraction wells, pumping costs, conveyance piping, or effluent monitoring. These designs and estimates were to be prepared under the following assumptions:

- Groundwater characteristics identical to the SADA bench-scale sample.
- Treatment objectives identical to IEPA requirements for the pilot-scale demonstration discharge (see Table 3-1).
- Treatment at the rate of 50 gpm.

Upon completion of the pilot-scale testing, the participants reevaluated, and where necessary revised, their preliminary full-scale treatment system designs and cost estimates based on data obtained during the demonstration at SADA.

Because there was significant variation among the vendors in the format and content of the initial cost estimates, it was requested that each of the participants revise the full-scale cost estimates to conform to a standard format. This standard format required the breakdown of capital, as well as operation and maintenance (O&M) costs. The following unit costs for electricity, acid, base, cooling water, and labor were specified:

• Electricity	$0.06 per kilowatt-hour.
• Caustic soda	$0.10 per pound based on 50% solution.
• Sulfuric acid	$0.07 per pound based on 93% solution.
• Water supply (i.e., cooling)	$3.78 per thousand gallons.
• Supervisor labor hours	$31.00 per hour.
• Laborer labor hours	$14.88 per hour.

Although the costs contained in the pilot-scale reports have been reviewed, it is not possible to ensure the accuracy of the participant cost estimates on the basis of the information contained in these vendor reports. A comparison of the capital and O&M costs provided by each of the participants following bench-scale and pilot-scale testing is provided in Table 4-4.

Life-cycle costs for each system, expressed as 30-year present worth values, were then calculated using the following factors and assumptions:

- 5.25% interest rate used to calculate the present worth of the annual O&M expenditures.
- 3.5% annual inflation.
- Salvage value at the end of the 30 years equal to 6.8% of the capital costs.
- No finance costs for the initial capital investment.
- No functional use or denial of use costs.

The present worth values calculated for each of the participants are shown in Table 4-5 and the spreadsheet used to calculate these values is provided in Appendix E.

Based on the cost summaries provided in Table 4-5, the capital costs for a UV/Ox system treating 50 gpm of groundwater at SADA could be expected to range from nearly $400,000 to as much as $700,000 exclusive of installation, groundwater extraction and supply, and compliance monitoring costs. Depending on the system selected, annual O&M costs for the UV/OX systems and pretreatment subsystems could range from close to $100,000 to over $450,000. These O&M costs are dominated by electrical power costs, which confirms the energy intensive nature of the technology. Power costs account for as little as 50% of the total O&M for the Purifics process and as much as 67% of total O&M for the VPSI process.

Replacement of the ultraviolet lamps is another significant component of the annual O&M costs ranging from nearly $30,000 to just over $50,000 for the four processes. Finally, most

Table 4-4

Bench-Scale Vs. Pilot-Scale Cost Comparison

	Bench-Scale Estimate		Pilot-Scale Revised Estimate	
Vendor	Capital Cost ($)	Annual O&M Cost ($)	Capital Cost ($)	Annual O&M Cost ($)
Purifics	695,230	115,632	687,500	112,216
Solarchem	600,000	189,000	480,000	239,936
Ultrox	583,000	87,904	393,000	96,813
VPSI	650,000	415,179	650,000	447,496

Full-Scale Cost Summary

Cost Components	Purifics		Solarchem		Ultrox		VPSI	
Capital Cost	**$687,500**		**$480,000**		**$393,000**		**$650,000**	
Operation & Maintenance Costs	**($/kgal)**	**($/year)**	**($/kgal)**	**($/year)**	**($/kgal)**	**($/year)**	**($/kgal)**	**($/year)**
Power	$2.12	$55,714	$4.96	$130,349	$2.45	$64,333	$11.40	$299,592
Acid	$0.24	$6,228	$0.86	$22,601	$0.21	$5,424	$0.19	$4,967
Base	$0.07	$1,918	$1.90	$49,932	$0.02	$442	$0.45	$11,695
Hydrogen Peroxide	$0.00	$0	$0.00	$0	$0.00	$0	$2.50	$65,700
Titanium Dioxide	$0.01	$210	$0.00	$0	$0.00	$0	$0.00	$0
Other Additives	$0.19	$4,914	$0.00	$0	$0.00	$0	$0.50	$13,140
Lamps, Quartz Sleeves, etc.	$1.52	$39,946	$1.11	$29,171	$0.97	$25,413	$1.94	$50,983
Labor	$0.13	$3,285	$0.30	$7,884	$0.05	$1,201	$0.05	$1,419
Total Operation and Maintenance	**$4.27**	**$112,216**	**$9.13**	**$239,936**	**$3.68**	**$96,813**	**$17.03**	**$447,496**
30-YEAR PRESENT WORTH VALUE	**$3,300,853**		**$6,082,350**		**$2,650,591**		**$11,102,291**	

of the remainder of the O&M costs are attributable to chemical costs for acids, bases, and chemical additives.

The following subsections provide further elaboration of the bench-scale and pilot-scale design and costs provided by each of the participants. In the revised cost estimates, and in the pilot-scale reports, inconsistencies in the assumptions used by the participants were identified. For example, calculation of O&M costs were made on the basis of a 350-day year by one participant while others used a 365-day year. To ensure comparable costs among all four participants, the 30-year present worth values were calculated using consistent assumptions. As a result, certain cost components in Table 4-5 differ from the values reported by the participants in their reports in Appendix D. Additionally, there were instances where the participants developed costs based on design parameters which were not demonstrated during the pilot-scale study at SADA. These instances are further described in the following subsections.

4.4.1 Purifics

Based on bench-scale testing, Purifics proposed a preliminary full-scale system with a total 69.63 kW power requirement. After the completion of pilot-scale testing, Purifics altered its full-scale system design to a unit with a 106.6 kW power requirement. Despite the increase in the size of the system, the capital costs quoted by Purifics decreased slightly from $695,230 in the bench-scale estimate to $687,500 in the revised pilot-scale estimate. The predicted O&M costs also decreased slightly from $115,632 to $112,216 per year. Purifics designed its full-scale system based on the operating conditions implemented during the final week of the pilot-demonstration when the process successfully achieved the discharge criteria for both 2,4,6-TNT and 1,3,5-TNB. The electrical energy consumption per 1,000 gallons expected from the full-scale unit is comparable to the efficiency of the pilot-scale system during the demonstration at SADA. The 30-year present worth value of the revised full-scale system proposed by Purifics is $3,300,853.

4.4.2 Solarchem

On the basis of the bench-scale testing, Solarchem proposed a preliminary full-scale system consisting of a 5 x 30 kW Rayox® reactor with a 350 pound/day ozone generator. After the completion of pilot-scale testing, Solarchem altered its full-scale system design to a 4 x 30 kW system with two reactors with two 30-kW UV lamps each and a 235 pound/day ozone generator. Solarchem also added a 40-ton chiller to the proposed full-scale system to minimize O&M costs associated with the once-through use of cooling water for the ozone generation system. In general, Solarchem used the operating data gained from the pilot-scale testing to size and cost the full-scale system. Exceptions to this practice included the assumption that 10 kWh would be required per pound of ozone produced instead of the 13.125 kWh/pound ozone obtained in the demonstration. Further more, Solarchem sized the ozone generator on the basis of achieving a 95% ozone uptake in the full-scale system by countercurrent ozone dosing in the two reactor vessels. Inefficiencies in the pilot-scale process system associated with the low flow rates chosen and ozone sparger fouling were cited as the cause of the minimal 45% ozone uptake during the field demonstration.

The capital cost for the full-scale system was estimated at $600,000 on the basis of bench-scale testing. Annual O&M costs for this process system were estimated at $189,000. A revised full-scale design capital cost of $480,000 and an annual O&M cost of approximately $239,936 were estimated for the revised design after pilot-scale testing. The 30-year present worth value of the revised full-scale system proposed by Solarchem is $6,082,350.

4.4.3 Ultrox

On the basis of two bench-scale test runs performed with different ozone dosing rates, Ultrox proposed two separate preliminary full-scale system designs. The first system was based on an ozone dosage of 120 mg/L and a 103-minute detention time and consisted of Ultrox F-3900 and F-1300 reaction tanks and a 100 pound/day ozone generator. The alternative system proposed was based on a 90 mg/L ozone dosage and a 138-minute detention time and consisted of two F-3900 reaction tanks and a 50 pound/day ozone

generator. The initial F-3900/1300 full-scale system design is more representative of the equipment used by Ultrox in the pilot-scale test. After completion of the pilot-scale testing, Ultrox revised its full-scale system design to a treatment system based on a single Ultrox F-4550 treatment tank with a 75 pound/day ozone generator. Ultrox identified in the pilot-scale test report that pretreatment for the removal of manganese from the SADA groundwater prior to treatment would not be necessary if the concentration of manganese is below 3 mg/L. Analytical results indicated that manganese was below 2 mg/L during the pilot-scale testing.

Capital costs for the Ultrox F-3900/1300 and F-3900/3900 systems specified after bench-scale testing were $583,000 and $601,800 respectively. Annual O&M costs for these two systems were $87,904 for the system with higher ozone dosage (F 3900/1300) and shorter detention time and $60,784 for the alternative (F3900/3900) system. The estimated capital cost for the single F-4550 system proposed after pilot-scale testing is $393,000 without manganese reduction and $423,000 with manganese reduction. Annual O&M costs were estimated at $96,813 per year without manganese removal and $113,819 per year with manganese removal. The 30-year present worth value of the revised full-scale treatment system without manganese removal proposed by Ultrox is $2,650,591.

4.4.4 VPSI

On the basis of bench-scale testing, VPSI proposed a full-scale design consisting of an SX reactor with 600 kW of power to the UV lamps and a 1,000-gallon capacity hydrogen peroxide storage and feed module. After the pilot-scale testing, VPSI revised its system design to an SX reactor with 570 kW of power to the UV lamps and a 5,000-gallon capacity hydrogen peroxide storage and feed module.

Upon review of VPSI's revised full-scale design presented in the pilot-scale report, inadequacies in the scale-up calculations performed by VPSI were identified. Throughout the pilot-scale testing period, VPSI made numerous adjustments to the dosing rates of acid, caustic, and hydrogen peroxide and to system flow. VPSI appears to have used selected data

from multiple operating conditions at different times for scale-up to the full-scale design. For example, VPSI determined that a hydrogen peroxide dosing rate of 300 mg/L is sufficient on the basis of a single effluent sample collected during operation at a flowrate of 2 gpm. The dosage rate for Catalyst Formula I was determined from the results from other selected data points. Similarly, VPSI's derivation of a full-scale oxidation time appears to have been based on comparisons of another, separate set of data points. No explanation of the derivation of the proposed 2.8-minute oxidation time was provided.

VPSI's derivation of the 570kW full-scale power requirement was based on the average electricity consumption over the duration of the pilot-scale testing. This method is questionable since VPSI's pilot-scale system met the effluent discharge criteria on only one day of the test period and the electrical consumption over that day was more than twice the average consumption (312.8 kWhr/kgal vs. 154.6 kWhr/kgal). Consequently , the proposed full-scale system may be significantly undersized.

Based on the initial bench-scale cost estimate, capital costs, exclusive of a filtration system, were estimated at $650,000. Annual O&M costs were estimated at $324,999 exclusive of maintenance labor costs and filtration-related O&M costs. It should be noted that the largest single annual O&M cost component in the VPSI estimate was the electrical power at $220,320 at $0.0425/kWh. At the prescribed rate of $0.06/kWh, the electrical cost becomes $311,040 per year and the total annual O&M cost, exclusive of maintenance labor and filtration costs, becomes $415,719.

The estimated capital cost for this system of $650,000, exclusive of filtration system costs, is identical to that proposed after the bench-scale study. The revised annual O&M cost estimate is $447,496 exclusive of filtration system maintenance costs. The 30-year present worth value of the revised full-scale system proposed by VPSI is $11,102,291. It should be noted that exclusion of capital and O&M costs associated with the filtration system from the life-cycle calculation results in an under estimation of the present worth value of the system.

SECTION 5

SUMMARY AND CONCLUSIONS

5.1 DISCUSSION OF PILOT-SCALE SYSTEM PERFORMANCES

Overall, all four of the AOP processes that were demonstrated displayed the ability to meet the treatment criteria for both TNT and TNB at one time or another during the 14-day period. However, there was considerable variation in the consistency with which each process met the discharge limitations and in the energy input necessary to achieve these criteria. For both TNT and TNB, the daily average effluent criteria of 7 μg/L were developed by the IEPA (See Table 3-1). With the exception of the Purifics process in which 1,3-DNB was persistent, TNT and TNB were the rate limiting compounds, and successful treatment of these compounds ensured achievement of the treatment criteria for all the other nitroaromatics. Depending on the influent concentrations, this discharge criteria equated to required destruction efficiencies ranging from 98.9% to 99.4% for TNT, and 98.7% to 99.1% for TNB.

The Ultrox process was the only participant that was able to meet the discharge criteria for all target compounds on all 14 days of the demonstration. With the exception of one sample, the Ultrox process achieved non-detect results for all compounds for every effluent sample that was collected during the pilot-scale testing program. Its average overall electrical energy consumption during the demonstration was 41.0 kWh/kgal, and it demonstrated successful treatment at electrical energy consumption rates as low as 39.7 kWh/kgal.

The Solarchem process met all the discharge criteria on three days of the demonstration and consumed an average of 134.9 kWh/kgal. The lowest electrical energy consumption that demonstrated successful treatment for the Solarchem process was 90.0 kWh/kgal.

The VPSI process achieved the discharge criteria on only one day. While the overall average electrical energy consumption was 154 kWh/kgal, the consumption on the day that the treatment criteria were achieved was 312.8 kWh/kgal.

The Purifics process did not meet all the treatment criteria on any day of the demonstration, because of the presence in its effluent of 1,3-DNB at concentrations slightly above the discharge criterion of 4 μg/L. The overall electrical efficiency of the process was 39.2 kWh/kgal. The process was able to achieve the discharge criteria for both 2,4,6-TNT and 1,3,5-TNB at an energy consumption rate as low as 38.6 kWh/kgal. Effluent samples from the Purifics process that were analyzed for volatile and semi-volatile compounds exhibited concentrations of acetone of 3,700 and 3,400 μg/L.

The results of the demonstration program indicate that all of the UV/Ox processes are capable of treating nitroaromatics in groundwater, despite periodic exceedences of the stringent discharge criteria applied to the process effluents during the testing period. It is likely that additional process optimization, expanded startup and troubleshooting procedures, and equipment and control instrumentation typical of full-scale systems would minimize or eliminate the occurrence of such exceedences. Clearly, hybrid treatment trains based on a combination of UV/Ox treatment followed by GAC polishing would also be capable of meeting the discharge criteria on a continuous basis with minimal quantities of post-treatment residuals requiring off-site regeneration or treatment. Consequently, it is concluded on the basis of this demonstration that UV/Ox technologies can provide effective treatment of explosives-contaminated groundwater and that their potential use should be evaluated as an alternative to GAC treatment strategies for this application.

5.2 ADEQUACY OF BENCH-SCALE TESTING

As previously stated, one of the primary objectives of this pilot-scale demonstration of UV/Ox technologies for the remediation of explosives-contaminated groundwater was to determine the reliability and adequacy of bench-scale testing data for the determination of relative costs and the design of full-scale treatment systems. If sufficiently accurate, the

performance of a bench-scale test could obviate the need for costly pilot-scale testing in certain situations. Based on the modifications to the full-scale system designs and cost estimates provided by the UV/Ox system vendors after pilot-scale testing, it appears that the present state of the art in bench-scale testing is inadequate for use in the specification of a full-scale system and in the preparation of reliable cost estimates. Although Ultrox demonstrated that its bench-scale effort provided sufficient information to configure its pilot-scale system to treat the SADA groundwater to concentrations below the treatment criteria, a significant reduction in capital cost (33%) was associated with the specification of a single F-4550 treatment system based on pilot-scale testing in lieu of the F-3900/3900 or F-3900/1300 combination systems specified after the bench-scale testing. Solarchem reduced the initial capital cost estimate by 20% after pilot-scale testing. The capital cost for the VPSI system remained the same after pilot-testing. Purifics' capital cost estimate remained about the same, however, it modified its treatment strategy significantly based on lessons learned from the pilot-scale demonstration. Lastly, it must be noted that other similar investigations and testing conducted by WESTON on the treatment of VOC-contaminated groundwaters have shown a similar trend in that there is a wide disparity between costs and designs of full-scale UV/Ox processes that were based on bench-scale versus pilot-scale test data (Kesari et. al., 1992).

The elimination of pilot-scale testing may be inherently difficult for several reasons. First, if vendors are asked to prescribe and guarantee full-scale equipment based on performance criteria such as discharge limitations, they would necessarily be conservative in a full-scale design based solely on bench-scale testing. Otherwise, they would risk undersizing the equipment and being financially responsible for the required upgrades in the system. Secondly, the characteristics of the groundwater submitted for bench-scale testing may differ considerably from the actual concentrations encountered over the course of a full-scale remediation. For example, the volumes of groundwater required by the participants in the SADA demonstration for bench-scale testing ranged from 8 gallons to 170 gallons. These volumes are clearly not as representative as the characterization of the cumulative total of nearly 60,000 gallons actually treated during the pilot-scale demonstration at SADA. Two samples were analyzed from the groundwater collected for the bench-scale testing from the

undeveloped monitoring well used to provide groundwater during the demonstration. The results of these analyses indicated the following quality:

- Average TNT and TNB concentrations of 1,450 and 730 μg/L, respectively.
- Average iron and manganese concentrations of 582 and 2,930 μg/L, respectively.
- Average alkalinity and hardness of 170 and 582 mg/L, respectively.

For comparison, the average values of the influent groundwater samples taken throughout the SADA demonstration were:

- Average TNT and TNB concentrations of 769 and 623 μg/L, respectively.
- Average iron and manganese concentrations of 319 and 1,741 μg/L, respectively.
- Average alkalinity and hardness of 190 and 336 mg/L, respectively.

The demonstration concentrations of TNT and manganese were significantly lower than the concentrations measured in the bench-scale samples. This is just one of the numerous uncertainties that can affect design when proceeding directly to full-scale design from the bench-scale testing.

Despite the apparent inadequacy of bench-scale testing for providing sufficient information for use in full-scale design and development of O&M costs, the fact that the pilot-scale systems of all four vendors demonstrated the ability to achieve the TNT and TNB treatment criteria indicates that bench-scale testing is useful for sizing and developing operating parameters for the pilot-scale units. The full-scale cost estimates provided after the bench-scale testing were within an order of magnitude of the revised costs provided after completion of the pilot-scale demonstration. In addition, the relative costs for each of the processes with respect to the competing processes remained unchanged. The need for full and open competition is an important component of the U.S. Army's technology selection process and cannot be eliminated. However, the ability to replace competitive pilot-scale

studies with competitive bench-scale studies would result in considerable economic benefits. The results of the UV/Ox demonstration at SADA indicate that this strategy may be feasible. Process solution based on the competitive bench-scale testing could then be followed by a single pilot-scale study. As additional experience in the treatment of explosives compounds and their breakdown products at bench-scale, pilot-scale, and full-scale levels is gained by the UV/Ox system vendors, refinements in the bench-scale testing protocols could be adopted which might provide sufficient information for full-scale design decisions and allow for more accurate assessment of the economics of these systems.

5.3 LESSONS LEARNED

The discussions presented below are assessments and evaluations not directly related to the results of the demonstration. Rather, they are lessons learned throughout the project that may provide insight for future AOP pilot-scale demonstrations or full-scale implementations. It is important to remember that these lessons are based on observations of four AOP pilot systems operating specifically for the removal of TNT and TNB from groundwater. As a result, these lessons may not be applicable in all situations.

5.3.1 Effectiveness of DTECH Test Kits

During the optimization period and during the demonstration itself, DTECH TNT field screening test kits were used by each of the participants to measure the concentrations of TNT in their effluents. This method provides a semi-quantitative detection of TNT in concentrations from 5 to 45 μg/L, but it is also cross-reactive with TNB concentrations exceeding 20 μg/L. As a result, a non-detect reading by this method ensured that the effluent TNT concentrations were below the treatment criterion, and that the effluent TNB concentrations, although not necessarily below the treatment criterion, were at least below 20 μg/L. For DTECH results above the minimum detection limit, however, it was impossible to determine whether the sample contained TNT, TNB, or a combination of both. Additionally, the DTECH method provides no indication of the presence of the other explosive compounds at low concentration levels. The DTECH method, at best, provides

a way to semi-quantitatively determine the disappearance of 2,4,6-TNT and 1,3,5-TNB. Laboratory analyses provide more information and should always be used in the optimization of treatment processes. The ability to individually quantify TNT and TNB, and identify and quantify the other contaminants of concern, enables vendors to better assess their system performance. The participants, with the exception of one vendor, each had some rapid turnaround (less than 48 hours) laboratory analyses performed. While these analyses aided in the optimization of their processes, additional laboratory testing might have yielded even more-effective treatment. One vendor, in not performing any laboratory analyses, did not properly optimize their process as the results indicate. A field laboratory would have provided a more available source for analytical testing, but mobilization/ demobilization costs (approximately $15,000) are prohibitive for a short study. Even with high unit costs, the generous use of rapid turnaround laboratory analyses is highly recommended. It is more cost effective than a field laboratory and provides essential information for a study of this kind.

5.3.2 Effectiveness of Hydrogen Peroxide in the Presence of TNB

As mentioned previously in Subsection 2.1.2, past studies had shown TNB to be more difficult than TNT to destroy by the AOPs, and it was likely that TNB concentrations would be the rate-limiting factor in the design of the pilot- and full-scale systems. Engineers at Solarchem had stated that their previous work with nitroaromatics had indicated that TNB was exceptionally difficult to break down when using hydrogen peroxide as an oxidant. The results of the SADA demonstration appear to support this theory. Both the Purifics and VPSI processes used hydrogen peroxide in their pilot-scale units at SADA. The VPSI process employed hydrogen peroxide for the entire duration of the demonstration, while the Purifics process used it intermittently during the first two weeks. While using hydrogen peroxide, the Purifics process was unable to reduce its effluent TNB levels to below 205 μg/L, but when Purifics switched processes to include a proprietary additive feed instead of hydrogen peroxide, the effluent TNB concentrations dropped below the treatment criterion. The VPSI process achieved the TNB discharge criteria of 7 μg/L on only one of the 14 days of the demonstration. The Solarchem process used ozone as an oxidant and,

although the process also occasionally exceeded the discharge criteria for TNB, the exceedances were less frequent and not as severe as those for the Purifics and VPSI processes. Through the use of ozone, the Ultrox process was able to satisfy the treatment criteria for every sample collected.

5.3.3 Effects of Temperature on Sodium Hydroxide Solutions

The pilot-scale demonstration at SADA was purposely conducted during a season when the ambient temperatures were not expected to drop below 32 °F for any significant periods. Freezing of the water lines would have resulted in ice-blocked or cracked pipes leading to temporary, if not long-term, delays in the performance of the demonstration. Although frozen water lines were not encountered during the SADA demonstration, temperatures did drop low enough to cause freezing of sodium hydroxide (caustic) feed lines in some of the participants' processes. The participants who encountered problems with their caustic feed were those who were directly dosing a 50% caustic solution to their process. At this concentration, the caustic begins to crystallize at approximately 54 °F to 59 °F, and solidifies at 41 °F (MCA, 1974). On several occasions during the demonstration, nighttime temperatures dropped well below 40 °F causing some delayed startups for these processes. The other participants, who were feeding caustic at concentrations of 15% or less, did not encounter these freezing problems. For future implementation, dilute concentrations of caustic should be considered to prevent freezing, or else heating or insulating measures should be taken to ensure the temperature of the caustic does not drop below its freezing point.

5.3.4 Scheduling of Bench-Scale and Pilot-Scale Studies

As mentioned above, the pilot-scale demonstration was scheduled so as to complete the on-site work before freezing conditions occurred. As a consequence, the entire program, was conducted under an expedited schedule. The pilot-testing commenced very shortly after the completion of the bench-scale testing. Ideally, additional time would have been allocated to allow for revisions to the bench-scale test reports and for additional effort in the design,

fabrication, and mobilization of the pilot-scale systems by the participants. More aggressive review and discussion of bench-scale results, including repeats of inconclusive tests may have improved some of the pilot-scale performances.

5.3.5 Selection of Target Compounds for Analysis

When evaluating treatment provided by AOPs, it is often not sufficient to measure only the disappearance of the target compounds because intermediate compounds may be formed as a result of the oxidation reactions. With respect to the SADA demonstration, the primary target compounds were 2,4,6-TNT and 1,3,5-TNB. These compounds were included among the nitroaromatics analyzed in each influent and effluent sample. However, TNB is known to be a potential intermediate product of the TNT oxidation, and it should always be analyzed when TNT is the target compound, even if it is not present in the raw groundwater. Near the end of the study, a set of effluent samples was collected from each of the participants and subjected to a comprehensive analysis for volatile and semi-volatile organic compounds to determine the extent of treatment being provided and to identify any residual intermediates. The results of this analysis indicated that the Purifics process was generating detectable concentrations of acetone. These analyses revealed an important design consideration that would not have been evident based solely on the disappearance of the target compounds.

5.3.6 Materials Considerations

Previous pilot-scale studies of UV/Ox processes at Milan Army Ammunition Plant demonstrated a potential problem with UV/Ox processes that should be considered anytime these systems are implemented. Effluent samples from the pilot process exhibited toxicity to *Ceriodaphnia dubia*, despite the fact that the target organic compounds were being effectively destroyed. This toxicity was eventually traced to the leaching of toxic metals from various metal components in the system.

To ensure that this would not occur during the demonstration at SADA, each participant was contacted and questioned about the metals present in the various components of their systems. For the four systems operated at SADA, all metal components that had the potential to come in contact with the process water were required to be constructed of stainless steel.

SECTION 6

RECOMMENDED APPROACH FOR EVALUATING IMPLEMENTATION OF ADVANCED OXIDATION PROCESSES

Based on the findings of the pilot-scale demonstration at SADA of selected UV/Ox technologies available from commercial vendors, the following approach has been developed for evaluating the cost and effectiveness of this treatment technology for remediating explosives-contaminated groundwater at other DOD sites. The following are the major elements of the recommended approach:

- Develop a work plan for rigorous bench-scale testing by multiple vendors.
- Issue a Request For Proposals (RFP) to selected UV/Ox system vendors.
- Evaluate proposals received from the vendors and select the vendors to participate in the bench-scale testing.
- Perform bench-scale testing with oversight.
- Evaluate vendor bench-scale test reports and select vendor(s) for on-site pilot-scale testing.
- Perform additional confirmatory bench-scale testing, if necessary.
- Perform pilot-scale testing with oversight.
- Evaluate pilot-scale test results and full-scale system sizing calculations.

The following paragraphs describe the specific components of each of the elements listed above and the rationale for their inclusion in the recommended approach for the evaluation of UV/Ox systems.

6.1 BENCH-SCALE AND PILOT-SCALE TEST PLAN

The results of the demonstration study at SADA indicate that bench-scale testing should be performed in accordance with a test plan under oversight. The system vendors participating in the SADA field demonstration performed bench-scale testing using testing protocols

developed in-house on the basis of past experience with bench-scale testing. In several cases, data obtained in the bench-scale testing was suspected to be erroneous because of analytical problems (presumed false positives) or because of cross-contamination within the UV/Ox test apparatus. It is recommended that quick turnaround analyses (on the order of 48 hours) be performed during the bench-scale testing to allow the prompt identification and correction of contamination problems and analytical errors and, where necessary, reruns of any necessary testing. Because of differences in the equipment used for bench-scale testing of the commercially available processes, the bench-scale Test Plan should be flexible enough to allow each system vendor to test their various process-specific conditions. There are likely to be differences among the participants in the volume of sample water required to conduct the testing, the types of additives or oxidants included in the testing, the duration of each individual test, and the types of data generated by the different bench-scale testing strategies. Rather than imposing constraints on the bench-scale testing methods, the Test Plan should specify the sampling and analyses to be performed during each test, as well as the format for presenting the bench-scale testing results. Most importantly, all calculations and assumptions made by each system vendor in preparing an estimated full-scale unit size and cost should be well-documented.

In addition to treatment by UV/Ox only, bench-scale testing may also provide an assessment of combination treatment strategies such as UV/Ox and GAC or UV/Ox and air-stripping. Such processing trains may prove effective in certain applications in which the groundwater contains a variety of organic compounds. Often in such situations, one or more of the compounds may be difficult to air-strip or may not have a strong affinity for activated carbon. If the recalcitrant compound(s) happens to be easily oxidized by a UV/Ox process, a hybrid system may be more effective than either process alone. Similarly, UV/Ox systems are sometimes designed with GAC polishing of effluent to remove compounds that are resistant to oxidation.

6.2 ISSUE RFP TO VENDORS FOR BENCH-SCALE TESTING AND OPTIONAL PILOT-SCALE TESTING

Upon completion of the Test Plan, an RFP should be prepared for the performance of the bench-scale testing by multiple vendors. The Scope of Work (SOW) contained in the RFP should stipulate that the testing will be performed in accordance with the Test Plan which should be included as an appendix or attachment to the RFP. The RFP should indicate that the individual system vendors may perform additional bench-scale testing in addition to the tests specified in the Test Plan to provide any information deemed necessary for determining the treatability of the groundwater, the sizing of the pilot-scale test system, and the preliminary sizing of the proposed full-scale treatment system. While the RFP should indicate the requirements for performing subsequent pilot-scale testing, the SOW should not include the performance of such studies. In preparing the RFP for bench-scale testing, it is important to explicitly define the SOW to ensure that all respondents prepare bids with a similar level of effort. Standard bench-scale testing programs can vary greatly among vendors. Variables such as the number of tests, the total samples collected, analytical requirements, and the performance of confirmatory testing can significantly affect the total price of bench-scale testing. Therefore, the SOW should explicitly describe these minimum requirements and require written justification, by the proposers, for additional testing. This will facilitate comparison of the proposals submitted in response to the RFP.

6.3 EVALUATE PROPOSALS AND SELECT VENDOR(S)

Upon receipt of vendor proposals, a committee composed of technical and financial staff should review and rank the proposals according to a predetermined matrix of technical, qualifications and experience, and cost scores. Given the limited experience in treating explosives compounds in groundwater, technical merit and experience should be assigned higher scores than the cost components. As UV/Ox technology is increasingly applied to explosives and nitroaromatics, the relative weight of each of these evaluation criteria may change. The number of vendors selected for performing the bench-scale testing will depend on the funds available for performing the studies, the nature and complexity of the

contamination to be remediated, the competency of the vendors, and the quality of the proposals.

6.4 PERFORM BENCH-SCALE TESTING

After selection of the vendors, each participant should be provided with a sufficient volume of representative groundwater. The bench-scale testing should then be performed under oversight by technical support staff from the DOD or its designated representative. Deviations from the Work Plan should be documented in the field oversight logbooks and discussed in the bench-scale reports. Quick turnaround analyses should be employed by the vendors to provide rapid assessment of bench-scale system performance and to allow corrective action (such as bench-test reruns or reanalysis of samples) to be taken. Bench-scale reports should be prepared documenting the methods and materials used and the analytical results of the bench-scale tests. The reports should include an evaluation of the treatability of the groundwater by advanced oxidation processes, detailed information on the sizing calculations, assumptions, and costing of the pilot-scale and full-scale systems proposed for the remediation project. As with any pump and treat system, the groundwater quality can change over time. Therefore, the full-scale designs proposed by each participant should define the acceptable range of target compound concentrations in the influent groundwater for which the process can achieve the treatment criteria.

6.5 EVALUATE VENDOR BENCH-SCALE REPORTS AND SELECT VENDOR(S) FOR PILOT-SCALE TESTING

Draft vendor bench-scale reports should be evaluated by technical staff to verify the accuracy of the results, system sizing calculations, assumptions, uncertainties, and conclusions of the studies. Written comments on the bench-scale reports should be prepared and forwarded to the vendors for use in correcting deficiencies in the draft reports. Based on the committee's evaluation of the final bench-scale reports and the overall treatability of the groundwater by advanced oxidation processes, one or more vendors should be selected to participate in a pilot-scale study at the remediation site. By screening potential processes at the bench-scale level and limiting the pilot-scale testing to a single or only a few

processes, significant savings can be realized in the overall evaluation of the UV/Ox processes.

6.6 EXERCISE OPTION TO PERFORM PILOT-SCALE TESTING

An RFP should be prepared for issuance to the vendors selected on the basis of the bench-scale test program. Pilot-scale testing should be designed and implemented to fulfill the following objectives:

- Provide confirmation of groundwater treatability and bench-scale results.
- Obtain all information necessary to design the full-scale system(s), identify any necessary pretreatment or post-treatment requirements, and provide accurate life-cycle cost estimates.

As with bench-scale testing, the pilot-scale testing should be closely monitored and supervised by DOD personnel, particularly if multiple processes are being tested. Operating parameters, such as influent and effluent concentrations of the target compounds, electrical consumption, flowrates, and chemical usage should all be well documented. In addition, any modifications to process operating conditions or required maintenance should be noted.

6.7 EVALUATE PILOT-SCALE TEST RESULTS AND FULL-SCALE SYSTEM SIZING

The evaluation of the pilot-scale testing results will be used to select the process to be implemented at a particular site. If detailed and accurate information was collected during the pilot-scale demonstration, then the basis for the full-scale design and cost provided by each pilot-scale participant can be confirmed by DOD personnel. The process solution then becomes a simple matter of choosing the least expensive system that meets all full-scale design requirements, including the successful destruction of the target compounds to concentrations below the specified discharge limits.

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APPENDIX A

WORK PLAN

Evaluation of Ultraviolet Oxidation (UV/Ox) Methods for the Remediation of Explosives Contaminated Groundwater : Work Plan

Contract No. DACA31-91-D-0079
Task Order No. 06

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TASK ORDER 6

EVALUATION OF ULTRAVIOLET OXIDATION (UV/OX) METHODS FOR THE REMEDIATION OF EXPLOSIVES CONTAMINATED GROUNDWATER

WORK PLAN

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SECTION 1
INTRODUCTION

1.1 BACKGROUND

As a consequence of munition manufacturing, storage, testing, and disposal activities, groundwater contamination with explosives compounds, as well as other organic and inorganic constituents, exists at numerous U.S. Army installations. The U. S. Army has an Installation Restoration Program (IRP) in place for evaluating the nature and extent of contamination at U. S Army facilities and, where appropriate, implementing remedial actions to mitigate the contamination. While a variety of technologies have been utilized in the treatment of explosive contaminated wastewaters and groundwater, they are typically expensive to operate and require extensive operation and maintenance procedures.

Granular activated carbon (GAC) has been successfully used to treat explosives contaminated groundwater at U. S. Army facilities. However, this technology has several disadvantages. These disadvantages include the relatively high cost of the GAC material which is used to remove the explosive compounds by adsorption and the resulting hazardous residual waste (exhausted carbon) due to the adsorbed explosive compounds. Additional treatment is necessary to destroy the explosive compounds prior to disposal of the carbon, because the explosive compounds removed from the treated groundwater are adsorbed to the carbon.

An alternate treatment process, UV/Oxidation (UV/Ox), utilizes the formation of hydroxyl radicals to oxidize the explosive compounds. This process offers several advantages over GAC. UV/Oxidation is potentially less expensive and more efficient than GAC. Because the explosive constituents are completely destroyed by the UV/Oxidation process, no residual wastes are produced which require additional treatment prior to disposal. Finally, the UV/Oxidation systems may require less operation and maintenance (O&M) resources relative to GAC systems.

1.2 OBJECTIVES

The objectives of the pilot-scale UV/Ox demonstration program are:

- Demonstrate the technical and cost effectiveness of several commercial configurations of UV/Ox technology.

- Determine/identify a UV/Ox system which can best provide for the economical, efficient, and reliable treatment of explosives-contaminated groundwater.

- Evaluate the accuracy of bench-scale and pilot-scale assessments for cost and design considerations for full scale implementation of UV/Ox treatment systems.

The pilot-scale UV/Ox demonstration program tasks include:

- Select vendors and system hardware configurations.

- Perform bench-scale treatability studies on groundwater obtained from the SADA site.

- Determine pilot-scale system configuration, pretreatment requirements, and optimization based on bench-scale treatability testing.

- Provide a preliminary design of a full-scale system for the treatment of explosives-contaminated groundwater and estimate capital and O&M costs based on bench-scale treatability testing.

- Prepare the SADA site for pilot-scale field demonstration activities.

- Perform pilot-scale field demonstration of the UV/Ox technology.

- Decontaminate equipment and demobilize from the SADA test site.

- Evaluate UV/Ox systems performance.

- Prepare a report summarizing the UV/Ox demonstration, destruction efficiency, and predicted life-cycle capital and operating costs for each of the treatment systems tested.

- Determine the scalability, applicability, and reliability of estimates of system construction and O&M costs and performance derived from bench-scale testing to full-scale system design, construction, and operation.

This pilot-scale demonstration program is being performed to provide information on the destruction efficiency, operating conditions, O&M requirements, and costs associated with the use of UV/Ox technology for explosives compounds in groundwater. The information obtained from this study will be used to evaluate the feasibility of implementing full-scale UV/Ox-based groundwater treatment systems at U.S. Army facilities.

This document is the Work Plan for the pilot-scale demonstration of the UV/Ox technology at the Savanna Army Depot Activity (SADA) in northwestern Illinois. The objective of this document is to provide specifications and prepare for the performance of the pilot-scale demonstration and the subsequent data analysis and reporting of the demonstration results.

1.3 PROBLEM STATEMENT

As previously mentioned, groundwater contamination by explosives compounds is present at numerous U.S. Army facilities. Remedial actions at these facilities have typically incorporated GAC to remove explosives and other organic compounds from the groundwater. Among the disadvantages associated with the use of GAC as the primary treatment technology are high costs and problems associated with the disposal of explosives-contaminated spent carbon. Instead of being destroyed during the treatment process, explosives compounds are transferred from one media (groundwater) and concentrated in

another (GAC) by this approach. This necessitates the subsequent treatment of the spent carbon to destroy sorbed explosives.

Given the extent of explosives-contaminated groundwater at U.S. Army facilities and the high O&M costs associated with GAC treatment, the U.S. Army Environmental Center (USAEC) is assessing the feasibility of alternative treatment technologies which may eliminate or reduce the use of GAC by providing onsite destruction of explosives compounds in groundwater for application in the IRP. This pilot-scale demonstration program is being performed to document the destruction efficiency, operating conditions, O&M requirements, and costs associated with the use of UV/Ox technology for explosives compounds in groundwater. A number of patented vendor processes are available for the treatment of explosives-contaminated groundwater. Pilot studies are currently required of each of the vendor processes to accurately assess implementation costs. This approach is costly (approximately $50,000 per study per vendor) and time consuming. This demonstration study is intended to determine whether the results of bench-scale testing can provide sufficient information to accurately estimate the costs and treatment effectiveness of a full-scale UV/Ox system for the treatment of explosives-contaminated groundwater and, thus, avoid the time and expense associated with the performance of pilot-scale testing.

1.4 PROJECT ORGANIZATION

1.4.1 Personnel

The project organization chart for the UV/Oxidation pilot-scale demonstration of explosives-contaminated groundwater remediation at SADA is presented in Figure 1-1. This Task Order was contracted by USAEC to WESTON. USAEC defines the project objectives, establishes the project guidelines, oversees project activities, and reviews all project findings and reports. Mr. Peter J. Marks is the WESTON Program Manager for all USAEC Technology Development projects. For the UV/Oxidation Pilot-Scale Demonstration Program, Dr. Walter J. Wujcik will serve as Task Manager and the Project Engineers will be Mr. John O. Hammell and Mr. Charles T. Young.

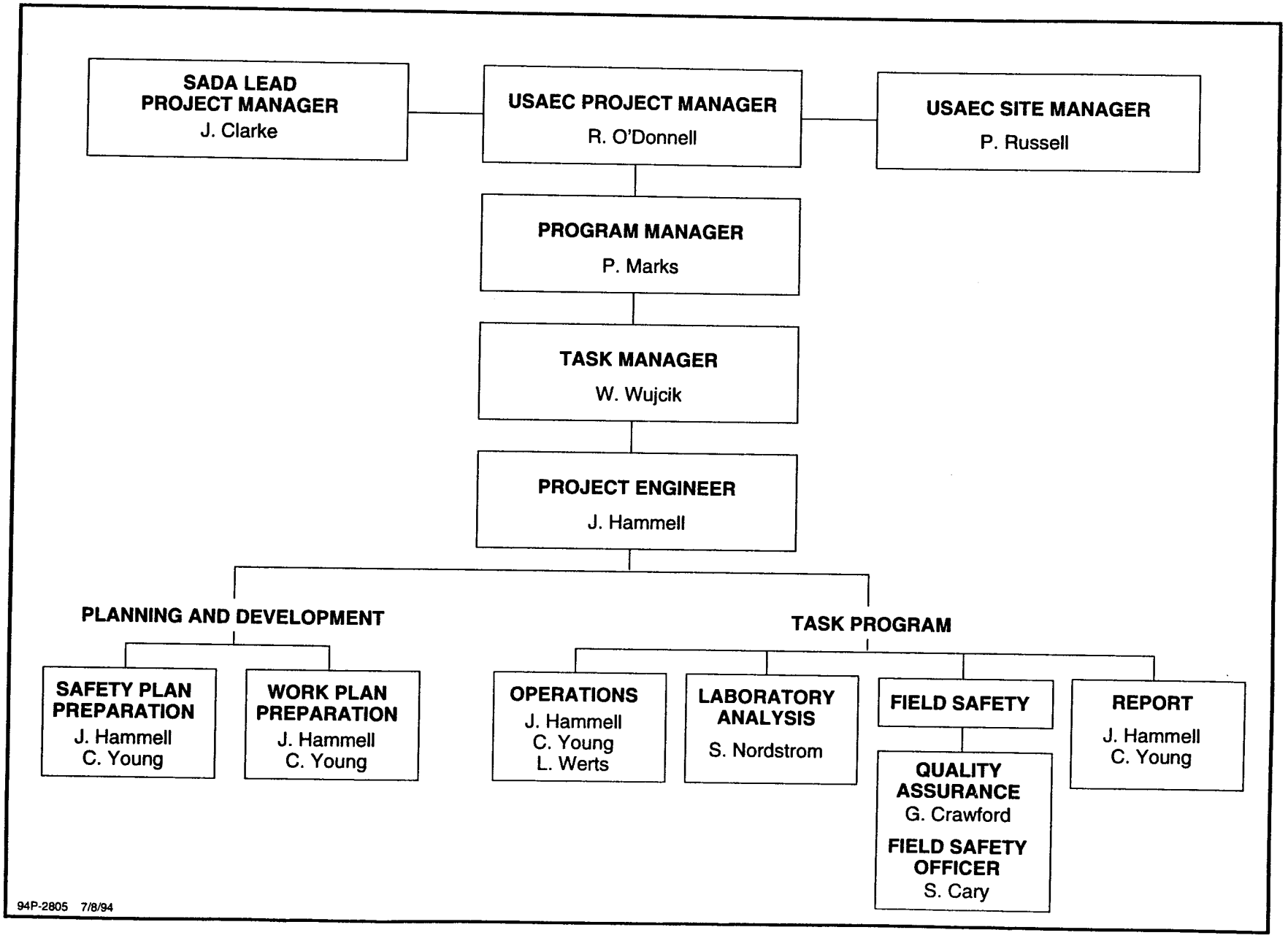

FIGURE 1-1 PROJECT ORGANIZATION CHART

1.4.2 Schedule

A tentative schedule for the completion of all tasks associated with the pilot-scale demonstration of the UV/Ox technology at SADA is presented in Figure 1-2. The Task Order was initiated May 1993. All project activities will be completed during February 1995.

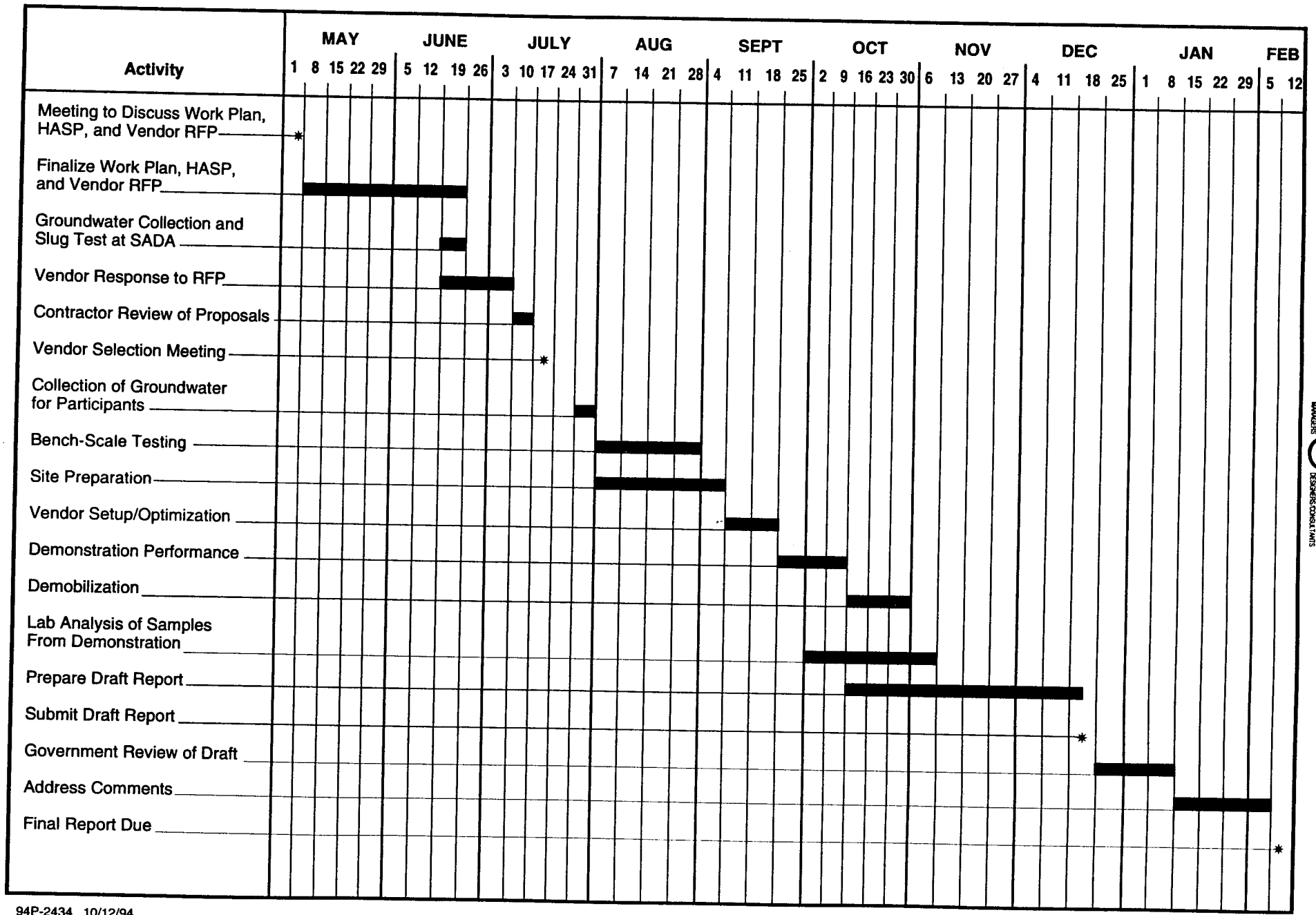

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FIGURE 1-2 UV OXIDATION PILOT - DEMONSTRATION PROJECT SCHEDULE

SECTION 2
PILOT STUDY PROGRAM

2.1 GROUNDWATER CHARACTERISTICS

2.1.1 Contaminants of Concern

The principal contaminants of concern in this pilot-scale demonstration of the UV/Ox process are 2,4,6-trinitrotoluene (TNT) and cyclomethylenetrinitramine (RDX). These compounds have been widely used in the construction of military explosives. Although the U. S. Environmental Protection Agency (EPA) has not promulgated maximum contaminant levels (MCLs) for TNT or RDX in drinking water, health advisory (HA) values for the two substances have been developed. The HA values include a drinking water equivalent level (DWEL) which is the lifetime exposure concentration protective of adverse, non-cancer health effects (assuming all exposure to the contaminant is from a drinking water source). The DWEL values are the lowest of the HA concentration values. The DWEL values for both TNT and RDX are 20 μg/L and 100 μg/L, respectively.

Other constituents of concern are propellant compounds and the breakdown products of TNT. Constituents for which DWEL values have been developed include 2,4-dinitrotoluene (2,4-DNT; 100 μg/L), 2,6-DNT (40 μg/L), and 1,3-dinitrobenzene (1,3-DNB; 5 μg/L). No DWEL values have been developed for the remaining constituents of concern: 2-amino-4,6-DNT (2-A-DNT), nitrobenzene (NB), 1,3,5-trinitrobenzene (1,3,5-TNB), trinitrophenylmethylnitramine (Tetryl), and cyclotetramethylenetetranitramine (HMX).

2.1.2 Other Parameters

Several other parameters have been identified that may potentially affect the performance of UV/Ox systems. Iron and manganese may interfere with UV/Ox efficiency by reducing the transmission of UV light by oxidation and subsequent deposition of precipitates on the surfaces of the UV lamps. Hardness may also produce precipitates (scale) on the lamp surfaces. Alkalinity can reduce process efficiency by depleting the highly reactive hydroxyl

radicals which are the primary agents responsible for the oxidation of organic constituents. The presence of dissolved or suspended humic materials and other organic compounds may also reduce the treatment effectiveness for the target compounds by scavenging the hydroxyl radicals.

2.2 TREATMENT OBJECTIVE

The pilot-scale demonstration of various UV/Ox processes will attempt to treat explosives-contaminated groundwater in the vicinity of the former TNT Washout Facility Leaching Lagoons at SADA to surface water discharge criteria developed by the Illinois Environmental Protection Agency (IEPA). The discharge criteria are shown in Table 2-1.

2.3 STUDY LOCATION

2.3.1 Site Selection

For each of 18 installations with documented groundwater contamination with explosive compounds, average, minimum, and maximum concentration values were determined for each of the five constituents for which there was data available in U. S. Army's Installation Restoration Data Management Information System (IRDMIS) database (note: alkalinity data was available for only 8 of the 18 sites). Once these values were determined, overall averages for the 18 installations were calculated to determine the constituent concentrations of a "representative" groundwater. The results of this study are presented in Table 2-2.

The Savanna Army Depot Activity was selected as the demonstration site. Various factors contributed to SADA's selection. Characteristics of the site which make it suitable for demonstrating the UV/Ox technology include the presence of both TNT and RDX in groundwater, the ongoing RI/FS and IRP activities at the facility, and favorable hydrogeological conditions for obtaining sufficient quantities of contaminated groundwater for treatment.

Table 2-1

UV/Ox System Treatment Criteria

Parameter	Monthly Average (mg/L)	Daily Average (mg/L)
2,4,6-Trinitrotoluene	-	0.007
2,4-Dinitrotoluene	0.003	0.006
2,6-Dinitrotoluene	-	0.009
1,3,5-Trinitrobenzene	-	0.007
Tetryl	-	0.044
HMX	-	0.013
1,3-Dinitrobenzene	-	0.004
2-Amino-4,6-Dinitrotoluene	-	0.036
Nitrobenzene	-	0.010
RDX	-	0.014
pH	-	6 - 9

TABLE 2-2
ULTRAVIOLET/OXIDATION PILOT-SCALE DEMONSTRATION
GROUNDWATER DATA FOR SITE SELECTION
(All values are in µg/l)

INSTALLATION	2,4,6-TNT			RDX			IRON (Fe)			MANGANESE (Mn)			ALKALINITY		
	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.
Alabama AAP	3256.2	27.2	22000.0				3341.8	73.0	12600	133.4	4.1	474.0			
Anniston AD	23.0	23.0	23.0	22.6	4.6	40.6	16725.3	142.0	390000	1628.2	6.0	18000.0			
Cornhusker AAP	298.0	22.0	5290.0	23.5	0.2	371.0	2314.3	116.0	23000	561.4	21.4	3440.0	238018	197	575000
Lexington-Blue Grass	130.0	122.0	138.0	130.3	31.8	200.0									
Iowa AAP	850.0	34.0	2200.0	2050.5	1.3	36000.0	69908.4	75.2	1400000	1394.5	4.7	18000.0			
Joliet AAP - East	898.0	30.0	4710.0	89.6	2.3	640.0	529.6	48.6	5430	136.2	3.4	2260.0			
Joliet AAP - West	981.0	21.1	2600.0	27.5	7.1	52.7	294.4	41.5	2000	198.1	2.9	4220.0			
Lake City AAP	25.0	25.0	25.0	30.0	0.5	1200.0	25150.0	0.0	742000	2015.4	0.0	26900.0	156	27	260
Louisiana AAP	1821.0	22.6	25000.0	1567.8	0.0	43200.0	21608.4	48.4	360000	658.6	6.1	7400.0			
Lone Star AAP	80.0	80.0	80.0	154.0	2.6	1800.0	2437.5	36.1	11000	631.0	6.3	9740.0			
Milan AAP	1900.0	21.3	26000.0	1642.2	0.3	30000.0	11405.2	47.5	230000	563.7	3.4	16000.0	136600	23000	256000
Picatinny Arsenal	220.0	220.0	220.0	9.7	0.7	86.0	8502.6	0.1	149000	847.2	0.0	10200.0	99	42	149
Savanna AD	473.6	24.1	4800.0	11.5	0.0	43.9	4305.8	119.0	12300	1787.3	10.7	18000.0			
Tooele AD - North	37.4	37.4	37.4	56.3	1.0	280.0	14155.9	75.9	77100	238.6	6.6	1060.0	623000	400000	952000
Tooele AD - South	52.5	30.0	77.0	6.9	0.8	15.8	638.7	97.3	1180	513.0	513.0	513.0	257500	255000	260000
Umatilla AD	3235.0	30.7	11000.0	883.8	0.7	10000.0	115.3	46.2	293	47.7	3.0	369.0	77087	142	194000
Volunteer AAP	434.9	21.0	1900.0				645.7	100.0	3900	1572.5	7.8	20000.0			
West Virginia Ordnance Works	2028.1	30.0	20000.0				12766.3	33.5	310000	1039.0	10.5	19000.0	94	37	144
Overall Averages	**930.2**			**447.1**			**11461.5**			**821.5**			**166569**		

2.3.2 Site Background

The site selected for the pilot-scale demonstration of the UV/Ox technology, SADA, is located in northwestern Illinois (Figure 2-1). The SADA site covers 13,172 acres on the eastern bank of the Mississippi River, approximately 12 miles north of Savanna, Illinois. Although most of the facility is located in Jo Daviess County, a small portion at the southern end of the facility is located in Carroll County. Land use in the vicinity of the facility is primarily agricultural. In addition to Savanna, the local communities include Hanover, Illinois to the east and Bellevue, Iowa to the northwest. Officially activated in 1918 as the Savanna Proving Ground, the facility was used as a proof and test facility for 75-millimeter (mm) and 155-mm artillery and ammunition. After the construction of additional ordnance storage facilities, the installation was renamed as the Savanna Ordnance Depot. In 1931, a facility was constructed to renovate and load 155-mm shells and 300-pound bombs. Extensive construction of additional storage magazines, bomb and shell loading facilities, and administration buildings occurred between 1939 and 1941. In 1943, ammunition washout began in the TNT Washout Facility located in the northern portion of the installation (Figure 2-2). Wastewater from the washout operation was discharged to four leaching lagoons. The four leaching lagoons were inactivated in 1961 and two new leaching lagoons were used until operations were discontinued at the TNT Washout Facility in 1969. In 1962 the depot was renamed the Savanna Army Depot under the administration of the U.S. Army Supply and Maintenance Command.

Renovation of 75-, 105-, and 155-mm projectiles filled with mustard agent was performed between 1947 and 1961. Fuse and burster assemblies were removed and reused in high explosive-filled ammunition. The mustard-filled projectiles were shipped to the Rocky Mountain Arsenal or destroyed by burning at SADA.

The U.S. Army Ordnance Ammunition, Surveillance, and Maintenance School commenced at SADA in 1950. In 1959, the installation was designated as a U.S. Army Ordnance Depot. A special ammunition area for assembly, disassembly and storage was operated from 1961 to 1974. The school was redesignated as the Army Material Command Ammunition School

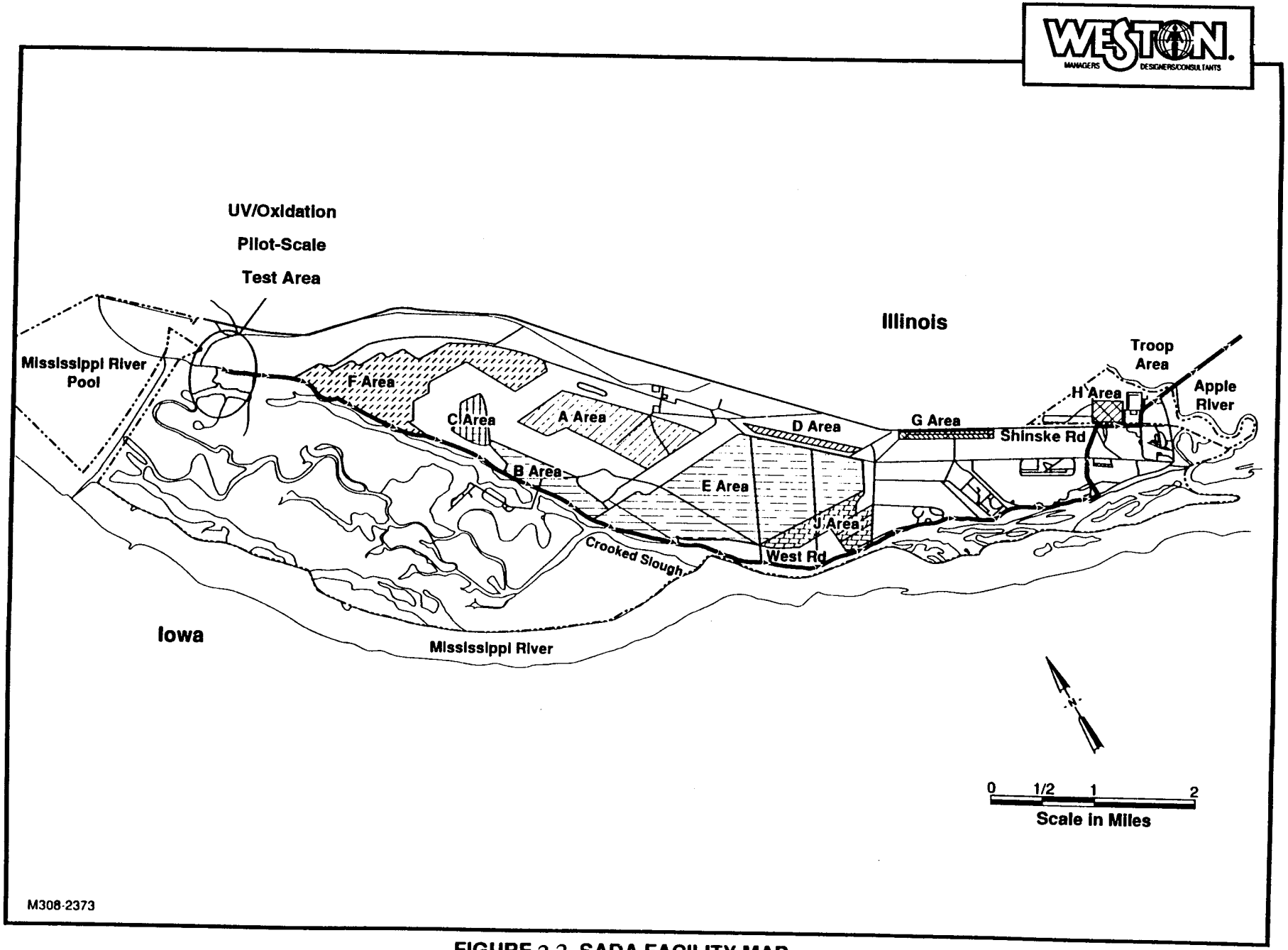


FIGURE 2-2 SADA FACILITY MAP

in 1966 and the U.S. Army Material Development and Readiness Command Ammunition School in 1977.

Currently, a Quality Assurance mission is performed at SADA for conventional ammunition, guided missiles, large rockets, ammunition components, explosives, and packing materials. Other operations at SADA include the fabrication and maintenance of ammunition-specific equipment and the receipt, inspection and storage of equipment.

2.3.3 Nature and Extent of Groundwater Contamination

The UV/Ox pilot-scale demonstration will be located in the vicinity of the TNT Washout Facility at SADA. Past investigations of soil, sediment, surface water, and groundwater contamination from the ammunition washout operations include studies by Environmental Science and Engineering (ESE) in 1982, WESTON in 1984, Hunter/ESE in 1989, and Dames and Moore, in 1990 and 1991. A Remedial Investigation (RI) report on the TNT Washout Facility Lagoons was completed in 1991 (Dames & Moore, 1991). The RI summarized the nature and extent of groundwater contamination from data obtained during previous ESE and Hunter/ESE investigations. The Feasibility Study (FS) for the TNT Washout Facility identified that a removal action, including the excavation of the lower lagoons, the overflow ditch, and the drain trough, should be performed (WESTON, 1991). A Record of Decision (ROD) for the site was approved by EPA and the Illinois Environmental Protection Agency (IEPA) which defined the explosive-contaminated soils associated with the TNT Washout Facility as an Operable Unit and indicated rotary kiln incineration as the approved treatment technology. Approximately 25,000 cubic yards of contaminated soils were subsequently excavated and treated by incineration. Remediation of the contaminated soils at the former TNT Washout Facility was completed in 1993. Contaminated groundwater at SADA is being investigated as part of an installation-wide RI/FS.

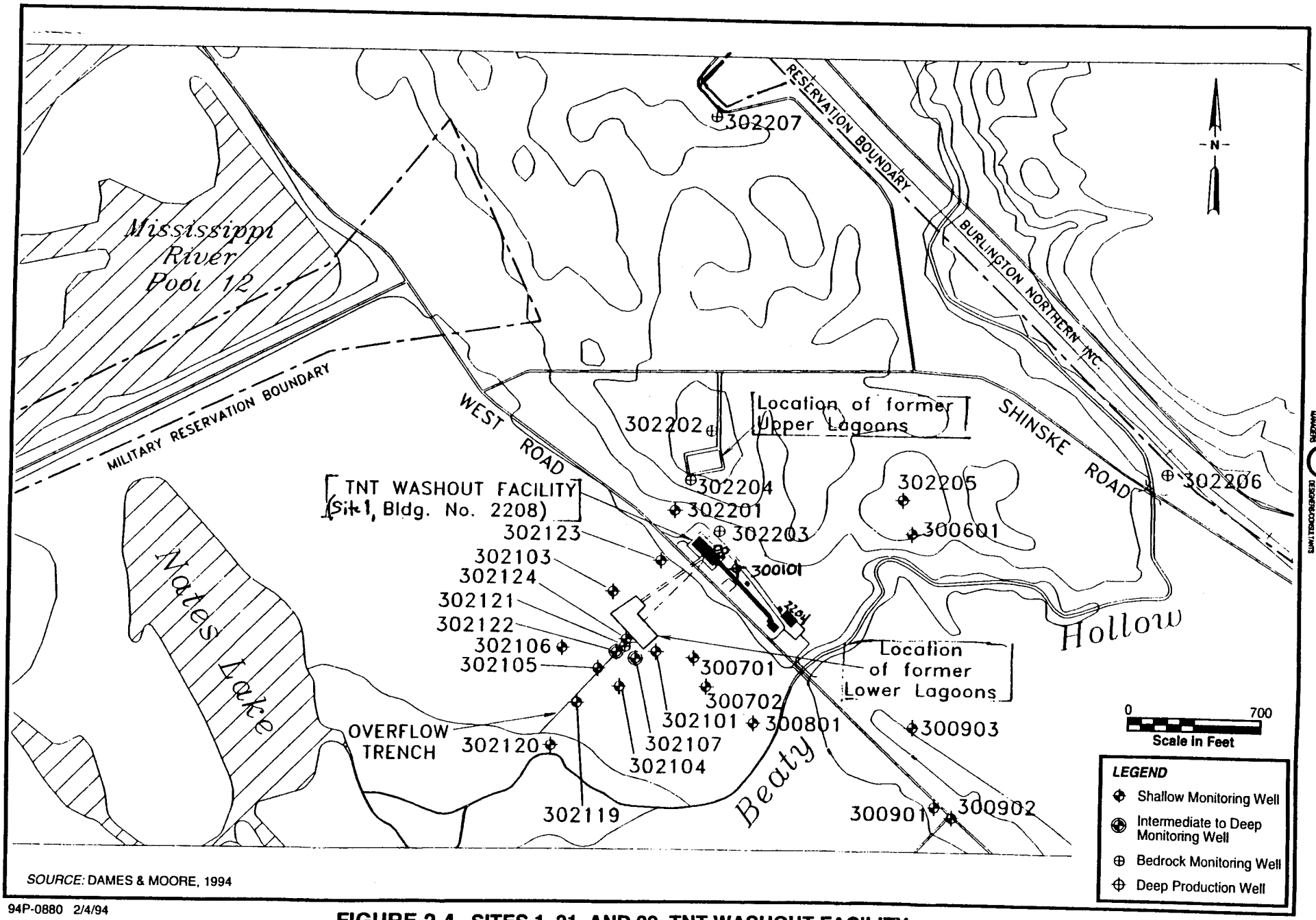
The RI report on the former TNT Washout Facility identified the distribution of contaminated groundwater in the vicinity of the Old and New Leaching Lagoons (Areas 21

and 22, respectively). Figure 2-3 shows the isoconcentration contours of total explosives in the shallow groundwater based on the 1989 Hunter/ESE data. Well 302102, located downgradient of the four Old Leaching Lagoons (Area 21), had the highest concentrations of TNT (3,420 μg/L), 2,4-DNT (246 μg/L), 2,6-DNT (49.4 μg/L), cyclotetramethylenetetranitramine (HMX; reported as > 28.6 μg/L), and Tetryl (226 μg/L) of the wells sampled in the 1989 Hunter/ESE and earlier ESE studies (1982). The highest concentrations of the explosive compound RDX were obtained from wells 302102 and 302105 (reported as > 43.6 μg/L). Well 302102 also contained additional breakdown products: 1,3,5-trinitrobenzene (1,3,5-TNB; 490 μg/L), 1,3-dinitrobenzene (1,3-DNB; 86 μg/L) and nitrobenzene (NB; 7.35 μg/L). In general, concentrations of explosives and breakdown products were lower in the groundwater in the vicinity of the New Leaching Lagoons (Area 22) than the Area 21 groundwater.

Since the completion of the TNT Washout Facility Lagoons RI report, additional wells have been installed in the vicinity of the lagoons and additional chemical characterization and slug tests have been performed by Dames & Moore in support of the facility-wide RI/FS (Eaton, personal communication, 1994). Locations of the additional monitoring wells and the previously installed monitoring wells in Areas 21 and 22 are shown in Figure 2-4. Chemical analysis of groundwater samples collected from wells in the vicinity of the Old Leaching Lagoons in March and May 1993 indicated the following concentration ranges of explosive and propellant compounds and their breakdown products:

- 2,4,6-TNT Non-detect (<0.426) to 830 μg/L.
- 2,4-DNT 0.356 to 79 μg/L.
- 2,6-DNT Non-detect (<0.6) to 79 μg/L.
- 1,3,5-TNB Non-detect (<0.21) to 870 μg/L.
- 1,3-DNB Non-detect (<0.458) to 12.9 μg/L.
- NB Non-detect (<0.645) to 58 μg/L.
- RDX Non-detect (<416) to 5.42 μg/L.

It is anticipated that Well 302124 will be used to supply contaminated groundwater for the UV/Ox demonstration. With the exception of 2,4-DNT which was not detected (at the relatively high detection level of < 90 μg/L) in the most recent round of sampling, well 302124 contained the highest concentrations of the target analytes and their breakdown



SOURCE: DAMES & MOORE, 1994

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FIGURE 2-4 SITES 1, 21, AND 22, TNT WASHOUT FACILITY, GROUNDWATER SAMPLING LOCATIONS

products. The most rece : groundwater data from the RI sampling program is provided in Appendix B.

Based on additional samples collected over the same period by Dames & Moore in the vicinity of the New Leaching lagoons, the concentrations of explosive constituents and their breakdown products in the Area 22 groundwater remain lower than those in the Area 21 groundwater. This is consistent with the findings of the earlier RI report on Areas 21 and 22 (Dames & Moore, 1991).

2.4 HEALTH AND SAFETY

Onsite work performed in conjunction with the UV/Ox pilot-scale demonstration program at SADA will follow the health and safety procedures contained in the site-specific Health and Safety Plan (HASP; WESTON, 1994). The HASP defines the health and safety requirements for field activities occurring at the UV/Ox pilot-scale demonstration program to be conducted at SADA. The HASP outlines the required field activities, presents the hazards associated with these activities, and establishes the protective measures to minimize and manage the hazards. The HASP also details emergency response procedures and field safety requirements.

The HASP will apply to all WESTON, vendor, government, and subcontractor personnel working on this assignment and to visitors at the project work site. All such personnel will be required to sign a statement to the effect that this document has been reviewed, understood, and will be adhered to prior to the start of on-site activities and/or visits to the SADA UV/Ox test site.

2.5 PILOT-SCALE DEMONSTRATION

2.5.1 Selection of UV/Ox Process Subcontractors

The pilot-scale demonstration of the UV/Ox technology for treating explosives-contaminated groundwater at SADA will include up to four different advanced oxidation processes. Four

commercial systems will perform concurrent treatment of groundwater during the three week demonstration. The following list contains the commercial system vendors that received Requests for Proposals (RFP) to participate in this program and a brief description of their processes:

- Solarchem, Inc. - High-intensity UV lamps with the addition of ozone and hydrogen peroxide as oxidants.
- Vulcan Peroxidation Systems, Inc. (VPSI) - High-intensity UV lamps with hydrogen peroxide as the oxidant.
- Ultrox, Inc. - Low-intensity UV lamps with hydrogen peroxide and/or ozone as the oxidants.
- Matrix Photocatalytics, Inc. - Low-intensity UV lamps with a titanium dioxide catalyst.
- Purifics Environmental Technologies, Inc. - Low-intensity UV lamps with a titanium dioxide catalyst.
- Magnum Water Technology, Inc. - UV lamps and hydrodynamic cavitation to form hydroxyl radicals. Hydrogen peroxide may also be used as a supplemental oxidant for certain contaminants.
- Sun River Innovations, Inc. - UV lamps with ozone as the oxidant. In addition to treating the aqueous stream, the process also incorporates air phase treatment of volatile constituents by means of air stripping with UV irradiation and GAC polishing of the post-treatment air stream.

In addition to receiving an RFP for the pilot-scale demonstration program, WESTON supplied each vendor with a sufficient quantity of explosives-contaminated groundwater from the SADA site for sample characterization in support of proposal preparation. The groundwater samples were collected by WESTON from the well 302124, designated for use during the demonstration program, and shipped to the vendors in compliance with all applicable federal, state, and local regulations. In addition to chemical characterization sampling, rising head/falling head slug tests were performed on the prospective recovery well (302124) by WESTON geologists to ascertain that sufficient yield will available for the test program.

WESTON reviewed the proposals received from the vendors in response to the RFP for performing the bench-scale and pilot-scale testing. The technical approach and understanding of the advanced oxidation process as applied to the treatment of explosives compounds was evaluated. WESTON made recommendations on those vendor processes which best demonstrated the capability to effectively and economically destroy the target compounds. The rationale for the vendor recommendations was summarized in a letter to USAEC. A vendor selection meeting was held at USAEC and the final list of participating vendors was approved. WESTON contacted each of the selected vendors to notify them of their inclusion in the demonstration program and to determine the volume of SADA groundwater necessary for the conduct of bench-scale treatability studies. WESTON subsequently collected and shipped the necessary samples to the participants.

The following four vendors were selected for the UV/Ox pilot scale demonstration program:

- Purifics Environmental Technologies, Inc.
- Solarchem, Inc.
- Ultrox, Inc.
- Vulcan Peroxidation Systems, Inc. (VPSI)

Process description summaries for the pilot-scale treatment systems were obtained from the vendor proposals. The Purifics system is based upon a photocatalytic oxidation/reduction process using low intensity UV lamps with a closed loop titanium dioxide (TiO_2) slurry design. Continuous separation of the TiO_2 catalyst from the slurry with recycle to the influent stream is used. The Solarchem system uses high intensity UV lamps with the addition of ozone (Rayox® process) for the destruction of explosive compounds. The Ultrox® process utilizes low intensity UV lamps with the addition of ozone as an oxidant for the destruction of explosive compounds. The VPSI perox-pure™ process utilizes high intensity UV lamps with the addition of hydrogen peroxide as an oxidant. All of the vendor processes incorporate pH adjustment as part of their process to achieve optimal treatment of the target contaminants.

2.5.2 PRECONSTRUCTION MEETING

Prior to mobilizing and performing site preparation activities, a preconstruction meeting was held at the SADA site. Representatives from SADA, USAEC, and WESTON attended the preconstruction meeting and planned the mobilization and performance of the pilot-scale test. Issues such as base security, site access, health and safety procedures, installation of the electrical components by SADA electricians, regulatory agency interface, project schedule, demobilization, and site restoration were discussed at the meeting.

2.5.3 MOBILIZATION

Prior to the conduct of the three week demonstration period and concurrent with the vendor bench-scale treatability studies, WESTON will perform various mobilization activities to prepare the site. The analytical results from chemical characterization samples and the findings from the slug tests on the proposed recovery well will be evaluated to determine whether the proposed recovery well is capable of providing a sufficient supply of explosives-contaminated groundwater for the pilot-scale test program. If the results of the initial testing indicate that the proposed recovery well is inadequate for the pilot-scale program, additional sampling, slug or pump testing of alternate wells may be necessary. WESTON will advise USAEC of any problems identified after evaluating the initial data and will assist in the development and implementation of any corrective action necessary to ensure the successful performance of the test program.

Site preparation activities will include the purchase and/or rental of equipment, coordination with USAEC, SADA, participating vendors and appropriate government officials and agencies, installation of groundwater pumps, distribution system piping, groundwater storage tank, a granular activated carbon (GAC) polishing system, electrical switching boxes, circuit breakers, and meters and the acquisition of an office trailer, phone services, and portable sanitary facilities.

The UV/Ox pilot-scale test systems will be installed at an existing 90 ft by 90 ft concrete pad with roof located adjacent to the former TNT Washout Facility. An area of approximately 30 ft by 90 ft will be used for the groundwater storage tank, the GAC polishing system, and any ancillary support equipment. Each vendor will be allotted a space of approximately 30 ft by 30 ft for test system installation. A sketch of the pilot testing area is shown in Figure 2-5. Electrical service for the pilot equipment will be supplied by SADA based on electrical requirements supplied by WESTON. Preliminary electrical requirements obtained from the potential participants range from 110 amperes (amps) at 120 volts alternating current (VAC) to 150 amps at 480 VAC (3-phase). Microprocessor-based meters will be provided to monitor electrical power consumption by each of the pilot systems. Potable water will be provided for equipment cooling purposes.

It is anticipated that one or more of the existing Area 21 monitoring wells will be used to provide groundwater for treatment during the demonstration program. If necessary, pumps will be installed in the each of the recovery wells and a manifold will be installed to supply the influent holding tank with contaminated groundwater. Groundwater from the influent holding tank will be delivered to a distribution manifold by a pump with pressure regulation between 40 and 60 pounds per square inch (psi). The pump will provide a maximum flow of 50 gpm of groundwater to the pilot systems. The distribution manifold will contain a shutoff valve, sample tap for collecting influent samples common to all vendor systems, pressure gauge, and up to six supply lines. Each supply line will include a flow totalizer, flowmeter, check valve, shutoff valve, and flanged fitting for pilot system connection.

Post-treatment effluent from each of the pilot-scale UV/Ox systems will be conveyed to a GAC polishing system for further treatment prior to discharge to Beaty Hollow Creek (see Subsection 2.8.1). Effluent from the individual systems will be discharged under pressure to an effluent holding tank. Each discharge line will include a check valve, shutoff valve, and a sample tap. The contents of the effluent holding tank will pumped through the GAC polishing system by a level-controlled pump. After polishing, the final effluent will discharge by gravity to Beaty Hollow Creek.

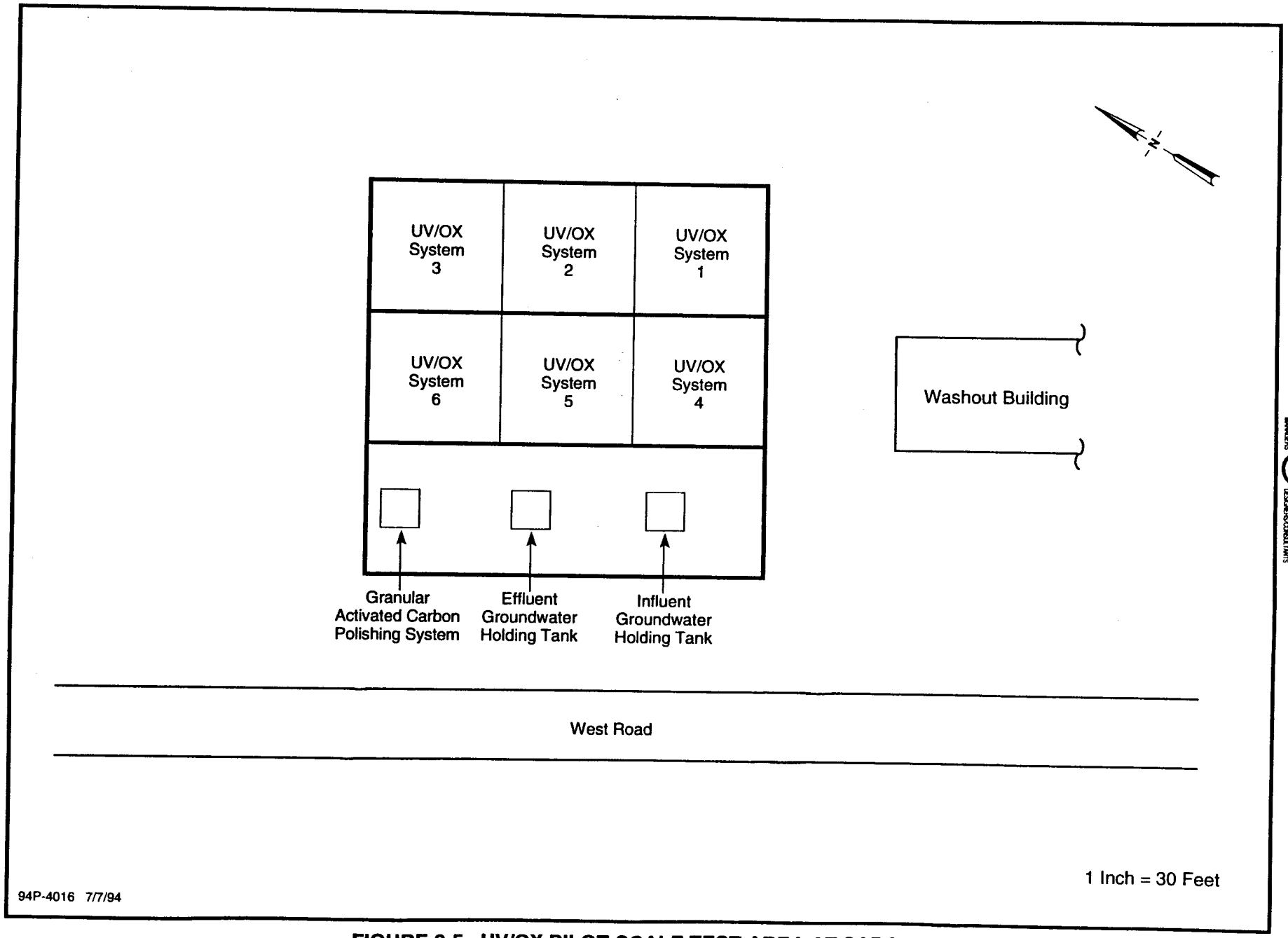


FIGURE 2-5 UV/OX PILOT-SCALE TEST AREA AT SADA

2.5.4 Pilot-Scale Testing

Upon completion of site mobilization activities, system installation, system startup, and optimization will be conducted by the vendors over a one week period. Optimization will consist of vendor operation of the pilot-scale systems with adjustments to the flow rate, and, where applicable, to the dosage of any oxidants, catalysts, and/or chemicals. The performance of the UV/Ox systems will be optimized to maximize the destruction of explosive constituents and their breakdown compounds. Field test kits will be used by WESTON field engineers to monitor influent and effluent concentrations of TNT in order to assist in UV/Ox system optimization (see Subsections 2.6 and 2.7). The vendors may arrange for the analysis of explosives compounds or other constituents to provide additional data for system optimization. In addition to optimizing the systems to achieve reductions of explosive and breakdown compounds in system effluent to concentrations below the discharge criteria, the vendors will attempt to optimize electrical consumption and chemical addition.

Upon completion of the optimization period, the pilot-scale demonstration will be performed on an operation schedule of five 8-hour days per week over a three week period. During the pilot-scale testing, various aspects of the vendor systems will be monitored. One WESTON engineer for every two participants will observe and document the daily operation and maintenance of the UV/Ox systems. Daily electrical power usage, influent flowrates, chemical and/or catalyst additions, any pretreatment implemented, and any system upsets, downtime, or process modifications will be documented by the WESTON field engineers by means of logbook notes, photographs, and video tape. WESTON field engineers will also perform all sampling and analysis specified in Subsections 2.6 and 2.7 of this Work Plan and will ship the samples to the approved laboratory for analysis.

In addition, a WESTON engineer/scientist will be designated as the onsite health and safety officer to ensure that the demonstration is conducted with the site-specific Health and Safety Plan (HASP) developed for the pilot-scale test program. Additional information on health

and safety is provided in Subsection 2.4 of this Work Plan and in the HASP (WESTON, 1994).

2.5.5 Demobilization

Upon completion of the three week pilot-scale UV/Ox demonstration, the following demobilization activities will be performed:

- Treatment of any residual groundwater contained in the influent and effluent holding tanks.
- Decontamination and removal of the influent and effluent holding tanks.
- Decontamination of any spill areas.
- Disposal of explosives-contaminated spent carbon from GAC polishing system.
- Disassembly and demobilization of vendor pilot units.
- Removal of all temporary utility services (electric and telephone).
- Return of all support facilities such as the office trailer and portable sanitary facilities.
- Meeting with SADA personnel to verify completion of demobilization and restoration of the site.

Upon the completion of demobilization of the pilot-scale UV/Ox demonstration study, a summary report will be prepared documenting the demobilization and site restoration activities (see Subsection 4.1). This demobilization report will be provided to USAEC and SADA.

2.6 SAMPLING PROTOCOL

2.6.1 Sampling Procedures and Sample Handling

Prior to the commencement of the onsite program, groundwater samples from the SADA demonstration site will be collected by WESTON and shipped to the vendors for preliminary characterization. Prior to collection and shipment of the characterization samples,

WESTON will contact the vendors to determine whether they want characterization samples for use in proposal preparation. Groundwater samples will be collected using a decontaminated bailer. The groundwater samples will be transferred to appropriately labeled, precleaned sample containers and preserved as required. Sample containers will then be placed in a sealed plastic bag and packed in an iced cooler for shipment to the vendors or the analytical laboratory. Prior to shipment of the samples, a Chain-of-Custody (COC) form will be completed. This form must be completed in ink and shall include the following information:

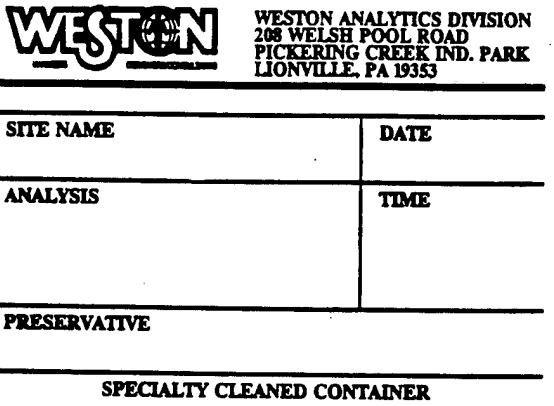
- Project name and number.
- Sample description and location.
- Sample identification numbers.
- Number of sample containers.
- Date and time of collection.
- Types of analyses for each sample.
- Sample preservation.

Upon transfer of possession of the samples, the person transferring the samples and the person accepting the samples must each sign and date the COC form. A typical sample label and COC form are shown in Figures 2-6 and 2-7, respectively. Samples will be shipped to the analytical laboratory in conformance with the QA/QC procedures (see Subsection 2.6.2) and within the holding times.

Additional sampling of the groundwater will be subsequently performed to obtain and ship a sufficient volume of batch samples for vendor bench-scale testing. These samples and those samples collected for system performance evaluation and effluent compliance monitoring during the conduct of the demonstration program will be collected and handled in accordance with the above-mentioned procedures. Additional information on the sampling and analysis of groundwater and post-treatment effluent samples is provided in subsection 2.7 and the QAPP (Appendix A).

FIGURE 2-6

TYPICAL SAMPLE LABEL



WESTON Analytics Use Only

Custody Transfer Record/Lab Work Request

WESTON MANAGERS DESIGNERS/CONSULTANTS

Page ____ of ____

Client _____

Est. Final Proj. Sampling Date _____

Work Order # _____

Project Contact/Phone # _____

AD Project Manager _____

QC _____ Del _____ TAT _____

Date Rec'd _____ Date Due _____

Account # _____

Refrigerator #

#/Type Container	Liquid	
	Solid	
Volume	Liquid	
	Solid	
Preservatives		

ANALYSES REQUESTED →

ORGANIC: VOA | BNA | Pest/PCB | Herb

INORG: Metal | CN

MATRIX CODES:
S - Soil
SE - Sediment
SO - Solid
SL - Sludge
W - Water
O - Oil
A - Air
DS - Drum Solids
DL - Drum Liquids
L - EP/TCLP Leachate
WI - Wipe
X - Other
F - Fish

Lab ID	Client ID/Description	Matrix QC Chosen (✓) MS	MSD	Matrix	Date Collected	Time Collected	WESTON Analytics Use Only

FIELD PERSONNEL: COMPLETE ONLY SHADED AREAS

Special Instructions:

DATE/REVISIONS:

1. _____
2. _____
3. _____
4. _____
5. _____
6. _____

Relinquished by	Received by	Date	Time

Relinquished by	Received by	Date	Time

WESTON Analytics Use Only

Samples were:
1) Shipped ___ or Hand Delivered ___
Airbill # _____
2) Ambient or Chilled
3) Received in Good Condition Y or N
4) Labels Indicate Properly Preserved Y or N
5) Received Within Holding Times Y or N

COC Tape was:
1) Present on Outer Package Y or N
2) Unbroken on Outer Package Y or N
3) Present on Sample Y or N
4) Unbroken on Sample Y or N

COC Record Present Upon Sample Rec't Y or N

Discrepancies Between Samples Labels and COC Record? Y or N
NOTES:

RFW 21-21-001/A-7/91

____ L372 ____ L373 ____ L375 ____ L377 ____ L378 Ref# _____ Cooler# _____

381-596a

FIGURE 2-7
CHAIN OF CUSTODY FORM

2.6.2 Quality Assurance/Quality Control (QA/QC)

2.6.2.1 Decontamination Procedures

To prevent cross-contamination of samples, all sampling equipment that comes into direct contact with the samples will be decontaminated prior to reuse at the sampling location or use at an alternate sampling location. Decontamination procedures shall be as follows:

- Rinse equipment with tap water.
- Steam clean.
- Rinse thoroughly with deionized water.

All rinse wastes from decontamination of equipment will be contained and discharged to the effluent holding tank for treatment by the GAC polishing units prior to discharge to the receiving stream.

2.6.2.2 Quality Control Samples

Standard analytical laboratory QC procedures, including method blanks, blank spikes, and blank spike duplicates will be performed on samples analyzed at the WESTON Analytics laboratory. If a matrix spike/spike duplicate (MS/MSD) set is analyzed, the laboratory also analyze a laboratory blank and blank spike sample with each analytical batch. If no MS/MSD is analyzed, the laboratory will analyze a laboratory blank, blank spike, and blank spike duplicate with each analytical batch. Additional information on QC procedures is contained in the QAPP (Appendix A).

Field QC samples will include splits or replicates of field samples and rinsate blanks. QC splits of the sample will be collected and introduced into the sample flow in an inconspicuous fashion. A minimum of one duplicate and one MS/MSD sample will be performed daily. If sampling equipment is reused at additional sampling locations, field rinsate blanks will be collected after sampling equipment decontamination.

2.7 SAMPLING AND ANALYSIS

2.7.1 Field Analyses

Field analyses will be performed at the pilot-scale demonstration site for the following parameters: 2,4,6-TNT; pH; and temperature. The test method for 2,4,6-TNT will be the immunoassay-based D TECH field test kit manufactured by EM Science/Strategic Diagnostics, Inc. of Gibbstown, New Jersey or equivalent. The D TECH TNT field test method is capable of detecting TNT at concentrations ranging from 5 to 50 μg/L. A portable pH meter will be used to measure pH in the field.

Split samples of the groundwater collected during the initial characterization sampling will be shipped to the WESTON Lionville Laboratory to be analyzed for explosives and other parameters. In addition, a groundwater sample will be analyzed onsite for pH and TNT by the D TECH field test method and the results recorded in a field logbook. The TNT results obtained by the D TECH field test method will be subsequently compared with the results obtained for TNT by analysis using EPA Method 8330 at the WESTON laboratory.

The results from the field analyses are intended for use by WES and the vendors in optimizing system performance during the system optimization period and the three week test program. However, since the D TECH field method does not respond to the other nitroaromatic compounds, additional analyses may be necessary for the optimization process. The vendors will be responsible for sampling and analyzing the effluent for any other explosives or other regulated constituents during the optimization period.

It is anticipated that approximately 500 samples will analyzed by the field test method during the onsite demonstration. In addition, the field test method will be used to test the effluent from the post-treatment GAC polishing units for monitoring compliance with the effluent limits.

2.7.2 WESTON Analytics

The analytical laboratory for the UV/Ox demonstration study will be WESTON Analytics at 208 Welsh Pool Road, Lionville, PA 19341. The analyte-specific test methods, sample containers, preservatives, and maximum holding times are provided in Table 2-3. Each sample of pretreatment and post-treatment groundwater will be analyzed for the following parameters: 2,4,6-TNT; 2,4-DNT; 2,6-DNT; 2-A-4,6-DNT; 1,3,5-TNB; 1,3-DNB; NB; RDX; HMX; and Tetryl by EPA Method 8330 using second column confirmation, where necessary to confirm positives. Twenty (20) samples of pretreatment groundwater will be analyzed for iron, manganese, alkalinity, and hardness. A summary of the sampling and analysis to be performed during the UV/Ox pilot testing period is provided in Table 2-4. Upon completion of analyses, WESTON Analytics will provide analytical data sheets summarizing the concentrations of the specific analytes.

2.7.3 Vendor Sample Splits

If desired, vendors may obtain split samples of any of the samples collected by WESTON for performance analysis of the vendors' UV/Ox system. Any split samples which are taken by vendors may be independently analyzed at the vendors' analytical laboratory. Any vendor split samples must be analyzed by the same analytical methods and QA/QC procedures specified in this Work Plan and QAPP.

2.8 RESIDUALS MANAGEMENT

2.8.1 Post-Treatment Effluent

This project is intended to demonstrate the feasibility of the UV/Ox technology for treating explosives-contaminated groundwater by parallel testing of multiple pilot-scale systems. The UV/Ox systems will require optimization during startup and operation and may experience upsets or incomplete destruction of the target compounds. Consequently, post-treatment effluent from the pilot-scale systems may contain residual explosives. In order to ensure that explosives are eliminated from the combined post-treatment effluent from the systems, a

Table 2-3

Analytical Methods, Containers, Preservation, and Holding Times

Parameter	Method	Container	Preservation	Maximum Holding Time
Explosives: 2,4,6-TNT, 2,4-DNT, 2,6-DNT, 2-A-4, 6-DNT, 1,3,5-TNB, 1,3-DNB, NB, RDX, HMX, and Tetryl	8330	(2) 1 L Glass	Cool to 4°C	7 days extraction 40 days analysis
Iron and manganese	6010	500 mL Polyethylene	HNO_3	6 months
Alkalinity (as $CaCO_3$)	310.1	250 mL Polyethylene	NONE	14 days
Hardness (as $CaCO_3$)	130.2	250 mL Polyethylene	H_2SO_4	6 months
pH	150.1		None required	Analyze immediately

Table 2-4

Sampling and Analysis Summary

Parameter	Test Samples	Duplicates	MS/MSD	Total
Characterization				
Explosives	2	1	1	4
Iron, manganese, alkalinity, hardness	2	1	1	4
Optimization Period				
TNT*	90			90
Test Period				
Explosives	353	20	18	391
TNT*	360			360
Iron, manganese, alkalinity, hardness	10	3	2	15
GAC Effluent Monitoring				
Explosives	5			5
TNT*	25			25
Decontamination Confirmatory				
TNT*	25			25

* TNT determinations will be performed in the field using the D TECH field test method. All other analyses will be performed at the WESTON Analytics Laboratory in Lionville, PA.

GAC polishing system will be installed and operated during the demonstration program. All explosives-contaminated wastewaters, including decontamination solutions and rinsates, will be treated by the GAC polishing system prior to discharge. The effluent from the GAC polishing system will be discharged to Beaty Hollow Creek at its intersection with West Road. Periodic testing will be performed on the final effluent using the D TECH TNT field test method. If TNT is detected by the field test kit, the UV/Ox systems will be shutdown to cease the discharge of effluent until corrective action can be taken. A sample of the GAC effluent will be collected once weekly for explosives analysis by EPA Method 8330. The discharge procedure, effluent limits, and compliance monitoring method may be modified based on regulatory agency (EPA and IEPA) requirements.

2.8.2 Other Residuals

Upon completion of the demonstration program, spent carbon from the GAC polishing system will be shipped off-site for regeneration or disposal at a RCRA-permitted treatment, storage, or disposal facility (TSDF). With the exception of the explosives-contaminated groundwater and decontamination fluids which will be treated by the GAC polishing system and discharged during and prior to demobilization, aqueous or solid hazardous wastes generated during the program will also be treated and/or disposed at a RCRA-permitted TSDF.

SECTION 3

DATA MANAGEMENT AND ANALYSIS

3.1 TECHNICAL DATA

3.1.1 Data Management

Analytical data will be collected at various times throughout the demonstration program. Results of field testing of the UV/Ox systems influent and effluent and GAC polishing system effluent concentrations of TNT and other parameters will be recorded in bound field logbooks along with the sample location and time of sample collection and analysis. The field testing results and the results from offsite analysis of samples by WESTON Analytics will be entered into spreadsheets for subsequent evaluation.

3.1.2 Analysis of Technical Data

The analytical data obtained from field and laboratory testing will be evaluated to determine the effectiveness of each of the systems in destroying explosives compounds. Treatment effectiveness will be determined by calculating the destruction removal efficiency (DRE). The DRE for each of the UV/Ox test systems will be calculated from the influent and effluent concentrations of explosives compounds in accordance with the following equation:

$$\text{DRE (in \%)} = \frac{\text{Influent Concentration - Effluent Concentration}}{\text{Influent Concentration}} \text{X } 100$$

Minimum, maximum, and mean DREs over the test period will be identified for each of the test systems to characterize process variability.

In addition to comparing treatment effectiveness between the vendor systems, the effluent concentrations of explosives from individual vendor systems over the duration of the test period will be examined to determine whether performance variations occur due to factors such as scaling on the UV lamps, changes in flow rate, and other system modifications or

upsets. Minimum, maximum, and mean effluent concentrations of the target constituents will also be tabulated and evaluated. These values will be compared with the treatment criteria contained in Table 2-1, the projected treatment levels estimated by each of the vendors on the basis of the bench-scale testing, and the influent concentrations of the target constituents. Other parameters which will be examined include the residual concentration vs. oxidant and electrical usage.

3.2 ECONOMIC DATA

3.2.1 Data Management

Daily electrical power usage, influent flowrates, chemical and/or catalyst additions, any pretreatment implemented, and any system upsets, downtime, or process modifications will be documented by the WESTON field engineers by means of logbook notes, photographs, and video tape for subsequent evaluation. In addition, the relative labor intensity associated with UV/Ox system operation and maintenance (O&M) requirements will also be documented. These labor inputs may consist of items such as routine adjustment to system controls, excessive cleaning requirements for the UV lamps, and system restarts after shutdown.

3.2.2 Analysis of Economic Data

Information on O&M costs associated with electrical power consumption, chemical and/or catalyst additions, and the repair or replacement of system components and the volume of groundwater treated during the demonstration will be tabulated. The cost per gallon of groundwater treated by each of the vendor systems will be compared to determine their relative performance. These data will be used to develop estimates of the life-cycle cost for each of the UV/Ox pilot-scale systems and projections of the life-cycle costs for full-scale implementation of UV/Ox systems for remediating explosives-contaminated groundwater.

In addition, the economic information obtained from the pilot-scale testing of each of the vendor systems will be compared with the estimated treatment costs provided by the vendors

on the basis of their bench-scale treatability testing. The accuracy of the bench-scale estimates prepared by the vendors and the extent to which the pilot-scale systems meet their projected treatment levels will be evaluated. System reliability will be evaluated on the basis of the amount of downtime occurring during the scheduled 8-hour treatment periods. The amount of system maintenance required before and after the scheduled treatment day will also be considered in the assessment of system reliability and availability.

SECTION 4

REPORTS

4.1 DEMOBILIZATION REPORT

Upon the completion of demobilization of the pilot-scale UV/Ox demonstration study, a summary report will be prepared documenting the demobilization and site restoration activities. The demobilization report will be provided to USAEC and SADA. This report will include information on the following demobilization tasks:

- Treatment and disposal of any residual groundwater contained in the equalization tank.
- Decontamination of any spill areas, if applicable.
- Disposal of the explosives-contaminated spent carbon from the GAC polishing system
- Removal of all temporary utilities.
- The return of support facilities.
- Restoration of the site.
- Results of the demobilization meeting with SADA personnel.

4.2 DRAFT FINAL AND FINAL REPORTS

A draft final report will be prepared on the onsite UV/Ox demonstration study. The report will describe the extent to which the study achieves the following objectives:

- Demonstrating the technical and cost effectiveness of commercially available UV/Ox treatment systems.
- Determining which UV/Ox system can best provide for the economical, efficient, and reliable treatment of explosives-contaminated groundwater.
- Evaluating the accuracy of bench-scale and pilot-scale assessments for cost and design considerations for full-scale implementation.

This report will document any and all materials, methods, and results of the bench-scale treatability studies and the pilot-scale demonstration testing performed by each of the vendors. The report will include a comparison of the analytical and operating data from the vendor systems obtained during the pilot-scale test period. Pilot-scale testing results will be compared with the bench-scale testing results. Performance variations and system upsets observed during the pilot-scale testing will also be discussed and, where possible, the causative factors will be identified.

In addition to an evaluation of the treatment effectiveness of the UV/Ox systems, the report will contain an updated life-cycle cost estimate for each of the processes tested. These cost estimates will be based upon data collected during the demonstration program on UV/Ox system electrical power consumption, chemical and/or catalyst additions, repair or replacement of system components, and the volume of groundwater treated. The accuracy of vendor cost estimates prepared on the basis of bench-scale testing will be compared with the revised vendor cost estimates after pilot-scale testing. The report will contain an analysis of the need for pilot-scale testing, in addition to bench-scale testing, for the evaluation, selection, and design of commercial UV/Ox systems for full-scale implementation for remediating explosives-contaminated groundwater. Based on the operational experience obtained from the pilot-scale testing, a general description of recommended full-scale implementation procedures for UV/Ox systems for the treatment of explosives contaminated groundwater will be provided.

Comments received from USAEC on the draft final report will be addressed and incorporated in the Final Report.

SECTION 5

REFERENCES

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APPENDIX A

QUALITY ASSURANCE PROJECT PLAN (QAPP)

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SECTION A1
INTRODUCTION

A1.1 PROJECT DESCRIPTION

As described previously in Section 1 of the Work Plan, the U.S. Army Environmental Center (USAEC) is investigating the technical feasibility and cost effectiveness of ultraviolet oxidation (UV/Ox) technologies for the treatment of explosives-contaminated groundwater. USAEC will conduct a pilot-scale demonstration of up to five commercially available UV/Ox treatment systems, plus an additional system developed by the Waterways Experiment Station (WES). Based on a variety of factors including favorable hydrogeological conditions and the presence of TNT and RDX in the groundwater, Savanna Army Depot Activity (SADA) was selected by USAEC as the site of this demonstration. Initially, WES and each participating commercial vendor will be required to conduct bench-scale testing of their respective systems to assist them in sizing and design of their pilot-scale systems. Once the bench-scale testing is completed, the pilot-scale treatment systems will be mobilized to SADA, where the participants will concurrently demonstrate their respective treatment systems by treating groundwater from a selected well at SADA. Daily samples will be taken to verify the extent of explosives removal being provided by each system. Additional process parameters including energy consumption, chemical additives, and waste generations will also be monitored and documented.

A1.2 PURPOSE OF THE QUALITY ASSURANCE PROJECT PLAN

The primary objective of this Quality Assurance Project Plan (QAPP) is to ensure that the analytical data generated during the performance of the pilot demonstration will be reliable and suitable for the evaluation of the individual UV/Ox systems. The QAPP is applicable to all activities described in the Work Plan and is intended to establish the overall project quality assurance. This QAPP describes the organization, policies, and procedures that will be implemented by both project management and field personnel during the performance of the UV/Ox demonstration.

SECTION A2

PROJECT ORGANIZATION

A2.1 PROGRAM MANAGER

The Program Manager is ultimately responsible for ensuring the quality of all aspects of the project. The Program Manager for the UV/Ox demonstration at SADA is Mr. Peter Marks. Mr. Marks has the authority to cease any of the activities in the program when those activities jeopardize the quality of the effort. He also has the authority to commit the necessary resources to the program to ensure that the reliability of results adequately meets the requirements set forth in the Work Plan and in this QAPP.

A2.2 TASK MANAGER

The Task Manager is responsible for ensuring that the policies and procedures outlined in the various plans associated with this project are implemented on a daily basis. The Task Manager for this project is Mr. Walter Wujcik. He has the authority to cease operations; to reject policies, procedures, recommendations, data, and conclusions when the quality of the results is questionable; and to assign the necessary time, materials, and resources to perform the tasks to ensure the timely delivery of quality results.

A2.3 PROJECT ENGINEER

The Project Engineers will oversee the field effort associated with the UV/Ox demonstration and will confirm that field personnel are implementing the correct procedures for collecting samples, conducting field analyses, shipping laboratory samples, and documenting site activities. The Project Engineers will correspond with the Task Manager on a daily basis to discuss the project status and will consult with the Task Manager whenever difficulties are encountered at the site. The Project Engineers for the UV/Ox demonstration at SADA will be Mr. John Hammell and Mr. Charles Young.

A2.4 CORPORATE HEALTH AND SAFETY OFFICER

WESTON's Corporate Health and Safety Officer is Mr. George Crawford. Mr. Crawford will ensure that all chemical-specific, site-specific, and action-specific hazards that will be

present during the performance of the demonstration have been adequately addressed in the Site Health and Safety Plan. In addition, Mr. Crawford will serve as the point of contact for the Field Safety Officer, if and when any unforseen health and safety issues should arise at the site.

A2.5 FIELD SAFETY OFFICER

The Field Safety Officer (FSO) for the UV/Ox demonstration will be Ms. Sharon Cary. Ms. Cary will ensure that the health and safety procedures presented in the project Health and Safety Plan (HASP) are implemented on a daily basis by all WESTON and subcontracted personnel. Alternate FSOs for the project include John Hammell and Charles Young.

A2.6 ANALYTICAL QA COORDINATOR

The Analytical QA Coordinator is Ms. Sharon Nordstrom. Ms. Nordstrom will ensure that the analytical procedures specified in the Work Plan and in this QAPP are implemented for all samples collected for laboratory analysis under this program. Ms. Nordstrom will schedule laboratory analyses such that holding times are not exceeded, and will review and approve all laboratory reports generated under this program. In addition, Ms. Nordstrom will be consulted when laboratory questions, discrepancies, or problems arise.

SECTION A3

SAMPLING PROTOCOL

The sampling to be performed in association with the UV/Ox demonstration consists of a series of on-site field measurements as well as the collection of samples for laboratory analysis. Rapid turnaround of sample results is important for the evaluation and adjustment of the individual treatment processes during the performance of the demonstration. As a result, a field analysis for TNT will be implemented for a portion of the effluent samples which will be collected from each participant's system. These field analyses will be confirmed through the samples which are analyzed in the laboratory.

A3.1 SAMPLE COLLECTION

At various times during the performance of the pilot-scale demonstration, samples of the groundwater influent to the participants' treatment units, as well as the treated effluent from each of the units will be sampled for temperature, pH, and TNT concentrations. For measurement of temperature and pH, water samples will be collected from designated sampling ports on the treatment units directly into clean disposable sampling cups in which the temperature and pH will be immediately measured using a thermometer and portable pH analyzer. The time, date, and results of these field measurements will be recorded in bound logbooks. The pH meter used to take these field measurements will be calibrated against standard buffer solutions on a daily basis prior to use.

The samples which will undergo the field TNT analysis will be collected from the same sampling ports directly into labeled sample vials. The vials will be labeled with the time, date, and sample location. The samples will then undergo analysis for TNT in an onsite laboratory. The results of these field TNT analyses will be recorded in the bound logbooks. At certain predetermined sampling intervals, additional samples will be collected for more comprehensive analyses at WESTON's analytical laboratory. The required parameters will include pH, hardness, alkalinity, iron, manganese, and a full range of nitroaromatics (including TNT). These samples will be collected directly into the appropriate sampling containers as specified in Table A3-1.

Table A3-1

Analytical Methods, Containers, Preservation, and Holding Times

Parameter	Method	Container	Preservation	Maximum Holding Time
Explosives: 2,4,6-TNT, 2,4-DNT, 2,6-DNT, 2-A-4,6-DNT, 1,3,5-TNB, 1,3-DNB, NB, RDX, HMX, and Tetryl	8330	(2) 1 L Glass	Cool to 4°C	7 days extraction 40 days analysis
Iron and manganese	6010	500 mL Polyethylene	HNO_3	6 months
Alkalinity (as $CaCO_3$)	310.1	250 mL Polyethylene	NONE	14 days
Hardness (as $CaCO_3$)	130.2	250 mL Polyethylene	H_2SO_4	6 months
pH	150.1		None required	Analyze immediately

A3.2 PRESERVATIVES

To prevent/retard the degradation of analytes in samples during transportation and storage, some of the samples will require that preservatives be added to the sampling containers. To ensure that preservation efforts are initiated immediately at the time of sampling and to expedite the field sampling effort, the necessary preservatives will be added to the sample containers prior to their shipment to the site. A summary of the required preservatives are listed in Table A3-1. In addition, the samples will be packed on ice during transportation to ensure that they are cooled to below 4 degrees Celsius.

A3.3 SAMPLE SHIPMENT

After collection of the samples and packaging of the containers within a shipping cooler, the samples will be transported by an overnight carrier to WESTON Analytics in Lionville, Pennsylvania, which will ensure that the analytical holding times specified in Table A3-1 can be met.

A3.4 CUSTODY

When samples are collected, they will be considered to be in the custody and control of the sampler. As samples are collected in the field, relevant information for each sample will be entered on a chain-of-custody sheet, including name of sample, date of collection, time of collection, and analyses to be performed. A sample chain-of-custody sheet is provided in Figure A3-1. This chain-of-custody sheet will be shipped with the cooler of samples, and the originals will be included with the lot data packages.

A3.5 DOCUMENTATION

A bound field notebook will be used to record any measurements and/or observations made in the field and to record the sample time and location. Entries will be made in ink as the samples are collected. In addition, each sample container will be marked with the following:

WESTON Analytics Use Only

Custody Transfer Record/Lab Work Request

WESTON DESIGNERS/CONSULTANTS MANAGERS

Page ____ of ____

Client _____
Est. Final Proj. Sampling Date _____
Work Order # _____
Project Contact/Phone # _____
AD Project Manager _____
QC _____ Del _____ TAT _____
Date Rec'd _____ Date Due _____
Account # _____

Refrigerator #
#/Type Container — Liquid / Solid
Volume — Liquid / Solid
Preservatives

ANALYSES REQUESTED →

ORGANIC: VOA | BNA | Pest/PCB | Herb
INORG: Metal | CN

MATRIX CODES:
S - Soil
SE - Sediment
SO - Solid
SL - Sludge
W - Water
O - Oil
A - Air
DS - Drum Solids
DL - Drum Liquids
L - EP/TCLP Leachate
WI - Wipe
X - Other
F - Fish

Lab ID	Client ID/Description	Matrix QC Chosen (✓)	Matrix	Date Collected

Special Instructions:

DATE/REVISIONS:
1. _____
2. _____
3. _____
4. _____
5. _____
6. _____

Relinquished by	Received by	Date	Time	Relinquished by	Received by	Date	Time

Discrepancies Between Samples Labels and COC Record? Y or N
NOTES:

WESTON Analytics Use Only

Samples were:
1) Shipped ___ or Hand Delivered ___
Airbill # _____
2) Ambient or Chilled
3) Received in Good Condition Y or N
4) Properly Preserved Y or N
5) Received Within Holding Times Y or N

COC Tape was:
1) Present on Outer Package Y or N
2) Unbroken on Outer Package Y or N
3) Present on Sample Y or N
4) Unbroken on Sample Y or N
COC Record Present Upon Sample Rec't Y or N

RFW 21-21-001/A-8/90 ____ L372 ____ L373 ____ L375 ____ L377 ____ L378 Ref# _____ Cooler# _____

94P-3425 6/30/94

FIGURE A3-1 CHAIN-OF-CUSTODY FORM

- Source of the sample
- Unique sequential field identification number
- Date of sampling
- Preservative utilized
- Analytes required

SECTION A4

ANALYSES

A4.1 FIELD ANALYSES

A4.1.1 Method Description

At predetermined intervals, samples from each of the treatment systems participating in the demonstration will be analyzed using the D TECH™ TNT field test kit (or an equivalent method) which employs an immunoassay screening technique. The D TECH technique can quantify TNT in water in the range of 5 to 45 parts per billion (ppb) using a special color detector meter. From start to finish, the D TECH TNT field test kit can provide analytical results in less than 20 minutes.

A4.1.2 Correlation and Specificity

Based on the results of a study conducted by the manufacturer, the D TECH TNT test kit has been shown to correlate with the EPA SW-846 HPLC Method 8330. For 376 samples collected at various munitions production facilities and Army Ammunition Plants, the methods showed agreement on the presence or absence of TNT within the detectable range of the field kit (5 to 45 ppb). Using recommended EPA definitions, the correlation statistics can be summarized as follows:

Correlated values	96%
False positives	3%
False negatives	<1%

In addition, the D TECH TNT field kit was tested for cross-reactivity with other compounds. The degree of cross reactivity is indicated by a Minimum Detection Limit (MDL), which is defined as the lowest concentration of a particular compound that yields a positive result equivalent to the TNT detection limit of 5 ppb. The MDLs for compounds for which cross-reactivity has been tested are presented below:

Compound	MCL (ppb)
TETRYL	15
1,3,5-trinitrobenzene (TNB)	20
2-amino-4,6-dinitrotoluene	30
2,4-dinitrotoluene	120
4-amino-2,6-dinitrotoluene	>500
2,6-dinitrotoluene	>500
2,6-diaminonitrotoluene	>500
2-nitrophenol	>500
4-nitrophenol	>500
2,4-dinitrophenol	>500
RDX	>500
HMX	>500

4.1.3 Procedure

A single D TECH TNT test kit contains all the materials and equipment necessary to perform four (4) analyses. Detailed, step-by-step instructions are printed on the underside of the lid of the test kit. The analysis requires that 1 milliliter of sample be combined with various reagents and transferred to a specially designed cup assembly. The degree of color change in this cup assembly is then measured using the DTECHTOR hand-held reflectometer which interprets the color change by measuring the percent reflectance of the sample relative to a reference. The DTECHTOR meter provides a digital readout which can then be converted to an equivalent TNT concentration reading in ppb using a standard curve provided with the test kit. If the concentration of TNT in a test sample is greater than the upper limit of the test method, then a dilution step may be added to the procedure. The TNT concentration for the sample would then be calculated by multiplying the concentration determined for the diluted sample by the dilution factor.

A4.2 LABORATORY ANALYSES

In addition to the field analyses which will be performed, samples of effluent from each of the participating treatment systems will also be submitted to WESTON Analytics for various

laboratory analyses including quantitation of explosives by EPA Method 8330. The results of these analyses will be used to confirm the results of field analyses and will also serve to document the efficiency of each of the participating treatment systems. Because the results of the laboratory analyses will not be available by the completion of the demonstration, these results will not be used to optimize the efficiency of the treatment units.

A4.2.1 Sample Management

When samples arrive at the laboratory, the chain-of-custody sheets accompanying the samples will be signed by the sample custodian to formally acknowledge receipt of the samples. At the time of log-in, internal laboratory identification numbers will be assigned by the computerized laboratory tracking system. The computerized system assigns sequential log-in lot numbers to each batch of samples as well as each individual sample. The following information will be entered into the laboratory tracking system:

- Client name.
- Date of collection.
- Date of receipt.
- Administrative information such as work order numbers.
- Client references (sample identifications).
- Analytes.
- Matrix.
- Client-specified due date, if applicable.

The sample custodian will add a due date based on the earliest of:

- Client-specified due date.
- Analyte holding time.

Samples will be held in locked refrigerators until they are relinquished by the sample custodian to the analysts. Chain-of-custody forms will be signed to indicate the transfer of custody. Upon completion of analysis or when analysts have removed the aliquots for analysis, sample containers will be returned to the sample custodian.

Once samples are logged into the computerized internal tracking system, managers and analysts can access the data. The samples being held for a parameter or group of parameters will be tracked to allow for scheduling of analyses based on holding times, required turnaround times, and laboratory backlog.

A4.2.2 Sample Holding

Samples must be extracted and/or analyzed within the required holding time as specified in Table A3-1. Samples are normally held for 30 days after data have been reported.

A4.2.3 Calibration

Calibration of the instrument used for explosives analyses will be performed in accordance with the procedures specified in the organic analysis protocol for nitroaromatics and nitramines by HPLC. The organic analysis protocol for nitroaromatics/nitramines by HPLC SP-16L-8330.1 is provided as Attachment 1 of this QAPP.

A4.2.4 Analytical Procedures

The analytical methods that will be used to analyze the sample collected during the performance of the UV/Ox pilot demonstration are summarized in Table A3-1. Explosives analyses will be performed in accordance with the procedures specified in the organic analysis protocol for nitroaromatics and nitramines by HPLC (Attachment 1). Any deviations from these standard methods would need to be approved by USAEC prior to implementation. Extracts exceeding the calibration or approved range will be diluted into the approved range to produce a valid result. This will be noted in the laboratory report.

A4.2.5 Reference Materials

Reference materials for this program will be obtained from commercial vendors. Any characterization records for reference materials will be maintained in the laboratory and will be available for review. Records of all reference materials used in this program will be maintained by the laboratory.

A4.2.6 Data Reduction, Validation, and Reporting

Individual analysts will be responsible for data reduction for their analyses. Concentrations of contaminants in extracts will be determined from instrumental responses of the extracts applied to the instrument calibration curve. The resultant concentration will then be modified by applying the appropriate dilution/concentration, sample weight or volume, and

method accuracy factors to obtain a final reportable concentration in the original matrix (on a dry weight basis, if applicable). Aqueous samples will be reported in terms of micrograms per liter (μg/L) except for hardness and alkalinity which will be reported in terms of milligrams per liter (mg/L). Solid samples will be reported in terms of micrograms per gram (μg/g).

Data will contain no more than three significant figures and will be rounded only after all calculations have been completed. When samples are diluted into the certified range, the reported concentration will contain one less significant figure than an undiluted sample. Values less than the certified reporting limit (CRL) will be reported as "less than" the CRL. Analytical results will be submitted to the appropriate laboratory section manager or senior analytical personnel for review. The data will be reviewed for reasonableness and validity, as well as to ensure that the required QC was included in the analyses. The data will then be reviewed to verify that the systems were in control at the time of analyses. Out-of-control conditions will be reported to the appropriate section manager or senior analytical person for resolution.

Analytical data will be transmitted by a standard client report. The standard client report containing a transmittal letter and the following:

- case narrative describing: data qualifiers, sample collection, sample preparation (e.g., extraction or digestion) and analysis dates, and a description of any technical problems encountered with the analysis, and

- sample data summaries to include appropriate QC result summaries.

SECTION A5

SYSTEM CONTROLS

A5.1 SAMPLE CONTROL

The control of samples is an integral part of sample management. From the time of collection until the time of disposal, a sample is routinely accounted for through logbooks, chain-of-custody documents, shipping documents, laboratory work sheets, and computerized sample tracking systems. In the field, samples are under the control of field personnel until shipment to the laboratory. Within the laboratory, the samples are in the physical possession of personnel or locked in a storage refrigerator from the time of receipt until the time of disposal.

A5.2 DOCUMENT CONTROL

Documents form the basis of a legal record of a sample from the time of collection until disposal. They are also considered confidential information for the client and are treated accordingly. Only authorized personnel will be allowed access to notebooks, logbooks, analysis records, and client files.

A5.3 QC SAMPLES

Each analytical lot will contain, at a minimum, one method blank. The method blank will consist of the matrix of concern carried through the complete analytical procedure to include the addition of reagents. In addition, one (1) matrix spike/matrix spike duplicate pair will be analyzed with each batch of field samples. In the event that available sample volume is insufficient for matrix QC, a blank spike, spike duplicate pair will be analyzed with each analytical batch of up to 20 samples.

When method blanks with results above the CRL are encountered, the significance or impact of the results on the validity of the actual samples will be evaluated on a case-by-case basis. Generally, low-level positive results from method blanks would tend to have little significance if all samples yielded relatively high concentrations. On the other hand, if concentrations of samples and method blanks were comparable, little or no

contamination may exist at the site.

SECTION A6

RECORDKEEPING

A6.1 GENERAL

Separate logbooks will be specifically maintained for the UV/Ox Pilot Demonstration Project. All notebooks will be bound and will contain sequentially numbered pages. Any documentation sheets that were originally loose will be permanently affixed to the notebook if they are to be included as part of the entries.

All entries will be made in ink. Personnel making entries are required to date and sign the entries on each page. Corrections will be made by drawing a single line through the incorrect entry, entering the correction, and initialling and dating the entry.

A6.2 NOTEBOOKS AND LOGBOOKS TO BE MAINTAINED

A6.2.1 Field Notebooks

WESTON oversight personnel will document the performance of the field demonstration and will maintain field logbooks in which they will record a chronological record of all the activities conducted by the two vendors they have been assigned to observe. This recorded information will include daily electrical usage, chemical additions, system upsets, any modifications made to operating parameters, any pH or temperature readings, and the results of any TNT analyses which may be performed.

A6.2.2 Sampling

Sampling notebooks will be kept in an installation-specific notebook indicating:

- Name of installation.
- Date and time of sampling event.
- Site information to uniquely identify sampling locations.
- Unique sequential field identification number for each sample.
- Matrix being sampled.
- Method of sampling to include filtering, if applicable.
- Number of samples taken.
- Preservatives added to samples.
- Analytes for which samples were taken.
- Observations that may affect the validity of the results.
- Number of shipping containers and samples shipped.
- Date of shipping.

- Printed name and signature of the sampler.

A6.2.3 Log-In

Information to be contained in the log-in notebook will include:

- Date of receipt.
- Carrier from whom received.
- Number of shipping containers received.
- Field identification numbers.
- Condition of samples upon arrival.
- Analytes requested.
- Internal laboratory identification numbers assigned.

A6.2.4 Sample and Standards Preparation

Notebooks will be maintained that describe the preparation of samples and calibration standards. Typical information for these notebooks includes:

- Date.
- Operation (extraction, digestion, distillation, etc.).
- Weights and volumes used.
- Sources of reagents or standards.
- Sample identification.
- Concentrations or reagents and standards as well as dilution schedules.
- Signature of analyst.

A6.2.5 Instrument Analysis

Instrumental notebooks will contain information on instrument calibration and sample analyses. Each instrument will have a specific notebook assigned to it. Typical information contained in these notebooks includes:

- Date.
- Analyte(s) of concern.
- Responses and concentrations of calibration standards.
- External calibration checks.
- Sample identification.
- Signature of analyst.

A6.2.6 Reference Materials

A notebook documenting transactions involving reference materials will be maintained by the laboratory.

Information contained in this document will include:

- Date of transaction.
- Nature of transaction (receipt of reference material, disbursement of reference material, and request for reference material).
- Sources of reference materials.
- Identification of reference materials (lot numbers, date of subsampling, etc.).
- Internal characterization records.
- Quantities available.
- Purities or concentrations.
- Signature of person conducting the transaction.

A6.2.7 Instrument Maintenance

A separate notebook will be maintained to document instrument maintenance and repairs. Information contained in these notebooks will include:

- Date of activity.
- Nature of activity (repair, periodic maintenance, parts replacement, etc.).
- Malfunctions observed.
- Signature of person performing the activity.

SECTION A7

AUDITS

A7.1 EXTERNAL

External audits may be conducted by members of the USAEC Environmental Technology Division to resolve discrepancies or weaknesses in project plans and to verify compliance with project requirements. The results of these audits will be distributed by the auditor to the USAEC Project Officer, USAEC Environmental Technology Division, and the WESTON Task Manager.

A7.2 INTERNAL

The laboratory will routinely conduct internal audits. These formal laboratory audits will be documented in the project audit notebook, and the notebook will be available for inspection upon request.

As part of the internal audit, the procedures and documentation associated with the UV/Ox Pilot-scale Demonstration Project will be reviewed. The review will include an evaluation of the adherence in actual practice to the procedures outlined in project plans and documents. In particular, procedures concerned with preparation of standards, instrumental analyses, documentation, QC samples, and data management will be inspected. Deviations from approved procedures will be noted as well as actions taken to correct the condition. Copies of the laboratory audit will be distributed by the laboratory to the WESTON Task Manager and USAEC.

A summary of internal findings will be submitted to the WESTON Task Manager for inclusion in the final task report.

SECTION A8

CORRECTIVE ACTIONS

Corrective actions are taken when policies, procedures, or documentation are not in conformance with project direction or goals. Such actions are most effective if discrepancies are recognized and resolved at the lowest level since, at these levels, the actions tend to be most immediate. The rapid resolution of problems many times prevents the occurrence of subsequent problems that may be more difficult, expensive, or time-consuming to correct.

In accordance with this philosophy, when a discrepancy in the analytical system is observed, actions will be designed to immediately correct the problem and to bring the system into conformance with project direction and goals. The corrective action will be implemented at the lowest level to ensure rapid response. Problems that cannot be resolved at one level will be brought to the attention of the next successive level for resolution.

Data resulting from the problem area will be reviewed for validity. If the data are deemed questionable, actions will be taken either to verify the results or to repeat the procedure after the problem is corrected. In no case will questionable data be used or reported. All corrective actions will be summarized in corrective action reports, which will be included in the lot data package.

SECTION A9

QC REPORTS

A9.1 QC SAMPLE ANALYSIS

Results of QC samples analyzed with installation samples will be provided with the standard laboratory report.

ATTACHMENT 1

ORGANIC ANALYSIS PROTOCOL
NITROAROMATICS/NITRAMINES BY HPLC
SP No. 21-16L-8330.1

ORGANIC ANALYSIS PROTOCOL
Nitroaromatics and Nitramines by HPLC

UNCONTROLLED

CONTROLLED DISTRIBUTION

COPY # : 015
ISSUED TO : USAEC SADA

Full Signature Approvals Are Kept on File
with WESTON's Analytics Division
QA Standard Practice Records

REVISION NUMBER: 00

1.0 PURPOSE

This method is intended for the analysis of explosives residues in soil, water, or sediments. This method is limited to use by analysts experienced in handling and analyzing explosives. Specific compounds are summarized in the following table.

ID	Compound	CAS No.*
HMX	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine	2691-41-0
RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine	121-82-4
1,3,5-TNB	1,3,5-Trinitrobenzene	99-35-4
1,3-DNB	1,3-Dinitrobenzene	99-65-0
Tetryl	Methyl-2,4,6-trinitrophenylnitramine	479-45-8
NB	Nitrobenzene	98-95-3
2,4,6-TNT	2,4,6-Trinitrotoluene	118-96-7
2,6-DNT	2,6-Dinitrotoluene	606-20-2
2,4-DNT	2,4-Dinitrotoluene	121-14-2
2-A-4,6-DNT	2-Amino-4,6-dinitrotoluene	355-72-78-2
4-A-2,6-DNT	4-Amino-2,6-dinitrotoluene	1946-51-0
2-NT	2-Nitrotoluene	88-72-2
4-NT	4-Nitrotoluene	99-99-0
3-NT	3-Nitrotoluene	99-08-1

* Chemical Abstracts Service Registry Number

2.0 REFERENCES

2.1 "Draft Method 8330, Nitroaromatics and Nitramines by High Performance Liquid Chromatography (HPLC)", Revision 0, November 1990. This method was obtained from the US Army Corps of Engineers (COE), as a draft document developed by the COE for submittal and eventual approval for publication in EPA SW846, Test Methods for Evaluating Solid Waste, 3rd Edition.

2.2 Supplemental bibliography is given in Section 11.

3.0 SCOPE AND APPLICATION

3.1 This method is used to determine the concentration of the compounds listed in Section 1 in water, soil, or sediment.

3.2 A salting-out extraction procedure for low concentration, i.e., parts per billion (micrograms per liter) of explosives residues in surface or ground water. Direct injection of diluted and filtered water samples can be used for water samples of higher concentration. An ultrasonic extraction technique is described for soil and sediment samples.

3.3 All of the compounds listed in Section 1 either are used in the manufacture of explosives or are the degradation products of compounds used for that purpose. When making stock solutions for calibration, treat each compound as if it were extremely explosive.

3.4 This method is restricted to use by, or under the supervision of, analysts experienced in the use of HPLC, skilled in the interpretation of chromatograms, and experienced in handling explosive materials.

4.0 SUMMARY OF METHOD

This method provides instrument operating parameters for the detection of ppb levels of certain explosives in extracts of soil, sediment or water samples by high performance liquid chromatography (HPLC). The sample extracts must be generated by the appropriate sample preparation techniques.

4.1 Low-Level Salting-out Method

Aqueous samples of low concentration are prepared for analysis by a salting-out extraction procedure with acetonitrile and sodium chloride. The acetonitrile extract is further concentrated to less than 1.0 mL using a micro Kuderna-Danish evaporator and brought to 1.0 mL using acetonitrile. On the day of analysis, 200 µL of the extract is diluted with 600 µL of 1:2 methanol/water.

4.2 High-Level Direct Injection Method

Aqueous samples of higher concentration can be diluted 1/1 (v/v) with methanol or acetonitrile, filtered, and analyzed.

4.3 Soil and Sediment Samples

These are extracted using acetonitrile in an ultrasonic bath. On the day of analysis, 200 µL of the extract is diluted with 600 µL of 1:2 methanol/water.

5.0 INTERFERENCES

5.1 Solvents, glassware and other sample processing hardware may yield discrete artifacts and/or elevated baselines, causing misinterpretation of the chromatograms. All of these materials must be demonstrated to be free from interferences under the conditions of the analysis by running method blanks. Specific selection of reagents and purification of solvents by distillation in all-glass systems may be required.

5.2 2,4-DNT and 2,6-DNT elute at similar retention times on the ODS (C-18) column A large concentration of one isomer may mask the response of the other isomer. If it is not apparent that both isomers are present, an isometric mixture should be reported.

5.3 2-A-4,6-DNT and 4-A-2,6-DNT elute at similar retention times on the ODS column while 4-A-2,6-DNT and 2,4,6-TNT will elute at similar times on the CN column. If it is not apparent which amino-DNT isomer is present, an isomeric mixture should be reported.

5.4 Tetryl decomposes rapidly in methanol/water solutions, as well as with heat. When performing analysis by direct injection, all aqueous samples expected to contain tetryl should be diluted with acetonitrile prior to filtration. All samples expected to contain tetryl should not be exposed to temperatures above room temperature.

5.5 Degradation products of tetryl appear as a shoulder on the TNT peak when using the ODS column and is very close in retention time to the Amino-DNT isomers. Peak heights rather than peak areas should be used when tetryl is present in concentrations that are significant relative to the concentration of TNT. It is imperative that the automatic liquid samplers employed have the capability of being chilled to 7°C to minimize tetryl degradation while standards and samples are awaiting analysis.

6.0 APPARATUS AND MATERIALS

6.1 HPLC System

6.1.1 HPLC: equipped with a pump capable of achieving 4000 psi, a 50-µL loop injector and a 254-nm UV detector (Hewlett Packard 1050 or equivalent).

6.1.2 HPLC Columns:

C-18 reverse phase, 25 cm x 4.6 mm (5 µm particle size): Dupont Zorbax ODS or equivalent.

CN reverse phase, 25 cm x 4.6 mm (5 µm particle size): Dupont Zorbax CN or equivalent.

6.1.3 Chromotography Data System

6.1.4 Autosampler (optional)

6.2 Other Equipment

6.2.1 Temperature Controlled Ultrasonic Bath.

6.2.2 Balance, ± 0.1 mg.

6.3 Materials

6.3.2 Disposable Cartridge Filters: 0.45 µm Teflon® filter
0.20 µm Teflon® filter

6.3.3 Pipettes: 10 mL, 9 mL, 5 mL, 1 mL volumetric, Class A, glass

6.3.4 Pasteur Pipettes.

6.3.5 Scintillation Vials: 24 mL, glass

6.3.6 Vials: 12 mL glass, Teflon®-lined cap,
40 mL glass, Teflon®-lined cap,
4 mL amber glass,
1.5 mL autosampler.

6.3.7 Syringes: 10 µL, 50 µL, 100 µL, 250 µL glass with metal plunger.

6.3.8 Eppendorfs: 10 µL µL size, 100 µL-1000 µL size.

6.3.9 Disposable Syringes: Glaspak, 2.5 mL and 10 mL or equivalent.

6.3.10 Separatory Funnel: Glass, 1 L or 2 L with stopper.

6.3.10 Vacuum Desiccator: glass.

6.3.11 Volumetric Flask: 5.0 mL and 10.0 mL.

6.3.12 Micro Kuderna-Danish Evaporator, 4 mL with volume calibration marks on the concentrator tube (Supelco #6-4722 or equivalent).

6.3.12 Boiling Chips: solvent extracted, approximately 10/40 mesh (Teflon or equivalent).

6.3.12 Oven: forced air, without heating.

6.3.13 Beaker: 600mL.

6.3.13 Etching pen or scribe.

7.0 REAGENTS AND STANDARDS

7.1 Reagents

Use HPLC grade chemicals in all tests. It is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lowering the accuracy of the determination.

7.2 Analytical Standards

Analytes listed in Section 1.0. Allow ample lead time (e.g., up to six months) for obtaining these compounds. RDX and Tetryl are stored wet for stability during shipment. The primary source for these explosives is through military contracts. Some commerical vendors such as EM Science now have explosives available in solution. Other nitro-compounds are metabolites of the explosives and should be commercially available.

7.3 Internal Standard

Benzaldehyde, Reagent grade.

7.4 Other Reagents

7.4.1 Reagent Water: All references to water in this method refer to water in which an interference is not observed at the detection limit of the compounds of interest. Reagent water can be generated by passing tap water through a carbon filter feed containing about 1 pound of activated carbon. A water purification system may be used to generate organic-free deionized water.

7.4.2 Acetonitrile, HPLC grade

7.4.3 Methanol, HPLC grade, distilled in glass.

7.4.4 Sodium Chloride, NaCl, Reagent grade. Kilnes at 400·C for two hours. Stored in glass bottles.

7.4.5 Mobile Phase I: 50% water/34% MeOH/16% ACN
Mobile Phase II: 50% water/50% MeOH

Mobile phases may be varied to optimize separation.

7.6 Internal/Retention Time Standard

To monitor retention time stability and injection reproducibility for each standard and sample, an accurate amount of benzaldehyde is added to each sample and standard extract that is to be analyzed.

7.6.1 Stock Internal Standard Solution: Accurately weigh approximately 100 mg (weigh to 0.1 mg) of benzaldehyde and dissolve in acetonitrile. Adjust the final volume to 10.0 mL in a 10.0 mL volumetric flask. Store in a refrigerator at 4ºC in the dark. Calculate the concentration of the stock solution from the actual weight used.

7.7 Dilution Solutions

7.7.1 A diluent of water/methanol/acetonitrile (50/34/16) is required for the preparation of standards for analysis on the C-18 column. Using a microliter syringe or Eppendorf pipettor, inject 5 µL of the stock internal standard solution (section 7.6.1) into 180 mL of mobile phase I described in section 7.3.5. Mix well.

7.7.2 A diluent of water/methanol is required for the preparation of standard for the CN column and extracts for both the C-18 and CN columns. Using a microliter syringe or Eppendorf pipettor, inject 6 µL of stock internal standard solution (section 7.6.1) into 180 mL of 2:1 water/methanol. Mix well.

7.8 Working Standards

On the day of analysis, prepare a series of a minimum of five calibration standards and a calibration blank with relative concentrations of 0.5X to 200X (instructions follow), where X is close to the reporting limit (see Table 1). Note, for the low-level method: 0.1 µg/mL calibration x 10 = 1 µg/L sample.

7.9 Surrogate Standards

Specific projects may require performance monitoring of the extraction and analytical system and the effectiveness of the method in dealing with each sample matrix by spiking each sample, matrix spike, and reagent water blank with one or two surrogates (e.g., 3-NT or analytes not expected to be present in the sample).

8.0 SAMPLE COLLECTION, PRESERVATION, AND HANDLING

8.1 Grab samples must be collected and stored in glass containers. Follow conventional sampling procedures.

8.2 Samples and sample extracts must be kept below 4°C and in the dark, except soil/soild samples during drying.

8.3 Soil and sediment samples should be air dried to constant weight at room temperature or colder after collection.

8.4 All water samples must be extracted within 7 days of collection and analyzed within 40 days after extraction. All soil and sediment samples must be extracted within 14 days of collection and analyzed within 40 days after extraction.

~~9.0~~ PROCEDURE SEE 7.0 PROCEDURE PAGE 21a

9.1 Sample Preparation: Aqueous Samples

Option 1: The low-level method may be used for all samples, provided they

are diluted into the calibration range when necessary.

Option 2: If both low-level and high level methods are to be used, it is highly recommended that all samples of this type be screened with the high-level method (>50 µg/L) to determine if the low-level method (1-50 µg/L) is required.

9.1.1 Low-Level Method (Salting-Out Extraction)

9.1.1.1 Place a 400-mL aliquot of water sample in a separatory funnel and add 130g of NaCl. Vigorously shake the sample until all of the NaCl is completely dissolved. All NaCl must be dissolved before adding acetonitrile. Dissolution of the NaCl is more rapid if the samples are at room temperature.

9.1.1.2 Add a 100-mL volume of acetonitrile using a glass volumetric cylinder or a flask tilt-a-pet. Shake the separatory funnel vigorously for 5 minutes. Allow the funnel to stand undisturbed for 30 minutes while the two phases separate. Discard the water (lower) layer and collect the acetonitrile (upper) layer (approximately 23 mL) in a 40-mL Teflon®-capped vial. Rinse the separatory funnel with 5 mL of acetonitrile and add the rinsate to the extract.

9.1.1.3 If the collected extract was turbid, centrifuge the 40 mL vial at 4000 rpm's for 5 minutes. Remove the acetonitrile (upper) layer with a Pasteur pipette and transfer it to a clean vial.

9.1.1.4 Transfer the sample extract into a micro Kuderna-Danish Evaporator (K-D). Rinse the 40-mL vial with 2 mL of acetonitrile. Transfer the acetonitrile rinsate (upper layer) with a Pasteur pipette to the micro K-D.

9.1.1.5 **This step is necessary if a 100°C steam bath is not available.** Obtain four 200-mL plastic bottles (approximate diameter of 5 cm) and cut off the bottom and top. Arrange the four tubes in an upright position in a 2-L beaker. Add water to the 2-L beaker, place on a hot plate and bring to a vigorous boil. (The plastic tubes can be saved for subsequent concentration steps).

9.1.1.6 Place four of the K-D devices into each of the plastic tubes in the boiling water (the tubes will stabilize the K-D devices, allowing them to remain in an

upright position in the boiling water). Cover as much of the open areas at the mouth of the beaker with aluminum foil as possible, but do not cover the tops of the Snyder columns as the volatilized solvent must be allowed to escape. When the solvent volume in the K-D device has been reduced to between 0.5 to 0.8 mL, remove the K-D device from the boiling water. Adjust the total volume to 1.0 mL in the concentrator tube using acetonitrile. Rinse the concentrator tube three times with the 1.0 mL extract, then transfer the extract into 4 mL amber vials. **(NOTE: It is important to complete solvent concentration in less than 15 minutes, as compounds such as Nitrobenzene and the Nitrotoluenes may break down or volatilize upon prolonged exposure to heat. List the time required to concentrate each of the extracts in the extraction notebook. If necessary allow sufficient time for the water to re-heat before adding new K-D devices for concentration. If the water temperature is not high enough, the concentration process will take a longer period of time and possibly result in the partial degradation or volatilization of target compounds.)**

9.1.1.7 If the total volume after boil down was more than 1.0 mL read out the extract volume on the concentrator tube as the final volume. Rinse the concentactor tube three times with the extract, then transfer the extract into 4 mL amber vials.

9.1.1.8 On the day of analysis, dilute 200 µL of extract with 600 µL of 2:1 water/methanol.

9.1.2 High-Level Method

9.1.2.1 **Sample filtration: Place a 5-mL aliquot of each water sample in a scintillation** vial, add 5 mL of acetonitrile, shake thoroughly, and filter through a 0.45-µm Teflon® filter. Discard the first 3 mL of filtrate, and retain the remainder in a Teflon®-capped vial for RP-HPLC analysis as in Section 9.5. HMX quantitation can be improved with the use of methanol rather than acetonitrile for dilution before filtration. However, as stated in Section 5.3, the use of methanol may affect tetryl stability.

9.2 Sample Preparation: Soil and Sediment Samples

9.2.1 Sample homogenization: Dry soil samples in air at room temperature or colder, being careful not to expose the sample to direct sunlight. Pulverize the sample with a spatula and remove any sticks, rocks or other extraneous material. Particle size should resemble soil passed through a 30 mesh sieve.

Note: See safety section regarding extraction of wet soils for high level samples.

9.2.2 Sample extraction

9.2.2.1 Place a 2.0 g aliquot of each soil sample in a 24-mL glass vial. Add 10.0 mL of acetonitrile, cap with a Teflon®-lined screw cap.

9.2.2.2 On the screw cap for each sample, etch a unique ID which can be cross-referenced to the sample ID.

9.2.2.3 Place the 24-mL sample vials into a 600 mL beaker and fill with water to a level such that the vials will not become buoyant. If necessary, use a rubber band to keep the vials upright while in the beaker. Place the beaker into the ultrasonic bath and extract for 18 hours.

9.2.2.2 After sonication, allow the sample to settle for a minimum of 30 minutes.

9.2.2.3 Place the supernatant in a disposable syringe and filter through a 0.2 micron Teflon® filter.

9.2.2.4 On day of analysis, dilute 200 µL of sample with 600 µL of 2:1 water/methanol.

9.3 Chromatographic Conditions

Primary Column:	DuPont Zorbax ODS, or equivalent (C-18 Reverse Phase HPLC Column, 250 mm X 4.6 mm ID, 5 micron particle size)
Mobile Phase:	50% water/34% MeOH/16% ACN
Flow Rate:	1.5 mL/min
Injection volume:	50 µL
UV Detector:	254 nm
Column Temperature:	Stable; minimum 7·C above ambient room temperature
Secondary Column: (Option 1)	Dupont Zorbax CN, or equivalent (CN Reverse Phase HPLC Column, 250 mm x 4.6 mm ID, 5 micron particle size)
Mobile Phase:	50% Water/50% MeOH
Flow Rate:	1.5 mL/min
Injection Volume:	50 µL
UV Detector:	254 nm
Column Temperature:	Stable; minimum 7·C above ambient room temperature

9.4 Calibration of HPLC

9.4.1 All electronic equipment is allowed to warm up for thirty minutes. During this period, at least 15 void volumes of mobile phase are passed through the column (approximately 20 min at 1.5 mL/min) and continued until the baseline is level at the UV detector's greatest sensitivity range.

9.4.2 Analyze the working standards using the chroma.ographic conditions given in Section 9.3. Prepare a calibration curve using peak heights or peak areas, as appropriate. The calibration curve should be based on single injetions of a

minimum of 5 concentration levels of standard. Certain projects may require the use of triplicate injections for all calibration standards as described in Method 8330 in SW-846, with the average response obtained from the triplicate injections utilized for each level of the calibration curve. Projects with this requirement will be identified in the Technical Profile.

9.4.3 Initial calibration data are entered into the chromatography data system, which calculates a least squares regression using the responses as Y values and target concentrations as X values. The program will calculate an equation to describe the data. The general form of the equation is:

$Y = aX + b$,

Y = response
X = true concentration
a = slope of the regression line
b = Y intercept (X = 0)

Values of a and b are obtained from the computer regression calculations. Evaluate the correlation coefficient (r) of the least squares regression. A correlation coefficient of at least 0.996 is required for the quantitaion of target compound concentrations.

9.4.4 Analyze a continuing calibration verification standard (CCV) after every ten samples and at the end of the sequence. The response for a CCV should agree within ±15% of the response obtained from the initial calibration standards. If the response deviation for the CCV exceeds 15%, reanalyze the CCV. If the response for the second CCV is still greater than 15%, perform corrective action, such as re-preparing the CCV or, if necessary, recalibrate the instrument. All samples analyzed after an unacceptable CCV must be reanalyzed with a new calibration curve. CCV are at the 10X calibration level.

9.4.5 Analyze a daily CCV in triplicate at the beginning of each daily analytical sequence. The average response of this standard must be within ±15% of the response obtained from the initial calibration. Subsequent continuing calibration standards for that day require only a single injection with a comparison to the initial calibration data is described in Section 9.4.4.

9.5 HPLC Analysis

9.5.1 Analyze the samples using the chromatographic conditions given in Section 9.3. Evaluate the sample chromatograms for the presence of peaks which fall within the retention time windows established for target compounds (see section 9.5.4). Retention time windows are used as a guide for the analyst. Final interpretation of the chromatographic data is dependent upon an evaluation by an experienced analyst. All positive identifications observed on the C-18 column must be confirmed by injection onto the CN column.

9.5.2 In limited applications (e.g., aqueous process wastes), direct injection of filtered and diluted sample into the HPLC system with a 50 µL loop may be appropriate. The quantitation limits are high, therefore, it is only permitted where concentrations in excess of 50 µg/L are expected.

9.5.3 Dilute samples as necessary to obtain results within the calibration range for each analyte.

9.5.4 Calculate both the absolute and relative retention time windows daily using all standards analyzed. If the absolute retention timed shift over 3%, the relative retention time window is utilized for the identification of target compounds.

9.5.4.1 Absolute Retention Time Window:
Calculate the mean and standard deviation of RT for each analyte using all standards analyzed within a run sequence. Apply plus or minus three times the standard deviation to the mean RT. This range of retention times defines the absolute retention time window of the analyte. When utilizing triplicate injections during the initial calibration, establish the standard deviation from these standards and apply to all daily sequences until instrument recalibration. The mean retention time for a daily sequence is taken from the last of the three daily CCVs.

9.5.4.2 Relative Retention Time Window (when RTW >3.0%):
Calculate the relative retention time for each analyte, using the following equation:

$$\text{Relative RT of Analyte} = \frac{\text{RT of Analyte}}{\text{RT of Benzaldehyde}}$$

Calculate the mean and the standard deviation of relative RT for each analyte. Apply plus or minus three times the standard deviation to the mean relative RT. This range of retention times defines the relative retention time window of the analyte.

9.5.5 Table 2 presents the approximate retention times on both ODS and CN columns for the analytes determined by this method, using the operating conditions in Section 9.3.

9.5.6 Record the resulting peak sizes in peak heights or area units. The use of peak heights is recommended to improve reproducibility of low level samples.

9.5.7 Concentrations of target compounds in sample extracts are derived from the least squares regression calculation of the initial calibration data (Section 9.4.3). The peak area or height for the target compound is the Y variable. The concentration in the extract (X variable in µg/mL) is calculated from the three known variables.

9.5.8 Calculate results in the original matrix, using the following information:

µg/mL = concentration of the sample from the calibration curve.

DF = dilution required. All preparation schemes in this method have one dilution, prior to instrument analysis.

L or g = liters or grams, i.e., sample size

Calculate the final result using the following equations:

- Low-Level Water: µg/mL X DF ÷ 0.4 L = µg/L
- High-Level Water: µg/mL X DF X 1,000 = µg/L
- Soil: µg/mL X 10 X DF ÷ g = µg/g

9.5.8 If analytical interferences are suspected, or for the purpose of confirmation,

analysis using the second HPLC column is required.

10.0 QUALITY CONTROL

10.1 Prior to preparation of stock solutions, acetonitrile, methanol, and water blanks should be run to determine possible interferences with analyte peaks. If the acetonitrile, methanol, or water blanks show contamination, a different batch should be used.

10.2 Each analytical batch comprises up to 20 samples. For each batch, the following minimum QC should be performed:

Method Blank
Blank Spike
Blank Spike Duplicate (prepared only when an MSD or sample duplicate is not prepared)
Matrix Spike
Matrix Spike Duplicate or Sample Duplicate

Spike samples at ten times the reporting limit. Perform spikes with standards prepared independently from the calibration mix. Recoveries must be within laboratory quality control limits. Investigate any out of control analytes. Reanalyze any negatively affected samples.

10.3 Method Blanks, Blank Spikes and Blank Spike Duplicates

10.3.1 Method blanks for the analysis of aqueous samples should be reagent water carried through all sample storage, preparation and handling procedures.

10.3.2 Method blanks for the analysis of soil samples should be uncontaminated soil carried through all sample storage, extraction and handling procedures.

10.3.3 Blank spikes and blank spike duplicates are prepared with the same standard for matrix spikes at the level ten time the reporting limit. Samples batched with the BS/BSD must be re-extracted if the blank spike recoveries are outside the laboratory quality control limits.

10.4 Optional: Evaluate the peak height (or peak area) of the Internal Standard (Benzaldehyde) in all of the sample chromatograms. If the response of the internal standard changes by a factor of two or more (-50% to 100%) from the average value of the triplicate injections of the DCV standard, the HPLC must be inspected for malfunctions and corrections made as necessary. Samples with internal standard responses outside this acceptance limit must be re-analyzed.

11.0 SUPPLEMENTAL REFERENCES

11.1 Bauer, C.F., T.F. Jenkins, S.M. Koza, P.W. Schumacher, P.H. Miyares and M.E. Walsh (1989). "Development of an Analytical Method for the Determination of Explosive Residues in Soil. Part 3. Collaborative Test Results and Final Performance Evaluation". USA Cold Regions Research and Engineering Laboratory, CRREL Report 89-9.

11.2 Grant, C.L. A.D. Hewitt and T.F. Jenkins (1989) "Comparison of Low Concentration Measurement Capability Estimates in Trace Analysis: Method Detection Limits and Certified Reporting Limits". USA Cold Regions Research and Engineering Laboratory, Special Report 89-20.

11.3 Jenkins, T.F., C.F. Bauer, D.C. Leggett and C.L. Grant (1984). "Reversed-phase HPLC Method for Analysis of TNT, RDX, HMX and 2,4-DNT in munitions wastewater. USA Cold Regions Research and Engineering Laboratory, CRREL Report 84-29.

11.4 Jenkins, T.F. and M.E. Walsh (1987). "Development of an Analytical Method for Explosive Residues in soil." USA Cold Regions Research and Engineering Laboratory. CRREL Report 87-7.

11.5 Jenkins. T.F., P.H. Miyares and M.E. Walsh (1988a). "An improved RP-HPLC Method for Determining Nitroaromatics and Nitramines in Water." USA Cold Regions Research and Engineering Laboratory, Special Report 88-23.

11.6 Jenkins, T.F., P.W. Schumacher, M.E. Walsh and C.F. Bauer (1988b). "Development of an Analytical Method for the Determination of Explosive

Residues in Soil. Part II#: Further Development and Ruggedness Testing." USA Cold Regions Research and Engineering Laboratory. CRREL Report 88-8.

11.7 Leggett, D.C., T.F. Jenkins and P.H. Miyares (1990). "Salting-out Solvent Extraction for Pre-concentration of Neutral Polar Organic Solutes from Water." *Analytical Chemistry*, 62: 1355-1356.

11.8 Miyares, P.H. and T.F. Jenkins (1990). "Salting-out Solvent Extraction for Determining Low Levels of Nitroaromatics and Nitramines in Water." USA Cold Regions Research and Engineering Laboratory. Special Report 90-30.

12.0 SAFETY

12.1 Standard precautionary measures used for handling other organic compounds should be sufficient for safe handling of the analytes targeted by this method.

12.2 If samples are suspected of containing 10% or greater of explosives, the samples should be extracted without drying and reported on a wet weight basis. The laboratory may institute a screening program for wet soils, at its option.

TABLE 1. REPORTING QUANTITATION LIMITS

COMPOUND	LOW-LEVEL WATER (µg/L)	HIGH LEVEL WATER (µg/L)	SOIL/SEDIMENT (mg/kg)
HMX	1.1	125	2.2
RDX	0.54	125	1.1
1,3,5-TNB	0.13	250	0.25
1,3-DNB	0.12	62.5	0.25
Tetryl	0.38	62.5	0.75
NB	0.13	62.5	0.26
2,4,6-TNT	1.25	250	0.25
2,6-DNT	0.13	62.5	0.26
2,4-DNT	0.12	62.5	0.25
2-A-4,6-DNT	0.13	125	0.25
4-A-2,6-DNT	0.13	125	0.25
2-NT	0.5	125	1.0
4-NT	1.5	125	3.0
3-NT	0.5	125	1.0

See page 21d Table 1A

TABLE 2. RETENTION TIME OF ANALYTES BY HPLC (ANALYZED ACCORDING TO CONDITIONS SPECIFIED IN THIS OP)

COMPOUND	ODS Primary Column (minutes)	C8 Confirmation Column (minutes)
HMX	3.21	7.50*
RDX	4.05	7.70*
1,3,5-TNB	5.96	11.60
1,3-DNB	6.85	10.63
Tetryl	8.01	25.00
NB	8.47	11.10
2,4,6-TNT	10.06	19.12
2,6-DNT	10.68	16.34
2,4-DNT	10.95	16.15
2-A-4,6-DNT	9.65*	12.40
4-A-2,6-DNT	9.65*	12.90
2-NT	12.78	
4-NT	13.95	
3-NT	14.94	

* Coelute

TABLE 3. HPLC ANALYSIS LOG

WESTON® **HPLC ANALYSIS LOG**

INSTRUMENT #: _____ MOBILE PHASE: _____ ANALYST: _____
DETECTOR: _____ _____ FLOW RATE: _____
WAVELENGTH: _____ COLUMN TYPE: _____ COLUMN SERIAL #: _____
CALIBRATION STANDARD: _____ SPIKING STANDARD: _____

#	CLAS ID # & RUN #	INSTRUMENT FILE ID	ANALYSIS DATE/TIME	RFW SAMPLE # DESCRIPTION	DF	COMMENTS

REVIEWED BY/DATE _____

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7.0 PROCEDURE

7.1 Sample Preparation

7.1.1 Aqueous Samples: It is highly recommended that process waste samples be screened with the high-level method to determine if the low level method (1-50 µg/L) is required. Most groundwater samples will fall into the low level method.

7.1.1.1 Low-Level Method (salting-out extraction)

7.1.1.1.1 Add 251.3 g of sodium ~~sulfate~~ chloride to a 1 L volumetric flask (round). Measure out 770 mL of a water sample (using a 1 L graduated cylinder) and transfer it to the volumetric flask containing the salt. Add a stir bar and mix the contents at maximum speed on a magnetic stirrer until the salt is completely dissolved.

7.1.1.1.2 Add 164 mL of acetonitrile (measured with a 250 mL graduated cylinder) while the solution is being stirred and stir for an additional 15 minutes. Turn off the stirrer and allow the phases to separate for 10 minutes.

7.1.1.1.3 Remove the acetonitrile (upper) layer (about 8 mL) with a Pasteur pipet and transfer it to a 100 mL volumetric flask (round). Add 10 mL of fresh acetonitrile to the water sample in the 1 L flask. Again stir the contents of the flask for 15 minutes followed by 10 minutes for phase separation. Combine the second acetonitrile portion with the initial extract. The inclusion of a few drops of salt water at this point is unimportant.

7.1.1.1.4 Add 84 mL of salt water (325 g NaCl per 1000 mL of reagent water) to the acetonitrile extract in the 100 mL volumetric flask. Add a stir bar and stir the contents on a magnetic stirrer for 15 minutes followed by 10 minutes for phase separation. Carefully transfer the acetonitrile phase to a 10 mL graduated cylinder using a Pasteur pipet. At this

stage the amount of water transferred with the acetonitrile must be minimized. The water contains a high concentration of NaCl that produces a large peak at the beginning of the chromatogram where it could interfere with the HMX determination.

7.1.1.1.5 Add an additional 1.0 mL of acetonitrile to the 100 mL volumetric flask. Again stir the contents of the flask for 15 minutes followed by 10 minutes for phase separation. Combine the second acetonitrile portion with the initial extract in the 10 mL graduated cylinder (transfer to a 25 mL graduated cylinder if the volume exceeds 5 mL). Record the total volume of acetonitrile extract to the nearest 0.1 mL. (Use this as the volume of total extract [V_t] in the calculation of concentration after converting to µL). The resulting extract, about 5 - 6 mL, is then diluted 1:1 with reagent water prior to analysis.

7.1.1.1.6 If the diluted extract is turbid, filter it through a 0.45 - µm Teflon filter using a disposable syringe. Discard the first 0.5 mL of filtrate, and retain the remainder in a Teflon-capped vial for RP-HPLC analysis as in Section 7.4.

7.1.1.2 High-Level Method

7.1.1.2.1 Sample filtration: Place a 5 mL aliquot of each water sample in a scintillation vial, add 5 mL of acetonitrile, shake thoroughly, and filter through a 0.45-µm Teflon filter using a disposable syringe. Discard the first 3 mL of filtrate, and retain the remainder in a Teflon-capped vial for RP-HPLC analysis as in Section 7.4. HMX quantitation can be improved with the use of methanol rather than acetonitrile for dilution before filtration.

7.1.2 Soil and Sediment Samples

7.1.2.1 Sample homogenization: Dry soil samples in air at room temperature or colder to a constant weight, being careful not to expose the samples to direct sunlight. Grind and homogenize the dried sample thoroughly in an acetonitrile rinsed mortar to pass a 30 mesh sieve.

NOTE: Soil samples should be screened by Method 8510 prior to grinding in a mortar and pestle (See Safety Section 11.2).

7.1.2.2 Sample extraction

7.1.2.2.1 Place a 2.0 g subsample of each soil sample in a 15 mL glass vial. Add 10.0 mL of acetonitrile, cap with Teflon-lined cap, vortex swirl for one minute, and place in a cooled ultrasonic bath for 18 hours.

7.1.2.2.2 After sonication, allow sample to settle for 30 minutes. Remove 5.0 mL of supernatant, and combine with 5.0 mL of calcium chloride solution (Section 5.1.3) in a 20 mL vial. Shake, and let stand for 15 minutes.

7.1.2.2.3 Place supernatant in a disposable syringe and filter through a 0.45-µm Teflon filter. Discard first 3 mL and retain remainder in a Teflon-capped vial for RP-HPLC analysis as in Section 7.4.

TABLE 1A

8330 QUANTITATION RANGES (ug/L)

Analyte	8330 HIGH LEVEL HIGH	LOW	8330 RSOE MDL
HMX	8800	220	1.07
RDX	4320	108	0.6
1,3,5-TNB	1008	25	0.15
1,3-DNB	1002	25	0.12
Nitrobenzene	1040	26	0.13
Tetryl	3006	75	0.54
Amino-DNTs	1010	25	0.25
TNT	1008	25	0.15
2,6-DNT	1040	26	0.15
2,4-DNT	1002	25	0.15

APPENDIX B

ANALYTICAL DATA

APPENDIX B

RECENT AREA 21 RI GROUNDWATER DATA

Time: 15:02:19

Data Summary Table (Positive Hits Only) for Savanna - Total
Chemical Analysis Data
Anions/Inorganics - Groundwater
Criteria: Site - 21

Site ID:	21	21	21	21	21	21	21
Loc ID:	300101	302101	302104	302106	302119	302120	302121
Sample ID:	00101	02101	02104	02106	02119	02120	02121
SDG:							
Sample Date:	05/20/93	05/05/93	05/05/93	05/20/93	05/20/93	05/20/93	05/25/93
Depth:	340.0	11.7	21.8	11.8	20.6	17.7	150.4
Matrix:	CGW	CGW	CGW	CGW	CGW	CGW	CGW
Unit of Measure:	UGL	UGL	UGL	UGL	UGL	UGL	UGL

	L	V	R		L	V	R		L	V	R		L	V	R		L	V	R		L	V	R		L	V	R
CHLORIDE		873.000			1690.000			3080.000				8840.000				4470.000				NT				NT			
FLUORIDE		419.000			455.000			727.000				641.000				375.000				NT				NT			
NITRITE		8.840			46.600			91.300				51.000				140.000				24.400				41.400			
NITRITE, NITRATE	LT	10.000			32000.000			54000.000				25000.000				180000.000				180000.000				220.000			
PHOSPHORUS	LT	10.000			314.000			910.000				208.000				177.000				NT				NT			
SULFATE		16000.000			23000.000			40000.000				71000.000				44000.000				NT				NT			

Data Summary Table (Positive Hits Only) for Savanna - Total
Chemical Analysis Data
Anions/Inorganics - Groundwater
Criteria: Site - 21

Site ID:	21			21			
Loc ID:	302122			302123			
Sample ID:	02122			02123			
SDG:							
Sample Date:	05/25/93			05/12/93			
Depth:	64.5			26.4			
Matrix:	CGW			CGW			
Unit of Measure:	UGL			UGL			
		L	V	R		L	V	R
CHLORIDE	NT			NT			
FLUORIDE	NT			NT			
NITRITE	169.000			LT 5.000			
NITRITE, NITRATE	6900.000			3900.000			
PHOSPHORUS	NT			NT			
SULFATE	NT			NT			

Data Summary Table (Positive Hits Only) for Savanna - Total
Chemical Analysis Data
Explosive Compounds - Groundwater
Criteria: Site - 21

Site ID:	21						21						21						21						21						21					
Loc ID:	300101						302101						302103						302104						302105						302106					
Sample ID:	00101						02101						02103						02104						02105						02106					
SDG:																																				
Sample Date:	05/20/93						05/05/93						05/06/93						05/05/93						05/20/93						05/20/93					
Depth:	340.0						11.7						22.9						21.8						12.0						11.8					
Matrix:	CGW						CGW						CGW						CGW						CGW						CGW					
Unit of Measure:	UGL						UGL						UGL						UGL						UGL						UGL					
			L	V	R				L	V	R				L	V	R				L	V	R				L	V	R				L	V	R
1,3,5-TRINITROBENZENE	LT	0.227	K		I		2.930	C		IN		9.190	C		IN		5.570	C		IN		140.000	C		I		19.200	C		I		18.300	C		I
1,3-DINITROBENZENE	LT	0.458					5.170	C			LT	0.458					2.400	C				8.830	UQ				4.020	C				3.710	C		
2,4,6-TRINITROTOLUENE	LT	0.426					200.000	C			LT	0.426					0.504	UQ				170.000	C				24.500	UQ				20.000	UQ		
2,4-DINITROTOLUENE	LT	0.397		N			9.360	UQ				1.230	UQ				13.100	UQ				33.000	C		N		60.000	C		N		58.000	C		N
2,6-DINITROTOLUENE	LT	0.600				LT	6.000	JI			LT	0.600				LT	6.000	JI				19.000	C				41.600	C				37.100	C		
NITROBENZENE	LT	0.682				LT	0.682			N	LT	0.682			N	LT	0.682			N	LT	9.610	K			LT	23.900	K			LT	24.400	K		
RDX	LT	0.416					4.740	U				4.490	C			LT	0.416				LT	85.000	K				4.840	C				4.530	C		

Data Summary Table (Positive Hits Only) for Savanna - Total
Chemical Analysis Data
Explosive Compounds - Groundwater
Criteria: Site - 21

Site ID:	21	21	21	21	21	21	21
Loc ID:	302107	302119	302120	302121	302121	302121	302121
Sample ID:	02107	02119	02120	02121	02121A	02121B	02121C
SDG:							
Sample Date:	05/05/93	05/20/93	05/20/93	05/25/93	05/06/93	05/07/93	05/07/93
Depth:	67.6	20.6	17.7	150.4	24.0	55.0	78.0
Matrix:	CGW	CGW	CGW	CGW	CGW	CGW	CGW
Unit of Measure:	UGL	UGL	UGL	UGL	UGL	UGL	UGL

	L	V	R				L	V	R				L	V	R				L	V	R				L	V	R				L	V	R			
1,3,5-TRINITROBENZENE				26.000	C	EN				180.000	C	E	LT			0.210		E	LT			0.210				200.000	C	EN		9.640	CB	E		13.300	CB	E
1,3-DINITROBENZENE	LT			0.458						2.710	C		LT			0.458			LT			0.458				4.940	C		LT		0.458			LT		0.458	
2,4,6-TRINITROTOLUENE				0.612	UQ					7.290	UQ		LT			0.426			LT			0.426	7	J		310.000	C			3.330	UQ		LT		0.426	
2,4-DINITROTOLUENE				2.950	UQ					19.500	UQ	N				1.470	UQ	N	LT			0.397	7	NJR		79.000	C			4.450	UQ				1.170	UQ
2,6-DINITROTOLUENE	LT			6.000	JI					22.400	C					2.930	C		LT			0.600			LT	60.000	JI		LT	5.090	K		LT		0.600	
NITROBENZENE	LT			0.682		N	LT			16.800	K					1.160	K					0.850	UQ7	NJ	LT	6.800	JI	N	LT	0.682			LT		0.682	
RDX	LT			4.200	JI					0.974	U		LT			0.416			LT			0.416			LT	21.200	K			1.710	U				0.614	U

Data Summary Table (Positive Hits Only) for Savanna - Total
Chemical Analysis Data
Explosive Compounds - Groundwater
Criteria: Site - 21

Site ID:	21				21				21				21			
Loc ID:	302122				302123				302124				392101			
Sample ID:	02122				02123				02124				92101			
SDG:																
Sample Date:	05/25/93				05/12/93				05/26/93				03/18/93			
Depth:	64.5				26.4				22.8				18.0			
Matrix:	CGW				CGW				CGW				CGW			
Unit of Measure:	UGL				UGL				UGL				UGL			
			L	V	R			L	V	R			L	V	R	
1,3,5-TRINITROBENZENE		200.000	C			220.000	C				870.000	C		LT	0.449	
1,3-DINITROBENZENE		0.918	UQ		LT	0.458					12.900	C		LT	0.611	
2,4,6-TRINITROTOLUENE		11.100	UQ7	J		17.300	UQ				630.000	C7	J	LT	0.635	
2,4-DINITROTOLUENE	LT	7.900	JI7	NJR		6.580	UQ		LT		90.000	K7	NJR		0.356	
2,6-DINITROTOLUENE		23.700	C		LT	6.530	E				79.000	C			1.370	
NITROBENZENE		10.700	UQ7	NJ	LT	6.800	JI				58.000	U7	NJ	LT	0.645	
HMX	LT	8.300	JI		LT	17.300	E				5.420	UQ		LT	1.170	

Data Summary Table (Positive Hits Only) for Savanna - Total
Chemical Analysis Data
Dissolved Metals - Groundwater
Criteria: Site - 21

Site ID:	21	21	21	21	21	21	21
Loc ID:	300101	302101	302103	302104	302105	302106	302106
Sample ID:	00101	02101	02103	02104	02105	02106	02106DP
SDG:							
Sample Date:	05/25/93	05/05/93	05/06/93	05/05/93	05/20/93	05/20/93	05/20/93
Depth:	340.0	11.7	22.9	21.8	12.0	11.8	11.8
Matrix:	CGW	CGW	CGW	CGW	CGW	CGW	CGW
Unit of Measure:	UGL	UGL	UGL	UGL	UGL	UGL	UGL

	L V R		L V R		L V R		L V R		L V R		L V R
ALUMINUM	LT 112.000	138.000	LT 112.000	LT 112.000	LT 112.000	LT 112.000	LT 112.000
BARIUM	137.000	80.000	73.800	107.000	219.000	45.500	47.300
CALCIUM	49100.000	26400.000	71200.000	101000.000	141000.000	93700.000	90200.000
IRON	119.000	LT 77.500	LT 77.500	LT 77.500	LT 77.500	LT 77.500	LT 77.500
MAGNESIUM	34000.000	8990.000	40200.000	45800.000	55200.000	41000.000	39100.000
MANGANESE	LT 9.670	1800.000	175.000	LT 9.670	1010.000	134.000	128.000
MERCURY	LT 0.1000	0.2740	0.3930	0.2180	0.3300	0.2920	0.4220
POTASSIUM	2550.000	LT 1240.000	2730.000	LT 1240.000	1500.000	LT 1240.000	LT 1240.000
SODIUM	1390.000	2650.000	5890.000	6830.000	10100.000	7830.000	7280.000
THALLIUM	LT 125.000	LT 125.000	LT 125.000	LT 125.000	146.000	LT 125.000	LT 125.000
ZINC	LT 18.000	42.000	LT 18.000	LT 18.000	21.800	LT 18.000	LT 18.000

Data Summary Table (Positive Hits Only) for Savanna - Total
Chemical Analysis Data
Dissolved Metals - Groundwater
Criteria: Site - 21

Site ID:	21	21	21	21	21	21	21
Loc ID:	302107	302119	302121	302122	302123	302124	392101
Sample ID:	02107	02119	02121	02122	02123	02124	92101
SDG:							
Sample Date:	05/05/93	05/20/93	05/25/93	05/25/93	05/12/93	05/26/93	03/18/93
Depth:	67.6	20.6	150.4	64.5	26.4	22.8	18.0
Matrix:	CGW	CGW	CGW	CGW	CGW	CGW	CGW
Unit of Measure:	UGL	UGL	UGL	UGL	UGL	UGL	UGL

	L V R	L V R	L V R	L V R	L V R	L V R	L V R
ALUMINUM	LT 112.000	LT 112.000	LT 112.000	LT 112.000	LT 112.000	LT 112.000	LT 112.000
BARIUM	38.600	69.600	25.900	58.700	49.800	116.000	135.000 B I
CALCIUM	67300.000	60600.000	43400.000	78600.000	74900.000	104000.000	39100.000
IRON	LT 77.500	LT 77.500	LT 77.500	LT 77.500	LT 77.500	LT 77.500	LT 77.500
MAGNESIUM	25800.000	26200.000	28500.000	29300.000	25500.000	43900.000	13400.000
MANGANESE	13.500	32.800	251.000	LT 9.670	LT 9.670	3360.000	1420.000
MERCURY	0.1780	0.4750	0.1550	0.1240	0.2570	0.3670	LT 0.1000
POTASSIUM	2630.000	LT 1240.000	3230.000	2220.000	LT 1240.000	2040.000	2310.000
SODIUM	3770.000	5470.000	7240.000	7080.000	4820.000	7910.000	10400.000
THALLIUM	LT 125.000	LT 125.000	LT 125.000	LT 125.000	LT 125.000	LT 125.000	LT 125.000
ZINC	LT 18.000	LT 18.000	LT 18.000	LT 18.000	LT 18.000	LT 18.000	1120.000

Data Summary Table (Positive Hits Only) for Savanna - Total
Chemical Analysis Data
Anions/Inorganics - Sediment
Criteria: Site - 21

Site ID:	21	21	21	21	21	21
Loc ID:	362101	362102	362103	362104	362104	362105
Sample ID:	62101S	62102S	62103S	62104S	62104SDP	62105S
SDG:						
Sample Date:	05/20/92	05/20/92	05/20/92	05/21/92	05/21/92	05/20/92
Depth:	1.0	1.0	1.0	0.0	0.0	0.5
Matrix:	CSE	CSE	CSE	CSE	CSE	CSE
Unit of Measure:	UGG	UGG	UGG	UGG	UGG	UGG

	L V R		L V R		L V R		L V R		L V R		L V R	
CHLORIDE	LT	7.120	NT		21.500		13.700		LT	7.120	NT	
NITRITE, NITRATE		4.370		4.880		4.850		8.330		8.840		5.370
PHOSPHORUS		681.000	NT		1250.000		1520.000		880.000		NT	
SULFATE		127.000		NT		55.200		22.800		14.200		NT

Data Summary Table (Positive Hits Only) for Savanna - Total
Chemical Analysis Data
Environmental Indicators - Sediment
Criteria: Site - 21

Site ID:	21	21	21	21	21	21
Loc ID:	362101	362103	362104	362104	362110	362117
Sample ID:	62101S	62103S	62104S	62104SDP	62110S	62117S
SDG:						
Sample Date:	05/20/92	05/20/92	05/21/92	05/21/92	03/25/93	03/25/93
Depth:	1.0	1.0	0.0	0.0	3.0	2.0
Matrix:	CSE	CSE	CSE	CSE	CSE	CSE
Unit of Measure:	UGG	UGG	UGG	UGG		

	L	V	R	L	V	R	L	V	R	L	V	R	L	V	R	L	V	R
PH		7.800			7.200			6.200			6.200			7.300			7.300	

Data Summary Table (Positive Hits Only) for Savanna - Total
Chemical Analysis Data
Total Metals - Sediment
Criteria: Site - 21

Site ID:	21	21	21	21
Loc ID:	362101	362103	362104	362104
Sample ID:	62101S	62103S	62104S	62104SDP
SDG:				
Sample Date:	05/20/92	05/20/92	05/21/92	05/21/92
Depth:	1.0	1.0	0.0	0.0
Matrix:	CSE	CSE	CSE	CSE
Unit of Measure:	UGG	UGG	UGG	UGG

	L V R		L V R		L V R		L V R	
ALUMINUM		12900.000		41200.000		22700.000		17200.000
ARSENIC	LT	2.500	LT	2.500		9.820		7.270
BARIUM		127.000		353.000		256.000		216.000
BERYLLIUM	LT	0.427		1.200		2.160		1.720
CALCIUM		16400.000		29200.000		5540.000		4960.000
CHROMIUM		16.800		46.700		32.600		25.000
COBALT		6.480		17.200		15.100		13.200
COPPER		7.800		26.400		30.100		24.800
IRON		14800.000		46800.000		35000.000		30300.000
LEAD	LT	7.440		47.100		55.800		68.300
MAGNESIUM		5530.000		10100.000		4930.000		4070.000
MANGANESE		1900.000		1440.000		1130.000		1200.000
NICKEL		11.200		36.500		27.100		22.100
POTASSIUM		1980.000		5190.000		1830.000		1410.000
SODIUM		81.900		149.000		91.300		70.500
VANADIUM		28.200		74.800		41.700		34.100
ZINC		47.800		294.000		228.000		221.000

Data Summary Table (Positive Hits Only) for Savanna - Total
Chemical Analysis Data
Environmental Indicators - Soil
Criteria: Site - 21

Site ID:	21	21	21	21	21	21
Loc ID:	302119	302119	312131	312132	312133	312134
Sample ID:	12128A	12128C	12131	12132	12133	12134
SDG:						
Sample Date:	03/22/93	03/22/93	03/23/93	03/23/93	03/23/93	03/23/93
Depth:	0.0	5.0	2.0	2.0	1.5	1.5
Matrix:	CSO	CSO	CSO	CSO	CSO	CSO
Unit of Measure:	UGG	UGG				
	L V R	L V R	L V R	L V R	L V R	L V R
PH	6.600	6.100	7.700	7.600	7.700	8.000

Data Summary Table (Positive Hits Only) for Savanna - Total
Chemical Analysis Data
Total Metals - Soil
Criteria: Site - 21

Site ID:	21		21		
Loc ID:	302119		302119		
Sample ID:	12128A		12128C		
SDG:					
Sample Date:	03/22/93		03/22/93		
Depth:	0.0		5.0		
Matrix:	CSO		CSO		
Unit of Measure:	UGG		UGG		
		L V R		L V R	
ALUMINUM	17000.000		14700.000		
BARIUM	92.600		131.000		
BERYLLIUM	0.807		0.631		
CALCIUM	2070.000		3190.000		
CHROMIUM	20.800		22.900		
COBALT	12.900		7.620		
COPPER	11.000		10.200		
IRON	21100.000		20500.000		
LEAD	12.800		7.440	LT	
MAGNESIUM	2970.000		3320.000		
MANGANESE	408.000		476.000		
NICKEL	13.300		18.300		
POTASSIUM	894.000		1340.000		
SODIUM	38.700	LT	96.500		
VANADIUM	24.500		30.200		
ZINC	49.800		47.300		

Data Summary Table (Positive Hits Only) for Savanna - Total
Chemical Analysis Data
Total Organic Carbon - Soil
Criteria: Site - 21

Site ID:	21	21	21	21	21
Loc ID:	302119	302119	302119	302120	302120
Sample ID:	12128B	12128D	12128E	12129B	12129C
SDG:					
Sample Date:	03/22/93	03/22/93	03/22/93	03/19/93	03/19/93
Depth:	3.0	10.0	20.0	10.0	20.0
Matrix:	CSO	CSO	CSO	CSO	CSO
Unit of Measure:	UGG	UGG	UGG	UGG	UGG
	L V R	L V R	L V R	L V R	L V R
TOTAL ORGANIC CARBON	LT 1000.000	2000.000	LT 1000.000	3000.000	LT 1000.000

Data Summary Table (Positive Hits Only) for Savanna - Total
Chemical Analysis Data
Anions/Inorganics - Surface Water
Criteria: Site - 21

Site ID:	21	21	21	21
Loc ID:	352101	352102	352103	352105
Sample ID:	52101W	52102W	52103W	52105W
SDG:				
Sample Date:	05/20/92	05/20/92	05/20/92	05/20/92
Depth:	0.5	0.5	0.5	0.5
Matrix:	CSW	CSW	CSW	CSW
Unit of Measure:	UGL	UGL	UGL	UGL

	L V R	L V R	L V R	L V R
CHLORIDE	7450.000	NT	7060.000	NT
FLUORIDE	418.000	NT	432.000	NT
NITRITE, NITRATE	1000.000	1000.000	22.000	440.000
PHOSPHORUS	53.700	NT	54.400	NT
SULFATE	40000.000	NT	36000.000	NT

Data Summary Table (Positive Hits Only) for Savanna - Total
Chemical Analysis Data
Total Metals - Surface Water
Criteria: Site - 21

Site ID:	21			21				
Loc ID:	352101			352103				
Sample ID:	52101W			52103W				
SDG:								
Sample Date:	05/20/92			05/20/92				
Depth:	0.5			0.5				
Matrix:	CSW			CSW				
Unit of Measure:	UGL			UGL				
		L	V	R		L	V	R
ALUMINUM	349.000				1470.000			
BARIUM	109.000				107.000			
CALCIUM	68400.000				73200.000			
IRON	585.000				2010.000			
MAGNESIUM	37000.000				40200.000			
MANGANESE	185.000				483.000			
POTASSIUM	LT 1240.000				1450.000			
SODIUM	3990.000				4200.000			
ZINC	LT 18.000				26.100			

APPENDIX B-1

UV/OX PERFORMANCE EVALUATION DATA

WESTON

GLOSSARY OF EXPLOSIVE DATA

DATA QUALIFIERS

U = Indicates that the compound was analyzed for but not detected. The minimum detection limit for the sample (not the method detection limit) is reported with the U (e.g., 10U).

J = Indicates an estimated value. This flag is used in cases where a target analyte is detected at a level less than the lower quantification level. If the limit of quantification is 10 ug/L and a concentration of 3 ug/L is calculated, it is reported as 3J.

B = This flag is used when the analyte is found in the associated blank as well as in the sample. It indicates possible/probable blank contamination. This flag is also used for a TIC as well as for a positively identified TCL compound.

E = Indicates that the compound was detected beyond the calibration range and was subsequently analyzed at a dilution.

I = Interference.

ABBREVIATIONS

BS = Indicates blank spike in which reagent grade water is spiked with the CLP matrix spiking solutions and carried through all the steps in the method. Spike recoveries are reported.

BSD = Indicates blank spike duplicate.

MS = Indicates matrix spike.

MSD = Indicates matrix spike duplicate.

DL = Indicates that recoveries were not obtained because the extract had to be diluted for analysis.

NA = Not Applicable.

DF = Dilution Factor.

NR = Not Required.

SP = Indicates spiked compound.

USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS
DATE:		27-Sep-94			28-Sep-94			29-Sep-94	
SAMPLE NAME:	P09271	P09272	P09273	PUR09281	PUR09282	PUR09283	PUR09291	PUR09292	PUR09293
SAMPLE TIME:	12:09	15:20	17:57	10:09	13:20	15:40	9:56	13:10	16:10
HMX	8.8 U	7.2 U	5.4 U	6.3 U	15 U	21 U	9.9 U	11 U	13 U
RDX	4.3 U	3.5 U	2.6 U	3.1 U	7.3 U	10 U	4.8 U	5.4 U	6.2 U
1,3,5-Trinitrobenzene	750	780	770	750	690	640	380	320	430
1,3-Dinitrobenzene	11	11	13	12	9.9	8.0	77	43	66
Nitrobenzene	1.0 U	0.85 U	0.63 U	0.74 U	1.8 U	2.4 U	1.2 U	1.3 U	1.5 U
Tetryl	3.0 U	2.5 U	1.8 U	2.1 U	5.1 U	7.0 U	3.4 U	3.8 U	4.3 U
Amino DNTs	2.0 U	1.6 U	1.2 U	1.4 U	3.4 U	4.7 U	4.0	2.0	4.9
2,4,6-Trinitrotoluene	12	12	4.5	4.7	6.9	6.5	14	3.1	4.0
2,6-Dinitrotoluene	1.0 U	0.85 U	0.63 U	0.74 U	1.8 U	2.4 U	1.2 U	1.3 U	1.5 U
2,4-Dinitrotoluene	1.0 U	0.82 U	0.61 U	0.72 U	1.7 U	2.3 U	7.8	4.0	5.6
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

U = Analyte not detected. Value presented is the lower detection limit.
J = Analyte present below the lower detection limit.

USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS
DATE:		30-Sep-94			3-Oct-94			4-Oct-94	
SAMPLE NAME:	PUR09301	PUR09302	PUR09303	PUR10031	PUR10032	PUR10033	PUR10041	PUR10042	PUR10043
SAMPLE TIME:	10:03	12:44	15:10	9:55	13:15	16:00	9:00	12:00	14:30
HMX	11 U	5.5 U	8.4 U	17 U	6.9 U	8.0 U	5.7 U	20 U	16 U
RDX	5.5 U	2.7 U	4.1 U	8.3 U	3.4 U	3.9 U	2.8 U	10 U	7.6 U
1,3,5-Trinitrobenzene	290	290	390	360	160	95	380	480	510
1,3-Dinitrobenzene	12	13	55	48	5.6	2.8	14	17	89
Nitrobenzene	1.3 U	0.64 U	1.0 U	2.0 U	0.81 U	0.95 U	0.68 U	2.4 U	1.8 U
Tetryl	3.8 U	1.9 U	2.9 U	5.8 U	2.3 U	2.7 U	2.0 U	6.9 U	5.3 U
Amino DNTs	2.5 U	1.2 U	4.1	1.5	1.6 U	1.8 U	1.3 U	4.6 U	1.1
2,4,6-Trinitrotoluene	9.1	3.2	4.0	3.1	1.3	0.74	13	6.4	9.7
2,6-Dinitrotoluene	1.3 U	0.64 U	1.0 U	2.0 U	0.81 U	0.95 U	0.68 U	2.4 U	1.8 U
2,4-Dinitrotoluene	1.3 U	0.91	4.7	3.6	0.78 U	0.91 U	0.47	2.3 U	3.2
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

U = Analyte not detected. Value presented is the lower detection limit.
J = Analyte present below the lower detection limit.

USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS
DATE:		5-Oct-94			6-Oct-94			7-Oct-94	
SAMPLE NAME:	PUR10051	PUR10052	PUR10053	PUR10061	PUR10062	PUR10063	PUR10071	PUR10072	PUR10073
SAMPLE TIME:	9:48	12:30	14:45	9:35	11:50	14:35	8:35	11:10	13:35
HMX	14 U	14 U	14 U	14 U	14 U	14 U	14 U	14 U	14 U
RDX	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U
1,3,5-Trinitrobenzene	240	560	570	440	630	730	730	780	1.7
1,3-Dinitrobenzene	7.5	14	14	93	15	18	17	20	27
Nitrobenzene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U
Tetryl	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U
Amino DNTs	3.1 U	3.1 U	3.1 U	5.8	3.1 U	3.1 U	3.1 U	3.1 U	12
2,4,6-Trinitrotoluene	6.0	34	21	4.1	7.3	4.3	12	6.6	1.7
2,6-Dinitrotoluene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U
2,4-Dinitrotoluene	1.6 U	1.6 U	1.6 U	2.7	1.6 U	1.6 U	1.6 U	1.6 U	1.5
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

U = Analyte not detected. Value presented is the lower detection limit.
J = Analyte present below the lower detection limit.

USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS
DATE:		10-Oct-94			11-Oct-94			12-Oct-94	
SAMPLE NAME:	PUR10101	PUR10102	PUR10103	PUR10111	PUR10112	PUR10113	PUR10121	PUR10122	PUR10123
SAMPLE TIME:	9:50	13:30	15:30	10:10	13:45	15:45	10:50	13:45	16:00
HMX	14 U	14 U	14 U	14 U	14 U	14 U	15 U	21 U	14 U
RDX	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	7.3 U	11 U	6.7 U
1,3,5-Trinitrobenzene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.7 U	2.4 U	74
1,3-Dinitrobenzene	16	2.4	1.2	9.4	1.6 U	6.3	5.8	1.4	23
Nitrobenzene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.8 U	2.5 U	1.6 U
Tetryl	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	5.1 U	7.3 U	4.7 U
Amino DNTs	17	14	12	13	7.7	8.2	13	9.5	6.5
2,4,6-Trinitrotoluene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.7 U	2.4 U	1.1
2,6-Dinitrotoluene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.8 U	2.5 U	1.6 U
2,4-Dinitrotoluene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.7 U	2.4 U	1.6 U
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

U = Analyte not detected. Value presented is the lower detection limit.
J = Analyte present below the lower detection limit.

USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS
DATE:		13-Oct-94			14-Oct-94	
SAMPLE NAME:	PUR10131	PUR10132	PUR10133	PUR10141	PUR10142	PUR10143
SAMPLE TIME:	11:20	14:35	16:10	9:50	13:15	14:45
HMX	14 U	14 U	14 U	14 U	14 U	14 U
RDX	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U
1,3,5-Trinitrobenzene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	4.5
1,3-Dinitrobenzene	15	12	1.6	1.6 U	3.6	9.5
Nitrobenzene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U
Tetryl	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U
Amino DNTs	12	9.4	8.7	3.1 U	9.2	4.4
2,4,6-Trinitrotoluene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U
2,6-Dinitrotoluene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U
2,4-Dinitrotoluene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U
Hardness (in mg/L)	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-
Iron	-	-	-	-	-	-
Manganese	-	-	-	-	-	-

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J = Analyte present below the lower detection limit.

USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM
DATE:		27-Sep-94			28-Sep-94			29-Sep-94	
SAMPLE NAME:	S09271	S09272	S09273	SLR09281	SLR09282	SLR09283	SLR09291	SLR09292	SLR09293
SAMPLE TIME:	12:13	15:30	17:55	10:23	13:28	15:50	10:10	13:25	16:30
HMX	6.7 U	8.7 U	5.7 U	2.7 U	8.0 U	11 U	6.6 U	6.5 U	5.8 U
RDX	3.3 U	4.3 U	2.8 U	1.3 U	3.9 U	5.5 U	3.3 U	3.2 U	2.9 U
1,3,5-Trinitrobenzene	34	6.5	150	17	7.8	4.6	11	2.3	1.7
1,3-Dinitrobenzene	5.1	3.2	0.65 U	1.0	4.3	5.2	2.7	2.8	2.5
Nitrobenzene	0.80 U	1.0 U	0.68 U	0.32 U	0.95 U	1.3 U	0.79 U	0.77 U	0.69 U
Tetryl	2.3 U	3.0 U	2.0 U	0.93 U	2.7 U	3.8 U	2.3 U	2.2 U	2.0 U
Amino DNTs	1.6	2.0 U	1.3 U	0.62 U	1.8 U	2.6 U	1.5 U	1.5 U	1.3 U
2,4,6-Trinitrotoluene	0.76 U	0.98 U	1.4	23	2.2	26	0.76 U	5.4	0.66 U
2,6-Dinitrotoluene	0.80 U	1.0 U	0.68 U	0.32	0.95 U	1.3 U	0.79 U	0.77 U	0.69 U
2,4-Dinitrotoluene	4.3	2.0	0.65 U	1.6	2.6	4.0	2.5	2.1	1.1
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

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J = Analyte present below the lower detection limit.

USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM
DATE:		30-Sep-94			3-Oct-94			4-Oct-94	
SAMPLE NAME:	SLR09301	SLR09302	SLR09303	SLR10031	SLR10032	SLR10033	SLR10041	SLR10042	SLR10043
SAMPLE TIME:	10:15	13:03	15:30	10:05	13:35	16:20	9:20	12:20	14:50
HMX	6.2 U	7.8 U	5.9 U	8.4 U	3.7 U	3.9 U	5.1 U	8.0 U	7.4 U
RDX	3.0 U	3.8 U	2.9 U	4.1 U	1.8 U	1.9 U	2.5 U	3.9 U	3.7 U
1,3,5-Trinitrobenzene	9.9	0.88 U	1.4	91	0.90	1.7	21	0.91 U	0.84 U
1,3-Dinitrobenzene	1.9	0.88 U	1.5	4.0	0.58	1.2	3.2	2.5	2.5
Nitrobenzene	0.73 U	0.92 U	0.70 U	1.0 U	0.43 U	0.46 U	0.61 U	0.95 U	0.88 U
Tetryl	2.1 U	2.7 U	2.0 U	2.9 U	1.2 U	1.3 U	1.8 U	2.7 U	2.5 U
Amino DNTs	1.4 U	1.8 U	1.4 U	5.9	0.83 U	0.88 U	1.2 U	1.8 U	1.7 U
2,4,6-Trinitrotoluene	0.80	0.88 U	0.68 U	110	0.71	0.44 U	48	32	26
2,6-Dinitrotoluene	0.73 U	0.92 U	0.70 U	1.7	0.43 U	0.46 U	0.75	0.95 U	0.88 U
2,4-Dinitrotoluene	2.0	0.88 U	1.3	13	0.42 U	0.78	3.1	1.5	1.4
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

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J = Analyte present below the lower detection limit.

USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM
DATE:		5-Oct-94			6-Oct-94			7-Oct-94	
SAMPLE NAME:	SLR10051	SLR10052	SLR10053	SLR10061	SLR10062	SLR10063	SLR10071	SLR10072	SLR10073
SAMPLE TIME:	9:52	12:45	15:00	9:50	12:05	14:50	8:50	11:25	13:50
HMX	6.9 U	6.9 U	6.9 U	6.9 U	6.9 U	6.9 U	7.4 U	6.9 U	6.9 U
RDX	3.4 U	3.4 U	3.4 U	3.4 U	3.4 U	3.4 U	3.7 U	3.4 U	3.4 U
1,3,5-Trinitrobenzene	4.8	1.0	0.78 U	2.9	0.78 U	0.78 U	9.3	0.78 U	0.78 U
1,3-Dinitrobenzene	2.7	2.2	2.3	2.2	1.9	1.4	1.3	0.78 U	0.78 U
Nitrobenzene	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U	0.88 U	0.81 U	0.81 U
Tetryl	2.3 U	2.3 U	2.3 U	2.3 U	2.3 U	2.3 U	2.5 U	2.3 U	2.3 U
Amino DNTs	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.7 U	1.6 U	1.6 U
2,4,6-Trinitrotoluene	32	23	18	18	15	9.6	8.9	0.78 U	0.78 U
2,6-Dinitrotoluene	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U	0.88 U	0.81 U	0.81 U
2,4-Dinitrotoluene	1.5	1.6	1.0	0.90	0.78 U	0.78 U	0.84 U	0.78 U	0.78 U
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

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J = Analyte present below the lower detection limit.

USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM
DATE:		10-Oct-94			11-Oct-94			12-Oct-94	
SAMPLE NAME:	SLR10101	SLR10102	SLR10103	SLR10111	SLR10112	SLR10113	SLR10121	SLR10122	SLR10123
SAMPLE TIME:	11:00	13:30	15:30	10:10	13:52	15:45	10:50	13:45	16:00
HMX	6.9 U	6.9 U	6.9 U	6.9 U	6.9 U	6.9 U	7.4 U	6.9 U	6.9 U
RDX	3.4 U	3.4 U	3.4 U	3.4 U	3.4 U	3.4 U	3.7 U	3.4 U	3.4 U
1,3,5-Trinitrobenzene	25	1.4	3.2	2.2	0.78 U	0.78 U	3.5	1.2	0.78 U
1,3-Dinitrobenzene	2.0	1.2	1.4	1.3	1.5	1.3	1.5	0.67	0.64
Nitrobenzene	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U	0.88 U	0.81 U	0.81 U
Tetryl	2.3 U	2.3 U	2.3 U	2.3 U	2.3 U	2.3 U	2.5 U	2.3 U	2.3 U
Amino DNTs	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.7 U	1.6 U	1.6 U
2,4,6-Trinitrotoluene	90	19	21	29	22	19	21	0.78 U	9.5
2,6-Dinitrotoluene	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U	0.88 U	0.81 U	0.81 U
2,4-Dinitrotoluene	0.78 U	0.78 U	0.78 U	0.78 U	0.78 U	0.78 U	0.84 U	0.78 U	0.78 U
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

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USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM
DATE:		13-Oct-94			14-Oct-94	
SAMPLE NAME:	SLR10131	SLR10132	SLR10133	SLR10141	SLR10142	SLR10143
SAMPLE TIME:	11:20	14:35	16:10	10:20	13:15	14:45
HMX	6.9 U	6.9 U	6.9 U	6.9 U	6.9 U	6.9 U
RDX	3.4 U	3.4 U	3.4 U	3.4 U	3.4 U	3.4 U
1,3,5-Trinitrobenzene	0.97	0.78 U	0.78 U	0.78 U	0.78 U	0.78 U
1,3-Dinitrobenzene	1.4	1.2	0.78 U	1.7	0.98	0.78 U
Nitrobenzene	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U
Tetryl	2.3 U	2.3 U	2.3 U	2.3 U	2.3 U	2.3 U
Amino DNTs	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U
2,4,6-Trinitrotoluene	12	17	11	24	19	13
2,6-Dinitrotoluene	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U
2,4-Dinitrotoluene	0.78 U	0.78 U	0.78 U	0.78 U	0.78 U	0.78 U
Hardness (in mg/L)	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-
Iron	-	-	-	-	-	-
Manganese	-	-	-	-	-	-

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USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX
DATE:		27-Sep-94			28-Sep-94			29-Sep-94	
SAMPLE NAME:	U09271	U09272	U09273	ULT09281	ULT09282	ULT09283	ULT09291	ULT09292	ULTR09293
SAMPLE TIME:	12:10	15:30	17:50	10:20	13:22	15:54	10:05	13:19	16:25
HMX	6.9 U	7.0 U	4.6 U	6.1 U	8.8 U	5.5 U	6.1 U	5.6 U	4.7 U
RDX	3.4 U	3.4 U	2.2 U	3.0 U	4.3 U	2.7 U	3.0 U	2.7 U	2.3 U
1,3,5-Trinitrobenzene	0.78 U	0.79 U	0.52 U	0.69 U	1.0 U	0.62 U	0.69 U	0.64 U	0.53 U
1,3-Dinitrobenzene	0.78 U	0.79 U	0.52 U	0.69 U	1.0 U	0.62 U	0.69 U	0.64 U	0.53 U
Nitrobenzene	0.81 U	0.82 U	0.54 U	0.72 U	1.0 U	0.65 U	0.72 U	0.66 U	0.55 U
Tetryl	2.3 U	2.4 U	1.6 U	2.1 U	3.0 U	1.9 U	2.1 U	1.9 U	1.6 U
Amino DNTs	1.6 U	1.6 U	1.0 U	1.4 U	2.0 U	1.2 U	1.4 U	1.3 U	1.1 U
2,4,6-Trinitrotoluene	0.78 U	0.79 U	0.52 U	0.69 U	1.0 U	0.62 U	0.69 U	0.64 U	0.53 U
2,6-Dinitrotoluene	0.81 U	0.82 U	0.54 U	0.72 U	1.0 U	0.65 U	0.72 U	0.66 U	0.55 U
2,4-Dinitrotoluene	0.78 U	0.79 U	0.52 U	0.69 U	1.0 U	0.62 U	0.69 U	0.64 U	0.53 U
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

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USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX
DATE:		30-Sep-94			3-Oct-94			4-Oct-94	
SAMPLE NAME:	ULT09301	ULT09302	ULT09303	ULT10031	ULT10032	ULT10033	ULT10041	ULT10042	ULT10043
SAMPLE TIME:	10:12	13:01		10:03	13:30	16:15	9:15	12:15	14:45
HMX	7.1 U	4.7 U	BROKEN	6.5 U	3.2 U	3.2 U	4.0 U	6.9 U	6.9 U
RDX	3.5 U	2.3 U	DURING	3.2 U	1.6 U	1.6 U	2.0 U	3.4 U	3.4 U
1,3,5-Trinitrobenzene	0.80 U	0.53 U	SHIPMENT	0.74 U	0.36 U	0.36 U	0.46 U	0.78 U	0.78 U
1,3-Dinitrobenzene	0.80 U	0.53 U	-	0.74 U	0.36 U	0.36 U	0.46 U	0.78 U	0.78 U
Nitrobenzene	0.84 U	0.55 U	-	0.77 U	0.38 U	0.38 U	0.47 U	0.81 U	0.81 U
Tetryl	2.4 U	1.6 U	-	2.2 U	1.1 U	1.1 U	1.4 U	2.3 U	2.3 U
Amino DNTs	1.6 U	1.1 U	-	1.5 U	0.73 U	0.73 U	0.91 U	1.6 U	1.6 U
2,4,6-Trinitrotoluene	0.80 U	0.53 U	-	0.74 U	0.36 U	0.36 U	0.46 U	0.78 U	0.78 U
2,6-Dinitrotoluene	0.84 U	0.55 U	-	0.77 U	0.38 U	0.38 U	0.47 U	0.81 U	0.81 U
2,4-Dinitrotoluene	0.80 U	0.53 U	-	0.74 U	0.36 U	0.36 U	0.46 U	0.78 U	0.78 U
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

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J = Analyte present below the lower detection limit.

USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX
DATE:		5-Oct-94			6-Oct-94			7-Oct-94	
SAMPLE NAME:	ULT10051	ULT10052	ULT10053	ULT10061	ULT10062	ULT10063	ULT10071	ULT10072	ULT10073
SAMPLE TIME:	9:54	12:40	14:55	9:45	12:00	14:45	8:45	11:20	13:45
HMX	6.9 U	6.9 U	6.9 U	7.5 U	6.9 U	6.9 U	7.4 U	6.9 U	6.9 U
RDX	3.4 U	3.4 U	3.4 U	3.7 U	3.4 U	3.4 U	3.7 U	3.4 U	3.4 U
1,3,5-Trinitrobenzene	0.78 U	0.78 U	0.78 U	0.86 U	0.78 U	0.78 U	0.84 U	0.78 U	0.78 U
1,3-Dinitrobenzene	0.78 U	0.78 U	0.78 U	0.86 U	0.78 U	0.78 U	0.84 U	0.78 U	0.78 U
Nitrobenzene	0.81 U	0.81 U	0.81 U	0.89 U	0.81 U	0.81 U	0.88 U	0.81 U	0.81 U
Tetryl	2.3 U	2.3 U	2.3 U	2.6 U	2.3 U	2.3 U	2.5 U	2.3 U	2.3 U
Amino DNTs	1.6 U	1.6 U	1.6 U	1.7 U	1.6 U	1.6 U	1.7 U	1.6 U	1.6 U
2,4,6-Trinitrotoluene	0.78 U	0.78 U	0.78 U	0.86 U	0.78 U	0.78 U	0.84 U	0.78 U	0.78 U
2,6-Dinitrotoluene	0.81 U	0.81 U	0.81 U	0.89 U	0.81 U	0.81 U	0.88 U	0.81 U	0.81 U
2,4-Dinitrotoluene	0.78 U	0.78 U	0.78 U	0.86 U	0.78 U	0.78 U	0.84 U	0.78 U	0.78 U
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

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J = Analyte present below the lower detection limit.

USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX
DATE:		10-Oct-94			11-Oct-94			12-Oct-94	
SAMPLE NAME:	ULT10101	ULT10102	ULT10103	ULT10111	ULT10112	ULT10113	ULT10121	ULT10122	ULT10123
SAMPLE TIME:	11:00	13:30	15:30	10:10	13:50	15:45	10:50	13:45	16:00
HMX	11 U	6.9 U	6.9 U	6.9 U	6.9 U	7.1 U	8.8 U	6.9 U	6.9 U
RDX	5.6 U	3.4 U	3.4 U	3.4 U	3.4 U	3.5 U	4.3 U	3.4 U	3.4 U
1,3,5-Trinitrobenzene	6.6	0.78 U	0.78 U	0.78 U	0.78 U	0.80 U	1.0 U	0.78 U	0.78 U
1,3-Dinitrobenzene	1.3 U	0.78 U	0.78 U	0.78 U	0.78 U	0.80 U	1.0 U	0.78 U	0.78 U
Nitrobenzene	1.3 U	0.81 U	0.81 U	0.81 U	0.81 U	0.84 U	1.0 U	0.81 U	0.81 U
Tetryl	3.9 U	2.3 U	2.3 U	2.3 U	2.3 U	2.4 U	3.0 U	2.3 U	2.3 U
Amino DNTs	2.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	2.0 U	1.6 U	1.6 U
2,4,6-Trinitrotoluene	1.3 U	0.78 U	0.78 U	0.78 U	0.78 U	0.80 U	1.0 U	0.78 U	0.78 U
2,6-Dinitrotoluene	1.3 U	0.81 U	0.81 U	0.81 U	0.81 U	0.84 U	1.0 U	0.81 U	0.81 U
2,4-Dinitrotoluene	1.3 U	0.78 U	0.78 U	0.78 U	0.78 U	0.80 U	1.0 U	0.78 U	0.78 U
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

U = Analyte not detected. Value presented is the lower detection limit.
J = Analyte present below the lower detection limit.

USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX
DATE:		13-Oct-94			14-Oct-94	
SAMPLE NAME:	ULT10131	ULT10132	ULT10133	ULT10141	ULT10142	ULT10143
SAMPLE TIME:	11:20	14:35	14:35	10:10	13:15	14:45
HMX	6.9 U	6.9 U	6.9 U	6.9 U	6.9 U	9.7 U
RDX	3.4 U	3.4 U	3.4 U	3.4 U	3.4 U	4.8 U
1,3,5-Trinitrobenzene	0.78 U	0.78 U	0.78 U	0.78 U	0.78 U	1.1 U
1,3-Dinitrobenzene	0.78 U	0.78 U	0.78 U	0.78 U	0.78 U	1.1 U
Nitrobenzene	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U	1.1 U
Tetryl	2.3 U	2.3 U	2.3 U	2.3 U	2.3 U	3.3 U
Amino DNTs	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	2.2 U
2,4,6-Trinitrotoluene	0.78 U	0.78 U	0.78 U	0.78 U	0.78 U	1.1 U
2,6-Dinitrotoluene	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U	1.1 U
2,4-Dinitrotoluene	0.78 U	0.78 U	0.78 U	0.78 U	0.78 U	1.1 U
Hardness (in mg/L)	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-
Iron	-	-	-	-	-	-
Manganese	-	-	-	-	-	-

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USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI
DATE:		27-Sep-94			28-Sep-94			29-Sep-94	
SAMPLE NAME:	V09271	V09272	V09273	VPS09281	VPS09282	VPS09283	VPS09291	VPS09292	VPS09293
SAMPLE TIME:	1210	15:25	18:00	10:12	13:18	15:42	9:58	13:15	16:15
HMX	7.1 U	4.6 U	7.1 U	9.7 U	14 U	7.6 U	16 U	11 U	8.9 U
RDX	3.5 U	2.2 U	3.5 U	4.8 U	7.1 U	3.7 U	7.6 U	5.4 U	4.4 U
1,3,5-Trinitrobenzene	760	57	17	1.1 U	130	240	250	230	150
1,3-Dinitrobenzene	17	0.52 U	1.4	28	1.6 U	0.56	1.8 U	0.72	1.0 U
Nitrobenzene	0.84 U	0.54 U	0.84 U	1.1 U	1.7 U	0.89 U	1.8 U	1.3 U	1.1 U
Tetryl	2.4 U	1.6 U	2.4 U	3.3 U	4.9 U	2.6 U	5.3 U	3.8 U	3.0 U
Amino DNTs	1.6 U	1.0 U	1.6 U	9.0	3.3 U	1.7 U	3.5 U	2.5 U	2.0 U
2,4,6-Trinitrotoluene	70	0.52 U	55	1.1 U	2.1	3.9	1.8 U	1.2	2.9
2,6-Dinitrotoluene	0.84 U	0.54 U	0.84 U	1.1 U	1.7 U	0.89 U	1.8 U	1.3 U	1.1 U
2,4-Dinitrotoluene	3.7	0.52 U	2.1	18	1.6 U	0.86 U	1.8 U	1.2 U	1.0 U
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

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USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI
DATE:		30-Sep-94			3-Oct-94			4-Oct-94	
SAMPLE NAME:	VPS09301	VPS09302	VPS09303	VPS10031	VPS10032	VPS10033	VPS10041	VPS10042	VPS10043
SAMPLE TIME:	10:05	12:47	15:12	9:57	13:20	16:05	9:05	12:05	14:35
HMX	13 U	12 U	6.6 U	15 U	11 U	7.3 U	14 U	15 U	21 U
RDX	6.6 U	5.7 U	3.2 U	7.3 U	5.5 U	3.6 U	7.1 U	7.4 U	10 U
1,3,5-Trinitrobenzene	160	520	420	7.7	15	63	1.7	2.9	16
1,3-Dinitrobenzene	1.5 U	100	42	1.7 U	1.3 U	0.83 U	1.6 U	1.7 U	2.3 U
Nitrobenzene	1.6 U	1.4 U	0.78 U	1.8 U	1.3 U	0.86 U	1.7 U	1.8 U	2.4 U
Tetryl	4.6 U	4.0 U	2.2 U	5.1 U	3.8 U	2.5 U	4.9 U	5.1 U	7.0 U
Amino DNTs	3.1 U	2.6 U	1.6	3.4 U	2.5 U	1.7 U	3.3 U	3.4 U	4.7 U
2,4,6-Trinitrotoluene	2.1	1.3 U	1.6	1.7 U	1.3 U	2.0	1.6 U	1.7 U	2.3 U
2,6-Dinitrotoluene	1.6 U	1.4 U	0.78 U	1.8 U	1.3 U	0.86 U	1.7 U	1.8 U	2.4 U
2,4-Dinitrotoluene	1.5 U	1.3 U	1.6	1.7 U	1.3 U	0.83 U	1.6 U	1.7 U	2.3 U
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

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USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI
DATE:		5-Oct-94			6-Oct-94			7-Oct-94	
SAMPLE NAME:	VPS10051	VPS10052	VPS10053	VPS10061	VPS10062	VPS10063	VPS10071	VPS10072	VPS10073
SAMPLE TIME:	9:50	12:35	14:50	9:40	11:55	14:40	8:40	11:15	13:40
HMX	23 U	14 U	14 U	14 U	14 U	14 U	15 U	14 U	14 U
RDX	11 U	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	7.3 U	6.7 U	6.7 U
1,3,5-Trinitrobenzene	57	120	100	21	35	37	57	63	30
1,3-Dinitrobenzene	2.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.7 U	1.6 U	1.6 U
Nitrobenzene	2.7 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.8 U	1.6 U	1.6 U
Tetryl	7.8 U	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	5.1 U	4.7 U	4.7 U
Amino DNTs	5.2 U	3.1 U	3.1 U	3.1 U	3.1 U	3.1 U	3.4 U	3.1 U	3.1 U
2,4,6-Trinitrotoluene	2.6 U	2.1	2.2	1.6 U	1.6 U	1.6 U	1.7 U	1.6 U	1.6 U
2,6-Dinitrotoluene	2.7 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.8 U	1.6 U	1.6 U
2,4-Dinitrotoluene	2.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.7 U	1.6 U	1.6 U
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

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J = Analyte present below the lower detection limit.

USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI
DATE:		10-Oct-94			11-Oct-94			12-Oct-94	
SAMPLE NAME:	VPS10101	VPS10102	VPS10103	VPS10111	VPS10112	VPS10113	VPS10121	VPS10122	VPS10123
SAMPLE TIME:	11:10	13:30	15:30	10:10	13:47	15:45	10:50	13:45	16:00
HMX	14 U	14 U	14 U	14 U	14 U	14 U	17 U	14 U	14 U
RDX	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	8.4 U	6.7 U	6.7 U
1,3,5-Trinitrobenzene	98	130	150	210	120	230	330	28	33
1,3-Dinitrobenzene	1.6 U	0.83	1.0	1.6 U	1.6 U	1.6 U	1.6	1.6 U	1.6 U
Nitrobenzene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	2.0 U	1.6 U	1.6 U
Tetryl	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	5.8 U	4.7 U	4.7 U
Amino DNTs	3.1 U	3.1 U	3.1 U	3.1 U	3.1 U	3.1 U	3.9 U	3.1 U	3.1 U
2,4,6-Trinitrotoluene	1.6 U	1.6 U	1.6 U	5.1	1.5	8.4	24	1.6 U	1.6 U
2,6-Dinitrotoluene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	2.0 U	1.6 U	1.6 U
2,4-Dinitrotoluene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	2.0 U	1.6 U	1.6 U
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

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USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI
DATE:		13-Oct-94			14-Oct-94	
SAMPLE NAME:	VPS10131	VPS10132	VPS10133	VPS10141	VPS10142	VPS10143
SAMPLE TIME:	11:20	14:35	14:35	10:00	13:15	14:45
HMX	14 U	14 U	14 U	14 U	16 U	14 U
RDX	6.7 U	6.7 U	6.7 U	7 U	7.9 U	6.7 U
1,3,5-Trinitrobenzene	85	120	150	31	1.8 U	4.2
1,3-Dinitrobenzene	1.6 U	1.6 U	1.6 U	2 U	1.8 U	1.6 U
Nitrobenzene	1.6 U	1.6 U	1.6 U	2 U	1.9 U	1.6 U
Tetryl	4.7 U	4.7 U	4.7 U	5 U	5.5 U	4.7 U
Amino DNTs	3.1 U	3.1 U	3.1 U	3 U	3.7 U	3.1 U
2,4,6-Trinitrotoluene	1.6 U	1.4	2.3	2 U	1.8 U	1.6 U
2,6-Dinitrotoluene	1.6 U	1.6 U	1.6 U	2 U	1.9 U	1.6 U
2,4-Dinitrotoluene	1.6 U	1.6 U	1.6 U	2 U	1.8 U	1.6 U
Hardness (in mg/L)	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-
Iron	-	-	-	-	-	-
Manganese	-	-	-	-	-	-

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J = Analyte present below the lower detection limit.

USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT
DATE:		27-Sep-94			28-Sep-94			29-Sep-94	
SAMPLE NAME:	IN09271	IN09272	IN09273	IN09281	IN09282	IN09283	IN09291	IN09292	IN09293
SAMPLE TIME:	12:10		18:03	10:16	13:30	15:45	10:00	13:17	16:20
HMX	55 U	BROKEN	51 U	69 U	14 U	17 U	13 U	6.9 U	10 U
RDX	27 U	DURING	25 U	34 U	6.7 U	8.3 U	6.5 U	3.4 U	5.1 U
1,3,5-Trinitrobenzene	550	SHIPMENT	760	730	1100	640	650	750	740
1,3-Dinitrobenzene	25	-	25	10	16	24	25	6.6	18
Nitrobenzene	6.5 U	-	6.1 U	8.1 U	1.6 U	2.0 U	1.6 U	0.81 U	1.2 U
Tetryl	19 U	-	18 U	23 U	4.7 U	5.8 U	4.5 U	2.3 U	3.5 U
Amino DNTs	29	-	12 U	16 U	70	3.8 U	21	22	60 J
2,4,6-Trinitrotoluene	750	-	970	940	1500	830	840	920	910
2,6-Dinitrotoluene	9.8	-	6.1 U	8.1 U	1.6 U	2.0 U	7.9	2.7	7.4
2,4-Dinitrotoluene	64	-	68	28	120	49	54 J	17	84
Hardness (in mg/L)	-	-	343	-	-	304	-	-	353
Alkalinity (in mg/L)	-	-	168	-	-	182	-	-	196
Iron	-	-	665	-	-	570	-	-	394
Manganese	-	-	1770	-	-	1930	-	-	1760

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USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT
DATE:		30-Sep-94			3-Oct-94			4-Oct-94	
SAMPLE NAME:	IN09301	IN09302	IN09303	IN10031	IN10032	IN10033	IN10041	IN10042	IN10043
SAMPLE TIME:	10:10	12:49	15:15	9:59	13:25	16:10	9:10	12:10	14:40
HMX	9.2 U	12 U	10 U	26 U	9.2 U	6.0 U	13 U	15 U	17 U
RDX	4.5 U	6.0 U	5.1 U	13 U	4.5 U	2.9 U	6.3 U	7.2 U	8.2 U
1,3,5-Trinitrobenzene	730	730	730	610	460	500	610	620	610
1,3-Dinitrobenzene	17	8.8	8.9	40	9.4	18 J	9.3	14	19
Nitrobenzene	1.1 U	1.4 U	1.2 U	3.1 U	1.1 U	0.71 U	1.5 U	1.7 U	2.0 U
Tetryl	3.1 U	4.1 U	3.5 U	9.0 U	3.1 U	2.0 U	4.4 U	5.0 U	5.7 U
Amino DNTs	54	31	29	35	8.9	52	75	42	34
2,4,6-Trinitrotoluene	890	900	870	750	560	600	750	770	760
2,6-Dinitrotoluene	8.0	3.3	3.0	12	2.9	9.0	3.8	7.0	8.6
2,4-Dinitrotoluene	72	21	19	25	8.8	33	8.1	5.3	5.1
Hardness (in mg/L)	-	-	353	-	325	-	-	343	-
Alkalinity (in mg/L)	-	-	186	-	186	-	-	194	-
Iron	-	-	316	-	284	-	-	241	-
Manganese	-	-	1790	-	1700	-	-	1820	-

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USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT
DATE:		5-Oct-94			6-Oct-94			7-Oct-94	
SAMPLE NAME:	IN10051	IN10052	IN10053	IN10061	IN10062	IN10063	IN10071	IN10072	IN10073
SAMPLE TIME:	9:52	12:50	15:05	9:55	12:10	15:00	8:45	11:30	13:55
HMX	15 U	14 U	14 U	14 U	14 U	14 U	14 U	14 U	14 U
RDX	7.2 U	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	7.0 U	6.7 U
1,3,5-Trinitrobenzene	610	660	670	650	650	650	590	590	590
1,3-Dinitrobenzene	11	16	18	17	19	21	12	4.6	14
Nitrobenzene	1.7 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.7 U	1.6 U
Tetryl	5.0 U	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	4.8 U	4.7 U
Amino DNTs	32	52	76	53	82	84	45	34	55
2,4,6-Trinitrotoluene	740	820	810	800	790	790	690	700	680
2,6-Dinitrotoluene	5.5	8.3	8.3	8.6	6.5	6.3	4.4	3.3	5.2
2,4-Dinitrotoluene	3.9	2.3	2.6	2.5	1.3	1.2	0.67	0.80	1.4
Hardness (in mg/L)	-	343	-	-	333	-	-	343	-
Alkalinity (in mg/L)	-	188	-	-	2.0 U	-	-	196	-
Iron	-	191	-	-	183	-	-	147	-
Manganese	-	1790	-	-	1820	-	-	1690	-

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USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT
DATE:		10-Oct-94			11-Oct-94			12-Oct-94	
SAMPLE NAME:	IN10101	IN10102	IN10103	IN10111	IN10112	IN10113	IN10121	IN10122	IN10123
SAMPLE TIME:	11:00	13:30	15:30	10:10	13:55	15:45	10:50	13:45	16:00
HMX	14 U	14 U	14 U	14 U	14 U	14 U	18 U	14 U	14 U
RDX	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	8.9 U	6.7 U	6.7 U
1,3,5-Trinitrobenzene	610	520	560	560	550	600	430	590	560
1,3-Dinitrobenzene	15	13	18	15	10	14	16	16	16
Nitrobenzene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	2.1 U	1.6 U	1.6 U
Tetryl	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	6.2 U	4.7 U	4.7 U
Amino DNTs	84	54	60	56	44	52	54	62	63
2,4,6-Trinitrotoluene	720	690	700	690	670	700	530	690	670
2,6-Dinitrotoluene	4.8	1.6 U	1.6 U	5.2	4.4	4.6	5.2	5.8	6.1
2,4-Dinitrotoluene	1.2	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	2.0 U	1.6 U	1.6 U
Hardness (in mg/L)	-	332	-	-	335	-	-	335	-
Alkalinity (in mg/L)	-	168	-	-	192	-	-	184	-
Iron	-	149	-	-	216	-	-	124	-
Manganese	-	1710	-	-	1630	-	-	1650	-

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USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT
DATE:		13-Oct-94			14-Oct-94	
SAMPLE NAME:	IN10131	IN10132	IN10133	IN10141	IN10142	IN10143
SAMPLE TIME:	11:20	14:35	14:35	10:30	13:15	14:45
HMX	14 U	14 U	14 U	14 U	14 U	14 U
RDX	6.7 U	6.7 U	6.7 U	6.7 U	5.8	6.4
1,3,5-Trinitrobenzene	570	560	560	560	550	540
1,3-Dinitrobenzene	1.6 U	1.6 U	1.6 U	1.6 U	12	1.6 U
Nitrobenzene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U
Tetryl	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U
Amino DNTs	48	3.1 U	52	54	53	60
2,4,6-Trinitrotoluene	680	690	670	670	680	660
2,6-Dinitrotoluene	6.0	4.2	4.0	4.9	6.2	6.4
2,4-Dinitrotoluene	1.6 U	1.6 U	1.6 U	1.6 U	1.4	1.4
Hardness (in mg/L)	-	-	333	-	330	-
Alkalinity (in mg/L)	-	-	226	-	204	-
Iron	-	-	428	-	563	-
Manganese	-	-	1680	-	1640	-

U = Analyte not detected. Value presented is the lower detection limit.
J = Analyte present below the lower detection limit.

USAEC UV/OX PILOT-SCALE DEMONSTRATION
PERFORMANCE EVALUATION DATA (in ug/L unless otherwise noted))

VENDOR:	EFFLUENT	EFFLUENT	EFFLUENT	EFFLUENT
DATE:	27-Sep-94	3-Oct-94	6-Oct-94	11-Oct-94
SAMPLE NAME:	EF09271	EF10031	EF10061	EF10111
SAMPLE TIME:	15:45	10:01	9:33	10:10
HMX	7.7 U	6.7 U	6.9 U	6.9 U
RDX	3.8 U	3.3 U	3.4 U	3.4 U
1,3,5-Trinitrobenzene	0.87 U	0.76 U	0.78 U	0.78 U
1,3-Dinitrobenzene	0.87 U	0.76 U	0.78 U	0.78 U
Nitrobenzene	0.90 U	0.80 U	0.81 U	0.81 U
Tetryl	2.6 U	2.3 U	2.3 U	2.3 U
Amino DNTs	1.7 U	1.5 U	1.6 U	1.6 U
2,4,6-Trinitrotoluene	0.87 U	0.76 U	0.78 U	0.78 U
2,6-Dinitrotoluene	0.90 U	0.80 U	0.81 U	0.81 U
2,4-Dinitrotoluene	0.87 U	0.76 U	0.78 U	0.78 U
Hardness (in mg/L)	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-
Iron	-	-	-	-
Manganese	-	-	-	-

U = Analyte not detected. Value presented is the lower detection limit.
J = Analyte present below the lower detection limit

APPENDIX B-2

UV/OX EXPLOSIVES AND INORGANIC DATA

WESTON

GLOSSARY OF EXPLOSIVE DATA

DATA QUALIFIERS

U = Indicates that the compound was analyzed for but not detected. The minimum detection limit for the sample (not the method detection limit) is reported with the U (e.g., 10U).

J = Indicates an estimated value. This flag is used in cases where a target analyte is detected at a level less than the lower quantification level. If the limit of quantification is 10 ug/L and a concentration of 3 ug/L is calculated, it is reported as 3J.

B = This flag is used when the analyte is found in the associated blank as well as in the sample. It indicates possible/probable blank contamination. This flag is also used for a TIC as well as for a positively identified TCL compound.

E = Indicates that the compound was detected beyond the calibration range and was subsequently analyzed at a dilution.

I = Interference.

ABBREVIATIONS

BS = Indicates blank spike in which reagent grade water is spiked with the CLP matrix spiking solutions and carried through all the steps in the method. Spike recoveries are reported.

BSD = Indicates blank spike duplicate.

MS = Indicates matrix spike.

MSD = Indicates matrix spike duplicate.

DL = Indicates that recoveries were not obtained because the extract had to be diluted for analysis.

NA = Not Applicable.

DF = Dilution Factor.

NR = Not Required.

SP = Indicates spiked compound.

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS
DATE:		27-Sep-94			28-Sep-94			29-Sep-94	
SAMPLE NAME:	P09271	P09272	P09273	PUR09281	PUR09282	PUR09283	PUR09291	PUR09292	PUR09293
SAMPLE TIME:	12:09	15:20	17:57	10:09	13:20	15:40	9:56	13:10	16:10
RFW BATCH #:	9409L426	9409L426	9409L427	9409L427	9409L450	9409L450	9409L452	9410L473	9410L473
RFW#:	-	-	-	-	-	-	-	-	-
Re-Prep Dilution	-	-	-	-	-	-	-	-	-
HMX	-	-	-	-	-	-	-	-	-
RDX	-	-	-	-	-	-	-	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-	-	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-	-	-	-
Nitrobenzene	-	-	-	-	-	-	-	-	-
Tetryl	-	-	-	-	-	-	-	-	-
Amino DNTs	-	-	-	-	-	-	-	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-	-	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-	-	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-	-	-	-
RFW#:	-	008	-	-	-	-	-	-	-
Duplicate D.F.	-	1.00	-	-	-	-	-	-	-
HMX	-	7.4 U	-	-	-	-	-	-	-
RDX	-	3.7 U	-	-	-	-	-	-	-
1,3,5-Trinitrobenzene	-	560 E	-	-	-	-	-	-	-
1,3-Dinitrobenzene	-	9.8	-	-	-	-	-	-	-
Nitrobenzene	-	0.88 U	-	-	-	-	-	-	-
Tetryl	-	2.5 U	-	-	-	-	-	-	-
Amino DNTs	-	1.7 U	-	-	-	-	-	-	-
2,4,6-Trinitrotoluene	-	12	-	-	-	-	-	-	-
2,6-Dinitrotoluene	-	0.88 U	-	-	-	-	-	-	-
2,4-Dinitrotoluene	-	0.84 U	-	-	-	-	-	-	-
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS
DATE:		30-Sep-94			3-Oct-94			4-Oct-94	
SAMPLE NAME:	PUR09301	PUR09302	PUR09303	PUR10031	PUR10032	PUR10033	PUR10041	PUR10042	PUR10043
SAMPLE TIME:	10:03	12:44	15:10	9:55	13:15	16:00	9:00	12:00	14:30
RFW BATCH #:	9410L470	9410L468	9410L468	9410L484	9410L501	9410L501	9410L501	9410L522	9110L522
RFW#:	005	002	009	004	001	006	011	001	006
Initial Dilution Factor	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
HMX	11 U	5.5 U	8.4 U	17 U	6.9 U	8.0 U	5.7 U	20 U	16 U
RDX	5.5 U	2.7 U	4.1 U	8.3 U	3.4 U	3.9 U	2.8 U	10 U	7.6 U
1,3,5-Trinitrobenzene	280 E	180 E	270 E	300 E	140 E	74 E	200 E	390 E	390 E
1,3-Dinitrobenzene	12	14 E	57 E	48	5.6	2.8	14	17	51 E
Nitrobenzene	1.3 U	0.64 U	1.0 U	2.0 U	0.81 U	0.95 U	0.68 U	2.4 U	1.8 U
Tetryl	3.8 U	1.9 U	2.9 U	5.8 U	2.3 U	2.7 U	2.0 U	6.9 U	5.3 U
Amino DNTs	2.5 U	1.2 U	4.1	1.5	1.6 U	1.8 U	1.3 U	4.6 U	1.1
2,4,6-Trinitrotoluene	9.1	3.2	4.0	3.1	1.3	0.74	13	6.4	9.7
2,6-Dinitrotoluene	1.3 U	0.64 U	1.0 U	2.0 U	0.81 U	0.95 U	0.68 U	2.4 U	1.8 U
2,4-Dinitrotoluene	1.3 U	0.91	4.7	3.6	0.78 U	0.91 U	0.47	2.3 U	3.2
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-
RFW#:	005 DL	002 DL	009 DL	004 DL	001 DL	006 DL	011 DL	001 DL	006 DL
Second Dilution Factor	100	100	100	100	100	100	100	100	100
HMX	560 U	270 U	420 U	840 U	340 U	400 U	290 U	1000 U	780 U
RDX	270 U	130 U	210 U	410 U	170 U	200 U	140 U	500 U	380 U
1,3,5-Trinitrobenzene	290	290	390	360	160	95	380	480	510
1,3-Dinitrobenzene	64 U	13	55	96 U	39 U	46 U	32 U	120 U	89
Nitrobenzene	66 U	32 U	50 U	100 U	41 U	47 U	34 U	120 U	92 U
Tetryl	190 U	93 U	140 U	290 U	120 U	140 U	98 U	350 U	270 U
Amino DNTs	130 U	62 U	96 U	190 U	78 U	91 U	65 U	230 U	180 U
2,4,6-Trinitrotoluene	64 U	31 U	48 U	96 U	39 U	46 U	32 U	120 U	88 U
2,6-Dinitrotoluene	66 U	32 U	50 U	100 U	41 U	47 U	34 U	120 U	92 U
2,4-Dinitrotoluene	64 U	31 U	48 U	96 U	39 U	46 U	32 U	120 U	88 U

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS
DATE:		5-Oct-94			6-Oct-94			7-Oct-94	
SAMPLE NAME:	PUR10051	PUR10052	PUR10053	PUR10061	PUR10062	PUR10063	PUR10071	PUR10072	PUR10073
SAMPLE TIME:	9:48	12:30	14:45	9:35	11:50	14:35	8:35	11:10	13:35
RFW BATCH #:	9410L522	9410L530	9410L530	9410L530	9410L551	9410L551	9410L551	9410L551	9410L551
RFW#:	-	-	-	-	-	-	-	-	-
Re-Prep Dilution	-	-	-	-	-	-	-	-	-
HMX	-	-	-	-	-	-	-	-	-
RDX	-	-	-	-	-	-	-	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-	-	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-	-	-	-
Nitrobenzene	-	-	-	-	-	-	-	-	-
Tetryl	-	-	-	-	-	-	-	-	-
Amino DNTs	-	-	-	-	-	-	-	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-	-	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-	-	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-	-	-	-
RFW#:	012	-	-	-	-	-	-	-	-
Duplicate D.F.	2.00	-	-	-	-	-	-	-	-
HMX	14 U	-	-	-	-	-	-	-	-
RDX	6.7 U	-	-	-	-	-	-	-	-
1,3,5-Trinitrobenzene	30	-	-	-	-	-	-	-	-
1,3-Dinitrobenzene	1.6	-	-	-	-	-	-	-	-
Nitrobenzene	1.6 U	-	-	-	-	-	-	-	-
Tetryl	4.7 U	-	-	-	-	-	-	-	-
Amino DNTs	3.1 U	-	-	-	-	-	-	-	-
2,4,6-Trinitrotoluene	1.3	-	-	-	-	-	-	-	-
2,6-Dinitrotoluene	1.6 U	-	-	-	-	-	-	-	-
2,4-Dinitrotoluene	1.6 U	-	-	-	-	-	-	-	-
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS	PURIFICS
DATE:		13-Oct-94			14-Oct-94	
SAMPLE NAME:	PUR10131	PUR10132	PUR10133	PUR10141	PUR10142	PUR10143
SAMPLE TIME:	11:20	14:35	16:10	9:50	13:15	14:45
RFW BATCH #:	9410L641	9410L638	9410L639	9410L643	9410L642	9410L642
RFW#:	001	001	001	001	001	006
Initial Dilution Factor	2.00	2.00	2.00	2.00	2.00	2.00
HMX	14 U	14 U	14 U	14 U	14 U	14 U
RDX	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U
1,3,5-Trinitrobenzene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	4.5
1,3-Dinitrobenzene	15	12	1.6	1.6 U	3.6	9.5
Nitrobenzene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U
Tetryl	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U
Amino DNTs	12	9.4	8.7	3.1 U	9.2	4.4
2,4,6-Trinitrotoluene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U
2,6-Dinitrotoluene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U
2,4-Dinitrotoluene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U
Hardness (in mg/L)	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-
Iron	-	-	-	-	-	-
Manganese	-	-	-	-	-	-
RFW#:	-	-	-	-	-	-
Second Dilution Factor	-	-	-	-	-	-
HMX	-	-	-	-	-	-
RDX	-	-	-	-	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-
Nitrobenzene	-	-	-	-	-	-
Tetryl	-	-	-	-	-	-
Amino DNTs	-	-	-	-	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM
DATE:		27-Sep-94			28-Sep-94			29-Sep-94	
SAMPLE NAME:	S09271	S09272	S09273	SLR09281	SLR09282	SLR09283	SLR09291	SLR09292	SLR09293
SAMPLE TIME:	12:13	15:30	17:55	10:23	13:28	15:50	10:10	13:25	16:30
RFW BATCH #:	9409L426	9409L426	9409L427	9409L427	9409L450	9409L452	9409L452	9410L473	9410L470
RFW#:	-	-	-	-	-	-	-	-	-
Re-Prep Dilution	-	-	-	-	-	-	-	-	-
HMX	-	-	-	-	-	-	-	-	-
RDX	-	-	-	-	-	-	-	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-	-	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-	-	-	-
Nitrobenzene	-	-	-	-	-	-	-	-	-
Tetryl	-	-	-	-	-	-	-	-	-
Amino DNTs	-	-	-	-	-	-	-	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-	-	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-	-	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-	-	-	-
RFW#:	-	-	-	-	-	-	-	-	-
Duplicate D.F.	-	-	-	-	-	-	-	006	-
HMX	-	-	-	-	-	-	-	2.00	-
RDX	-	-	-	-	-	-	-	15 U	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-	-	7.5 U	-
1,3-Dinitrobenzene	-	-	-	-	-	-	-	2.3	-
Nitrobenzene	-	-	-	-	-	-	-	2.8	-
Tetryl	-	-	-	-	-	-	-	1.8 U	-
Amino DNTs	-	-	-	-	-	-	-	5.2 U	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-	-	3.5 U	-
2,6-Dinitrotoluene	-	-	-	-	-	-	-	5.4	-
2,4-Dinitrotoluene	-	-	-	-	-	-	-	1.8 U	-
Hardness (in mg/L)	-	-	-	-	-	-	-	2.1	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM
DATE:		30-Sep-94			3-Oct-94			4-Oct-94	
SAMPLE NAME:	SLR09301	SLR09302	SLR09303	SLR10031	SLR10032	SLR10033	SLR10041	SLR10042	SLR10043
SAMPLE TIME:	10:15	13:03	15:30	10:05	13:35	16:20	9:20	12:20	14:50
RFW BATCH #:	9410L470	9410L468	9410L468	9410L484	9410L501	9410L501	9410L501	9410L522	9410L522
RFW#:	-	-	-	-	-	-	-	-	-
Re-Prep Dilution	-	-	-	-	-	-	-	-	-
HMX	-	-	-	-	-	-	-	-	-
RDX	-	-	-	-	-	-	-	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-	-	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-	-	-	-
Nitrobenzene	-	-	-	-	-	-	-	-	-
Tetryl	-	-	-	-	-	-	-	-	-
Amino DNTs	-	-	-	-	-	-	-	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-	-	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-	-	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-	-	-	-
RFW#:	-	-	-	-	-	-	-	-	-
Duplicate D.F.	-	-	-	-	-	-	016	-	-
HMX	-	-	-	-	-	-	1.00	-	-
RDX	-	-	-	-	-	-	8.2 U	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-	4.0 U	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-	21	-	-
Nitrobenzene	-	-	-	-	-	-	3.2	-	-
Tetryl	-	-	-	-	-	-	0.97 U	-	-
Amino DNTs	-	-	-	-	-	-	2.8 U	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-	1.9 U	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-	49 E	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-	0.97 U	-	-
Hardness (in mg/L)	-	-	-	-	-	-	3.1	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM
DATE:		5-Oct-94			6-Oct-94			7-Oct-94	
SAMPLE NAME:	SLR10051	SLR10052	SLR10053	SLR10061	SLR10062	SLR10063	SLR10071	SLR10072	SLR10073
SAMPLE TIME:	9:52	12:45	15:00	9:50	12:05	14:50	8:50	11:25	13:50
RFW BATCH #:	9410L522	9410L530	9410L530	9410L530	9410L551	9410L551	9410L551	9410L551	9410L551
RFW#:	016	005	009	016	020	025	014	004	009
Initial Dilution Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
HMX	6.9 U	6.9 U	6.9 U	6.9 U	6.9 U	6.9 U	7.4 U	6.9 U	6.9 U
RDX	3.4 U	3.4 U	3.4 U	3.4 U	3.4 U	3.4 U	3.7 U	3.4 U	3.4 U
1,3,5-Trinitrobenzene	4.8	1.0	0.78 U	2.9	0.78 U	0.78 U	9.3	0.78 U	0.78 U
1,3-Dinitrobenzene	2.7	2.2	2.3	2.2	1.9	1.4	1.3	0.78 U	0.78 U
Nitrobenzene	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U	0.88 U	0.81 U	0.81 U
Tetryl	2.3 U	2.3 U	2.3 U	2.3 U	2.3 U	2.3 U	2.5 U	2.3 U	2.3 U
Amino DNTs	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.7 U	1.6 U	1.6 U
2,4,6-Trinitrotoluene	30 E	24 E	18	18	15	9.6	8.9	0.78 U	0.78 U
2,6-Dinitrotoluene	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U	0.88 U	0.81 U	0.81 U
2,4-Dinitrotoluene	1.5	1.6	1.0	0.90	0.78 U	0.78 U	0.84 U	0.78 U	0.78 U
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-
RFW#:	016 DL	005 DL	-	-	-	-	-	-	-
Second Dilution Factor	10.0	10.0	-	-	-	-	-	-	-
HMX	69 U	69 U	-	-	-	-	-	-	-
RDX	34 U	34 U	-	-	-	-	-	-	-
1,3,5-Trinitrobenzene	7.8 U	7.8 U	-	-	-	-	-	-	-
1,3-Dinitrobenzene	7.8 U	7.8 U	-	-	-	-	-	-	-
Nitrobenzene	8.1 U	8.1 U	-	-	-	-	-	-	-
Tetryl	23 U	23 U	-	-	-	-	-	-	-
Amino DNTs	16 U	16 U	-	-	-	-	-	-	-
2,4,6-Trinitrotoluene	32	23	-	-	-	-	-	-	-
2,6-Dinitrotoluene	8.1 U	8.1 U	-	-	-	-	-	-	-
2,4-Dinitrotoluene	7.8 U	7.8 U	-	-	-	-	-	-	-

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM
DATE:		10-Oct-94			11-Oct-94			12-Oct-94	
SAMPLE NAME:	SLR10101	SLR10102	SLR10103	SLR10111	SLR10112	SLR10113	SLR10121	SLR10122	SLR10123
SAMPLE TIME:	11:00	13:30	15:30	10:10	13:52	15:45	10:50	13:45	16:00
RFW BATCH #:	9410L570	9410L603	9410L603	9410L603	9410L599	9410L599	9410L603	9410L619	9410L619
RFW#:	-	-	-	-	-	-	-	-	-
Re-Prep Dilution	-	-	-	-	-	-	-	-	-
HMX	-	-	-	-	-	-	-	-	-
RDX	-	-	-	-	-	-	-	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-	-	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-	-	-	-
Nitrobenzene	-	-	-	-	-	-	-	-	-
Tetryl	-	-	-	-	-	-	-	-	-
Amino DNTs	-	-	-	-	-	-	-	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-	-	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-	-	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-	-	-	-
RFW#:	-	-	-	-	-	-			
Duplicate D.F.	-	-	-	-	-	-	022	-	-
HMX	-	-	-	-	-	-	1.00	-	-
RDX	-	-	-	-	-	-	6.9 U	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-	3.4 U	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-	3.5	-	-
Nitrobenzene	-	-	-	-	-	-	1.5	-	-
Tetryl	-	-	-	-	-	-	0.81 U	-	-
Amino DNTs	-	-	-	-	-	-	2.3 U	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-	1.6 U	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-	25 E	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-	0.81 U	-	-
Hardness (in mg/L)	-	-	-	-	-	-	0.78 U	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM	SOLARCHEM
DATE:		13-Oct-94			14-Oct-94	
SAMPLE NAME:	SLR10131	SLR10132	SLR10133	SLR10141	SLR10142	SLR10143
SAMPLE TIME:	11:20	14:35	16:10	10:20	13:15	14:45
RFW BATCH #:	9410L641	9410L641	9410L639	9410L643	9410L642	9410L642
RFW#:	005	009	002	003	004	009
Initial Dilution Factor	1.00	1.00	1.00	1.00	1.00	1.00
HMX	6.9 U	6.9 U	6.9 U	6.9 U	6.9 U	6.9 U
RDX	3.4 U	3.4 U	3.4 U	3.4 U	3.4 U	3.4 U
1,3,5-Trinitrobenzene	0.97	0.78 U	0.78 U	0.78 U	0.78 U	0.78 U
1,3-Dinitrobenzene	1.4	1.2	0.78 U	1.7	0.98	0.78 U
Nitrobenzene	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U
Tetryl	2.3 U	2.3 U	2.3 U	2.3 U	2.3 U	2.3 U
Amino DNTs	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U
2,4,6-Trinitrotoluene	12	17	11	25 E	19	13
2,6-Dinitrotoluene	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U
2,4-Dinitrotoluene	0.78 U	0.78 U	0.78 U	0.78 U	0.78 U	0.78 U
Hardness (in mg/L)	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-
Iron	-	-	-	-	-	-
Manganese	-	-	-	-	-	-
RFW#:	-	-	-	003 DL	-	-
Second Dilution Factor	-	-	-	10.0	-	-
HMX	-	-	-	69 U	-	-
RDX	-	-	-	34 U	-	-
1,3,5-Trinitrobenzene	-	-	-	7.8 U	-	-
1,3-Dinitrobenzene	-	-	-	7.8 U	-	-
Nitrobenzene	-	-	-	8.1 U	-	-
Tetryl	-	-	-	23 U	-	-
Amino DNTs	-	-	-	16 U	-	-
2,4,6-Trinitrotoluene	-	-	-	24	-	-
2,6-Dinitrotoluene	-	-	-	8.1 U	-	-
2,4-Dinitrotoluene	-	-	-	7.8 U	-	-

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX
DATE:		27-Sep-94			28-Sep-94			29-Sep-94	
SAMPLE NAME:	U09271	U09272	U09273	ULT09281	ULT09282	ULT09283	ULT09291	ULT09292	ULTR09293
SAMPLE TIME:	12:10	15:30	17:50	10:20	13:22	15:54	10:05	13:19	16:25
RFW BATCH #:	9409L426	9409L426	940L427	9409L427	9409L450	9409L452	9409L452	9410L473	9410L470
RFW#:	004	011	002	009	003	002	004	004	001
Initial Dilution Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
HMX	6.9 U	7.0 U	4.6 U	6.1 U	8.8 U	5.5 U	6.1 U	5.6 U	4.7 U
RDX	3.4 U	3.4 U	2.2 U	3.0 U	4.3 U	2.7 U	3.0 U	2.7 U	2.3 U
1,3,5-Trinitrobenzene	0.78 U	0.79 U	0.52 U	0.69 U	1.0 U	0.62 U	0.69 U	0.64 U	0.53 U
1,3-Dinitrobenzene	0.78 U	0.79 U	0.52 U	0.69 U	1.0 U	0.62 U	0.69 U	0.64 U	0.53 U
Nitrobenzene	0.81 U	0.82 U	0.54 U	0.72 U	1.0 U	0.65 U	0.72 U	0.66 U	0.55 U
Tetryl	2.3 U	2.4 U	1.6 U	2.1 U	3.0 U	1.9 U	2.1 U	1.9 U	1.6 U
Amino DNTs	1.6 U	1.6 U	1.0 U	1.4 U	2.0 U	1.2 U	1.4 U	1.3 U	1.1 U
2,4,6-Trinitrotoluene	0.78 U	0.79 U	0.52 U	0.69 U	1.0 U	0.62 U	0.69 U	0.64 U	0.53 U
2,6-Dinitrotoluene	0.81 U	0.82 U	0.54 U	0.72 U	1.0 U	0.65 U	0.72 U	0.66 U	0.55 U
2,4-Dinitrotoluene	0.78 U	0.79 U	0.52 U	0.69 U	1.0 U	0.62 U	0.69 U	0.64 U	0.53 U
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-
RFW#:	-	-	-	-	-	-	-	-	-
Second Dilution Factor	-	-	-	-	-	-	-	-	-
HMX	-	-	-	-	-	-	-	-	-
RDX	-	-	-	-	-	-	-	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-	-	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-	-	-	-
Nitrobenzene	-	-	-	-	-	-	-	-	-
Tetryl	-	-	-	-	-	-	-	-	-
Amino DNTs	-	-	-	-	-	-	-	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-	-	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-	-	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-	-	-	-

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX
DATE:		30-Sep-94			3-Oct-94			4-Oct-94	
SAMPLE NAME:	ULT09301	ULT09302	ULT09303	ULT10031	ULT10032	ULT10033	ULT10041	ULT10042	ULT10043
SAMPLE TIME:	10:12	13:01		10:03	13:30	16:15	9:15	12:15	14:45
RFW BATCH #:	9410L470	9410L468		9410L484	9410L501	9410L501	9410L501	9410L522	9410L522
RFW#:	006	006	SAMPLE	001	004	009	014	004	009
Initial Dilution Factor	1.00	1.00	CONTAINERS	1.00	1.00	1.00	1.00	1.00	1.00
HMX	7.1 U	4.7 U	BROKEN	6.5 U	3.2 U	3.2 U	4.0 U	6.9 U	6.9 U
RDX	3.5 U	2.3 U	DURING	3.2 U	1.6 U	1.6 U	2.0 U	3.4 U	3.4 U
1,3,5-Trinitrobenzene	0.80 U	0.53 U	SHIPMENT	0.74 U	0.36 U	0.36 U	0.46 U	0.78 U	0.78 U
1,3-Dinitrobenzene	0.80 U	0.53 U	-	0.74 U	0.36 U	0.36 U	0.46 U	0.78 U	0.78 U
Nitrobenzene	0.84 U	0.55 U	-	0.77 U	0.38 U	0.38 U	0.47 U	0.81 U	0.81 U
Tetryl	2.4 U	1.6 U	-	2.2 U	1.1 U	1.1 U	1.4 U	2.3 U	2.3 U
Amino DNTs	1.6 U	1.1 U	-	1.5 U	0.73 U	0.73 U	0.91 U	1.6 U	1.6 U
2,4,6-Trinitrotoluene	0.80 U	0.53 U	-	0.74 U	0.36 U	0.36 U	0.46 U	0.78 U	0.78 U
2,6-Dinitrotoluene	0.84 U	0.55 U	-	0.77 U	0.38 U	0.38 U	0.47 U	0.81 U	0.81 U
2,4-Dinitrotoluene	0.80 U	0.53 U	-	0.74 U	0.36 U	0.36 U	0.46 U	0.78 U	0.78 U
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-
RFW#:	-	-	-	-	-	-	-	-	-
Second Dilution Factor	-	-	-	-	-	-	-	-	-
HMX	-	-	-	-	-	-	-	-	-
RDX	-	-	-	-	-	-	-	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-	-	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-	-	-	-
Nitrobenzene	-	-	-	-	-	-	-	-	-
Tetryl	-	-	-	-	-	-	-	-	-
Amino DNTs	-	-	-	-	-	-	-	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-	-	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-	-	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-	-	-	-

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX
DATE:		5-Oct-94			6-Oct-94			7-Oct-94	
SAMPLE NAME:	ULT10051	ULT10052	ULT10053	ULT10061	ULT10062	ULT10063	ULT10071	ULT10072	ULT10073
SAMPLE TIME:	9:54	12:40	14:55	9:45	12:00	14:45	8:45	11:20	13:45
RFW BATCH #:	9410L522	9410L530	9410L530	9410L530	9410L551	9410L551	9410L551	9410L551	9410L551
RFW#:	015	004	008	015	019	024	013	003	008
Initial Dilution Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
HMX	6.9 U	6.9 U	6.9 U	7.5 U	6.9 U	6.9 U	7.4 U	6.9 U	6.9 U
RDX	3.4 U	3.4 U	3.4 U	3.7 U	3.4 U	3.4 U	3.7 U	3.4 U	3.4 U
1,3,5-Trinitrobenzene	0.78 U	0.78 U	0.78 U	0.86 U	0.78 U	0.78 U	0.84 U	0.78 U	0.78 U
1,3-Dinitrobenzene	0.78 U	0.78 U	0.78 U	0.86 U	0.78 U	0.78 U	0.84 U	0.78 U	0.78 U
Nitrobenzene	0.81 U	0.81 U	0.81 U	0.89 U	0.81 U	0.81 U	0.88 U	0.81 U	0.81 U
Tetryl	2.3 U	2.3 U	2.3 U	2.6 U	2.3 U	2.3 U	2.5 U	2.3 U	2.3 U
Amino DNTs	1.6 U	1.6 U	1.6 U	1.7 U	1.6 U	1.6 U	1.7 U	1.6 U	1.6 U
2,4,6-Trinitrotoluene	0.78 U	0.78 U	0.78 U	0.86 U	0.78 U	0.78 U	0.84 U	0.78 U	0.78 U
2,6-Dinitrotoluene	0.81 U	0.81 U	0.81 U	0.89 U	0.81 U	0.81 U	0.88 U	0.81 U	0.81 U
2,4-Dinitrotoluene	0.78 U	0.78 U	0.78 U	0.86 U	0.78 U	0.78 U	0.84 U	0.78 U	0.78 U
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-
RFW#:	-	-	-	-	-	-	-	-	-
Second Dilution Factor	-	-	-	-	-	-	-	-	-
HMX	-	-	-	-	-	-	-	-	-
RDX	-	-	-	-	-	-	-	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-	-	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-	-	-	-
Nitrobenzene	-	-	-	-	-	-	-	-	-
Tetryl	-	-	-	-	-	-	-	-	-
Amino DNTs	-	-	-	-	-	-	-	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-	-	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-	-	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-	-	-	-

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX
DATE:		10-Oct-94			11-Oct-94			12-Oct-94	
SAMPLE NAME:	ULT10101	ULT10102	ULT10103	ULT10111	ULT10112	ULT10113	ULT10121	ULT10122	ULT10123
SAMPLE TIME:	11:00	13:30	15:30	10:10	13:50	15:45	10:50	13:45	16:00
RFW BATCH #:	9410L570	9410L603	9410L603	9410L603	9410L599	9410L599	9410L603	9410L619	9410L619
RFW#:	-	-	-	-	-	-	-	-	-
Re-Prep Dilution	-	-	-	-	-	-	-	-	-
HMX	-	-	-	-	-	-	-	-	-
RDX	-	-	-	-	-	-	-	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-	-	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-	-	-	-
Nitrobenzene	-	-	-	-	-	-	-	-	-
Tetryl	-	-	-	-	-	-	-	-	-
Amino DNTs	-	-	-	-	-	-	-	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-	-	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-	-	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-	-	-	-
RFW#:	005	-	-	-	-	-	-	-	-
Duplicate D.F.	1.00	-	-	-	-	-	-	-	-
HMX	7.8 U	-	-	-	-	-	-	-	-
RDX	3.8 U	-	-	-	-	-	-	-	-
1,3,5-Trinitrobenzene	6.6	-	-	-	-	-	-	-	-
1,3-Dinitrobenzene	0.88 U	-	-	-	-	-	-	-	-
Nitrobenzene	0.92 U	-	-	-	-	-	-	-	-
Tetryl	2.7 U	-	-	-	-	-	-	-	-
Amino DNTs	1.8 U	-	-	-	-	-	-	-	-
2,4,6-Trinitrotoluene	0.88 U	-	-	-	-	-	-	-	-
2,6-Dinitrotoluene	0.92 U	-	-	-	-	-	-	-	-
2,4-Dinitrotoluene	0.88 U	-	-	-	-	-	-	-	-
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX
DATE:		13-Oct-94			14-Oct-94	
SAMPLE NAME:	ULT10131	ULT10132	ULT10133	ULT10141	ULT10142	ULT10143
SAMPLE TIME:	11:20	14:35	14:35	10:10	13:15	14:45
RFW BATCH #:	9410L641	9410L641	9410L638	9410L640	9410L642	9410L642
RFW#:	-	-	-	-	-	-
Re-Prep Dilution	-	-	-	-	-	-
HMX	-	-	-	-	-	-
RDX	-	-	-	-	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-
Nitrobenzene	-	-	-	-	-	-
Tetryl	-	-	-	-	-	-
Amino DNTs	-	-	-	-	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-
RFW#:	-	-	-	004**	-	-
Duplicate D.F.	-	-	-	1.00	-	-
HMX	-	-	-	6.9 U	-	-
RDX	-	-	-	3.4 U	-	-
1,3,5-Trinitrobenzene	-	-	-	0.78 U	-	-
1,3-Dinitrobenzene	-	-	-	0.78 U	-	-
Nitrobenzene	-	-	-	0.81 U	-	-
Tetryl	-	-	-	2.3 U	-	-
Amino DNTs	-	-	-	1.6 U	-	-
2,4,6-Trinitrotoluene	-	-	-	0.78 U	-	-
2,6-Dinitrotoluene	-	-	-	0.81 U	-	-
2,4-Dinitrotoluene	-	-	-	0.78 U	-	-
Hardness (in mg/L)	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-
Iron	-	-	-	-	-	-
Manganese	-	-	-	-	-	-

** RFW BATCH # 9410L643

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI
DATE:		30-Sep-94			3-Oct-94			4-Oct-94	
SAMPLE NAME:	VPS09301	VPS09302	VPS09303	VPS10031	VPS10032	VPS10033	VPS10041	VPS10042	VPS10043
SAMPLE TIME:	10:05	12:47	15:12	9:57	13:20	16:05	9:05	12:05	14:35
RFW BATCH #:	9410L470	9410L468	9410L468	9410L484	9410L501	9410L501	9410L501	9410L522	9410L522
RFW#:	004	004	010	003	002	007	012	002	007
Initial Dilution Factor	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
HMX	13 U	12 U	6.6 U	15 U	11 U	7.3 U	14 U	15 U	21 U
RDX	6.6 U	5.7 U	3.2 U	7.3 U	5.5 U	3.6 U	7.1 U	7.4 U	10 U
1,3,5-Trinitrobenzene	170 E	360 E	220 E	7.7	15	56 E	1.7	2.9	16
1,3-Dinitrobenzene	1.5 U	110 E	42 E	1.7 U	1.3 U	0.83 U	1.6 U	1.7 U	2.3 U
Nitrobenzene	1.6 U	1.4 U	0.78 U	1.8 U	1.3 U	0.86 U	1.7 U	1.8 U	2.4 U
Tetryl	4.6 U	4.0 U	2.2 U	5.1 U	3.8 U	2.5 U	4.9 U	5.1 U	7.0 U
Amino DNTs	3.1 U	2.6 U	1.6	3.4 U	2.5 U	1.7 U	3.3 U	3.4 U	4.7 U
2,4,6-Trinitrotoluene	2.1	1.3 U	1.6	1.7 U	1.3 U	2.0	1.6 U	1.7 U	2.3 U
2,6-Dinitrotoluene	1.6 U	1.4 U	0.78 U	1.8 U	1.3 U	0.86 U	1.7 U	1.8 U	2.4 U
2,4-Dinitrotoluene	1.5 U	1.3 U	1.6	1.7 U	1.3 U	0.83 U	1.6 U	1.7 U	2.3 U
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-
RFW#:	004 DL	004 DL	010 DL	-	-	007 DL	-	-	-
Second Dilution Factor	100	100	100	-	-	100	-	-	-
HMX	670 U	580 U	330 U	-	-	370 U	-	-	-
RDX	330 U	290 U	160 U	-	-	180 U	-	-	-
1,3,5-Trinitrobenzene	160	520	420	-	-	63	-	-	-
1,3-Dinitrobenzene	76 U	100	42	-	-	42 U	-	-	-
Nitrobenzene	80 U	69 U	39 U	-	-	43 U	-	-	-
Tetryl	230 U	200 U	110 U	-	-	120 U	-	-	-
Amino DNTs	150 U	130 U	75 U	-	-	83 U	-	-	-
2,4,6-Trinitrotoluene	76 U	66 U	38 U	-	-	42 U	-	-	-
2,6-Dinitrotoluene	80 U	69 U	39 U	-	-	43 U	-	-	-
2,4-Dinitrotoluene	76 U	66 U	38 U	-	-	42 U	-	-	-

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI
DATE:		5-Oct-94			6-Oct-94			7-Oct-94	
SAMPLE NAME:	VPS10051	VPS10052	VPS10053	VPS10061	VPS10062	VPS10063	VPS10071	VPS10072	VPS10073
SAMPLE TIME:	9:50	12:35	14:50	9:40	11:55	14:40	8:40	11:15	13:40
RFW BATCH #:	9410L522	9410L530	9410L530	9410L530	9410L551	9410L551	9410L551	9410L551	9410L551
RFW#:	-	-	-	-	-	-	-	-	-
Re-Prep Dilution	-	-	-	-	-	-	-	-	-
HMX	-	-	-	-	-	-	-	-	-
RDX	-	-	-	-	-	-	-	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-	-	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-	-	-	-
Nitrobenzene	-	-	-	-	-	-	-	-	-
Tetryl	-	-	-	-	-	-	-	-	-
Amino DNTs	-	-	-	-	-	-	-	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-	-	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-	-	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-	-	-	-
RFW#:	-	-	-						
Duplicate D.F.	-	-	-	014	-	-	-	-	-
HMX	-	-	-	2.00	-	-	-	-	-
RDX	-	-	-	14 U	-	-	-	-	-
1,3,5-Trinitrobenzene	-	-	-	6.7 U	-	-	-	-	-
1,3-Dinitrobenzene	-	-	-	21	-	-	-	-	-
Nitrobenzene	-	-	-	1.6 U	-	-	-	-	-
Tetryl	-	-	-	1.6 U	-	-	-	-	-
Amino DNTs	-	-	-	4.7 U	-	-	-	-	-
2,4,6-Trinitrotoluene	-	-	-	3.1 U	-	-	-	-	-
2,6-Dinitrotoluene	-	-	-	1.6 U	-	-	-	-	-
2,4-Dinitrotoluene	-	-	-	1.6 U	-	-	-	-	-
Hardness (in mg/L)	-	-	-	1.6 U	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI
DATE:		13-Oct-94			14-Oct-94	
SAMPLE NAME:	VPS10131	VPS10132	VPS10133	VPS10141	VPS10142	VPS10143
SAMPLE TIME:	11:20	14:35	14:35	10:00	13:15	14:45
RFW BATCH #:	9410L641	9410L638	9410L638	9410L643	9410L642	9410L642
RFW#:	002	002	007	002	002	007
Initial Dilution Factor	2.00	2.00	2.00	2.00	2.00	2.00
HMX	14 U	14 U	14 U	14 U	16 U	14 U
RDX	6.7 U	6.7 U	6.7 U	7 U	7.9 U	6.7 U
1,3,5-Trinitrobenzene	86 E	170 E	160 E	31	1.8 U	4.2
1,3-Dinitrobenzene	1.6 U	1.6 U	1.6 U	2 U	1.8 U	1.6 U
Nitrobenzene	1.6 U	1.6 U	1.6 U	2 U	1.9 U	1.6 U
Tetryl	4.7 U	4.7 U	4.7 U	5 U	5.5 U	4.7 U
Amino DNTs	3.1 U	3.1 U	3.1 U	3 U	3.7 U	3.1 U
2,4,6-Trinitrotoluene	1.6 U	1.4	2.3	2 U	1.8 U	1.6 U
2,6-Dinitrotoluene	1.6 U	1.6 U	1.6 U	2 U	1.9 U	1.6 U
2,4-Dinitrotoluene	1.6 U	1.6 U	1.6 U	2 U	1.8 U	1.6 U
Hardness (in mg/L)	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-
Iron	-	-	-	-	-	-
Manganese	-	-	-	-	-	-
RFW#:	002 DL	002 DL	007 DL	-	-	-
Second Dilution Factor	50.0	50.0	50.0	-	-	-
HMX	340 U	340 U	340 U	-	-	-
RDX	170 U	170 U	170 U	-	-	-
1,3,5-Trinitrobenzene	81	120	150	-	-	-
1,3-Dinitrobenzene	39 U	39 U	39 U	-	-	-
Nitrobenzene	41 U	41 U	41 U	-	-	-
Tetryl	120 U	120 U	120 U	-	-	-
Amino DNTs	78 U	78 U	78 U	-	-	-
2,4,6-Trinitrotoluene	39 U	39 U	39 U	-	-	-
2,6-Dinitrotoluene	41 U	41 U	41 U	-	-	-
2,4-Dinitrotoluene	39 U	39 U	39 U	-	-	-

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	VPSI	VPSI	VPSI	VPSI	VPSI	VPSI
DATE:		13-Oct-94			14-Oct-94	
SAMPLE NAME:	VPS10131	VPS10132	VPS10133	VPS10141	VPS10142	VPS10143
SAMPLE TIME:	11:20	14:35	14:35	10:00	13:15	14:45
RFW BATCH #:	9410L641	9410L638	9410L638	9410L643	9410L642	9410L642
RFW#:	003 DL	-	-	-	-	-
Duplicate Second D.F.	50.0	-	-	-	-	-
HMX	340 U	-	-	-	-	-
RDX	170 U	-	-	-	-	-
1,3,5-Trinitrobenzene	85	-	-	-	-	-
1,3-Dinitrobenzene	39 U	-	-	-	-	-
Nitrobenzene	41 U	-	-	-	-	-
Tetryl	120 U	-	-	-	-	-
Amino DNTs	78 U	-	-	-	-	-
2,4,6-Trinitrotoluene	39 U	-	-	-	-	-
2,6-Dinitrotoluene	41 U	-	-	-	-	-
2,4-Dinitrotoluene	39 U	-	-	-	-	-
RFW#:	-	-	-	-	-	-
Additional D.F.	-	-	-	-	-	-
HMX	-	-	-	-	-	-
RDX	-	-	-	-	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-
Nitrobenzene	-	-	-	-	-	-
Tetryl	-	-	-	-	-	-
Amino DNTs	-	-	-	-	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-
RFW#:	-	-	-	-	-	-
Additional Second D.F.	-	-	-	-	-	-
HMX	-	-	-	-	-	-
RDX	-	-	-	-	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-
Nitrobenzene	-	-	-	-	-	-
Tetryl	-	-	-	-	-	-
Amino DNTs	-	-	-	-	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT
DATE:		27-Sep-94			28-Sep-94			29-Sep-94	
SAMPLE NAME:	IN09271	IN09272	IN09273	IN09281	IN09282	IN09283	IN09291	IN09292	IN09293
SAMPLE TIME:	12:10		18:03	10:16	13:30	15:45	10:00	13:17	16:20
RFW BATCH #:	9409L426		9409L427	9409L427	9409L450	9409L450	9409L452	9410L473	9410L473
RFW#:	003 RE		001 RE	010 RE	007 RE	010 RE	005 RE	003 RE	010 RE
Re-Prep Dilution	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00
HMX	880 U		880 U	880 U	880 U	880 U	880 U	880 U	880 U
RDX	430 U		430 U	430 U	430 U	430 U	430 U	430 U	430 U
1,3,5-Trinitrobenzene	550		760	730	1100	640	650	750	740
1,3-Dinitrobenzene	100 U		100 U	100 U	100 U	100 U	100 U	100 U	100 U
Nitrobenzene	100 U		100 U	100 U	100 U	100 U	100 U	100 U	100 U
Tetryl	300 U		300 U	300 U	300 U	300 U	300 U	300 U	300 U
Amino DNTs	200 U		200 U	200 U	70	200 U	200 U	200 U	200 U
2,4,6-Trinitrotoluene	750		970	940	1500	830	840	920	910
2,6-Dinitrotoluene	100 U		100 U	100 U	100 U	100 U	100 U	100 U	100 U
2,4-Dinitrotoluene	100 U		100 U	100 U	120	100 U	100 U	100 U	100 U
RFW#:	-	-	-	-	-	010 REP	-	-	010 REP
Duplicate D.F.	-	-	-	-	-	-	-	-	-
HMX	-	-	-	-	-	-	-	-	-
RDX	-	-	-	-	-	-	-	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-	-	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-	-	-	-
Nitrobenzene	-	-	-	-	-	-	-	-	-
Tetryl	-	-	-	-	-	-	-	-	-
Amino DNTs	-	-	-	-	-	-	-	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-	-	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-	-	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-	-	-	-
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	343
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	527	-	-	-
						1830			

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT
DATE:		30-Sep-94			3-Oct-94			4-Oct-94	
SAMPLE NAME:	IN09301	IN09302	IN09303	IN10031	IN10032	IN10033	IN10041	IN10042	IN10043
SAMPLE TIME:	10:10	12:49	15:15	9:59	13:25	16:10	9:10	12:10	14:40
RFW BATCH #:	9410L470	9410L468	9410L468	9410L484	9410L501	9410L501	9410L501	9410L522	9410L522
RFW#:	003 RE	003 RE	011 RE	005 RE	003 RE	008 RE	013 RE	003 RE	008 RE
Re-Prep Dilution	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
HMX	880 U	880 U	880 U	880 U	880 U	880 U	880 U	880 U	880 U
RDX	430 U	430 U	430 U	430 U	430 U	430 U	430 U	430 U	430 U
1,3,5-Trinitrobenzene	730	730	730	610	460	500	610	620	610
1,3-Dinitrobenzene	100 U	100 U	100 U	100 U	100 U	100 U	100 U	100 U	100 U
Nitrobenzene	100 U	100 U	100 U	100 U	100 U	100 U	100 U	100 U	100 U
Tetryl	300 U	300 U	300 U	300 U	300 U	300 U	300 U	300 U	300 U
Amino DNTs	200 U	200 U	200 U	28	200 U	52	75	42	34
2,4,6-Trinitrotoluene	890	900	870	750	560	600	750	770	760
2,6-Dinitrotoluene	100 U	100 U	100 U	100 U	100 U	100 U	100 U	100 U	100 U
2,4-Dinitrotoluene	100 U	100 U	100 U	100 U	100 U	100 U	100 U	100 U	100 U
RFW#:	-	005	-	-	003 REP	-	-	003 REP	-
Duplicate D.F.	-	2.00	-	-	-	-	-	-	-
HMX	-	12 U	-	-	-	-	-	-	-
RDX	-	6.0 U	-	-	-	-	-	-	-
1,3,5-Trinitrobenzene	-	260 E	-	-	-	-	-	-	-
1,3-Dinitrobenzene	-	8.8	-	-	-	-	-	-	-
Nitrobenzene	-	1.4 U	-	-	-	-	-	-	-
Tetryl	-	4.1 U	-	-	-	-	-	-	-
Amino DNTs	-	31	-	-	-	-	-	-	-
2,4,6-Trinitrotoluene	-	370 E	-	-	-	-	-	-	-
2,6-Dinitrotoluene	-	3.3	-	-	-	-	-	-	-
2,4-Dinitrotoluene	-	21	-	-	-	-	-	-	-
Hardness (in mg/L)	-	-	-	-	323	-	-	343	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT
DATE:		5-Oct-94			6-Oct-94			7-Oct-94	
SAMPLE NAME:	IN10051	IN10052	IN10053	IN10061	IN10062	IN10063	IN10071	IN10072	IN10073
SAMPLE TIME:	9:52	12:50	15:05	9:55	12:10	15:00	8:45	11:30	13:55
RFW BATCH #:	9410L522	9410L530	9410L530	9410L530	9410L551	9410L551	9410L551	9410L551	9410L551
RFW#:	014	003	010	017	021	026	015	005	010
Initial Dilution Factor	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
HMX	15 U	14 U	14 U	14 U	14 U	14 U	14 U	14 U	14 U
RDX	7.2 U	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	7.0 U	6.7 U
1,3,5-Trinitrobenzene	340 E	510 E	520 E	510 E	590 E	580 E	16	210 E	520 E
1,3-Dinitrobenzene	11	16	18	17	19	21	1.6 U	4.6	14
Nitrobenzene	1.7 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.7 U	1.6 U
Tetryl	5.0 U	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	4.8 U	4.7 U
Amino DNTs	17	52	53	53	60	57	1.7	24	55
2,4,6-Trinitrotoluene	480 E	660 E	680 E	670 E	680 E	660 E	22	430 E	640 E
2,6-Dinitrotoluene	5.5	8.3	8.3	8.6	6.5	6.3	1.6 U	3.3	5.2
2,4-Dinitrotoluene	3.9	2.3	2.6	2.5	1.3	1.2	1.6 U	0.80	1.4
Hardness (in mg/L)	-	343	-	-	333	-	-	343	-
Alkalinity (in mg/L)	-	188	-	-	2.0 U	-	-	196	-
Iron	-	191	-	-	183	-	-	147	-
Manganese	-	1790	-	-	1820	-	-	1690	-
RFW#:	014 DL	003 DL	010 DL	017 DL	021 DL	026 DL	-	005 DL	010 DL
Second Dilution Factor	100	100	100	100	100	100	-	100	100
HMX	730 U	690 U	690 U	690 U	690 U	690 U	-	710 U	690 U
RDX	360 U	340 U	340 U	340 U	340 U	340 U	-	350 U	340 U
1,3,5-Trinitrobenzene	450	800	720	760	700	710	-	290	740
1,3-Dinitrobenzene	83 U	78 U	78 U	78 U	78 U	78 U	-	80 U	78 U
Nitrobenzene	86 U	81 U	81 U	81 U	81 U	81 U	-	84 U	81 U
Tetryl	250 U	230 U	230 U	230 U	230 U	230 U	-	240 U	230 U
Amino DNTs	170 U	160 U	160 U	160 U	160 U	160 U	-	160 U	160 U
2,4,6-Trinitrotoluene	620	1000	900	950	860	880	-	650	970
2,6-Dinitrotoluene	86 U	81 U	81 U	81 U	81 U	81 U	-	84 U	81 U
2,4-Dinitrotoluene	83 U	78 U	78 U	78 U	78 U	78 U	-	80 U	78 U

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT
DATE:		5-Oct-94			6-Oct-94			7-Oct-94	
SAMPLE NAME:	IN10051	IN10052	IN10053	IN10061	IN10062	IN10063	IN10071	IN10072	IN10073
SAMPLE TIME:	9:52	12:50	15:05	9:55	12:10	15:00	8:45	11:30	13:55
RFW BATCH #:	9410L522	9410L530	9410L530	9410L530	9410L551	9410L551	9410L551	9410L551	9410L551
RFW#:	-	-	-	-	-	-			
Duplicate Second D.F.	-	-	-	-	-	-	16	-	-
HMX	-	-	-	-	-	-	2.00	-	-
RDX	-	-	-	-	-	-	14 U	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-	6.7 U	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-	430 E	-	-
Nitrobenzene	-	-	-	-	-	-	12	-	-
Tetryl	-	-	-	-	-	-	1.6 U	-	-
Amino DNTs	-	-	-	-	-	-	4.7 U	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-	45	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-	570 E	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-	4.4	-	-
							0.67	-	-
RFW#:	-	-	-	-	-	-			
Additional D.F.	-	-	-	-	-	-	016 DL	-	-
HMX	-	-	-	-	-	-	100	-	-
RDX	-	-	-	-	-	-	690 U	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-	340 U	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-	510	-	-
Nitrobenzene	-	-	-	-	-	-	78 U	-	-
Tetryl	-	-	-	-	-	-	81 U	-	-
Amino DNTs	-	-	-	-	-	-	230 U	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-	160 U	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-	760	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-	81 U	-	-
							78 U	-	-
RFW#:	-	-	-	-	-	-			
Additional Second D.F.	-	-	-	-	-	-	016 RE	-	-
HMX	-	-	-	-	-	-	1.00	-	-
RDX	-	-	-	-	-	-	880 U	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-	430 U	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-	590	-	-
Nitrobenzene	-	-	-	-	-	-	100 U	-	-
Tetryl	-	-	-	-	-	-	100 U	-	-
Amino DNTs	-	-	-	-	-	-	300 U	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-	24	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-	690	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-	100 U	-	-
							100 U	-	-

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT
DATE:		10-Oct-94			11-Oct-94			12-Oct-94	
SAMPLE NAME:	IN10101	IN10102	IN10103	IN10111	IN10112	IN10113	IN10121	IN10122	IN10123
SAMPLE TIME:	11:00	13:30	15:30	10:10	13:55	15:45	10:50	13:45	16:00
RFW BATCH #:	9410L570	9410L603	9410L603	9410L603	9410L599	9410L599	9410L603	9410L619	9410L619
RFW#:	006 RE	005 RE	010 RE	015 RE	005 RE	010 RE	023 RE	005 RE	010 RE
Re-Prep Dilution	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
HMX	880 U	880 U	880 U	880 U	880 U	880 U	880 U	880 U	880 U
RDX	430 U	430 U	430 U	430 U	430 U	430 U	430 U	430 U	430 U
1,3,5-Trinitrobenzene	610	520	560	560	550	600	430	590	560
1,3-Dinitrobenzene	100 U	100 U	100 U	100 U	100 U	100 U	100 U	100 U	100 U
Nitrobenzene	100 U	100 U	100 U	100 U	100 U	100 U	100 U	100 U	100 U
Tetryl	300 U	300 U	300 U	300 U	300 U	300 U	300 U	300 U	300 U
Amino DNTs	84	200 U	200 U	200 U	200 U	200 U	200 U	200 U	200 U
2,4,6-Trinitrotoluene	720	690	700	690	670	700	530	690	670
2,6-Dinitrotoluene	100 U	100 U	100 U	100 U	100 U	100 U	100 U	100 U	100 U
2,4-Dinitrotoluene	100 U	100 U	100 U	100 U	100 U	100 U	100 U	100 U	100 U
RFW#:	-	-	-	-	005 REP	-	-	-	-
Duplicate D.F.	-	-	-	-	-	-	-	-	-
HMX	-	-	-	-	-	-	-	-	-
RDX	-	-	-	-	-	-	-	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-	-	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-	-	-	-
Nitrobenzene	-	-	-	-	-	-	-	-	-
Tetryl	-	-	-	-	-	-	-	-	-
Amino DNTs	-	-	-	-	-	-	-	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-	-	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-	-	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-	-	-	-
Hardness (in mg/L)	-	-	-	-	335	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	124	-	-	-	-
Manganese	-	-	-	-	1490	-	-	-	-

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT
DATE:		13-Oct-94			14-Oct-94	
SAMPLE NAME:	IN10131	IN10132	IN10133	IN10141	IN10142	IN10143
SAMPLE TIME:	11:20	14:35	14:35	10:30	13:15	14:45
RFW BATCH #:	9410L641	9410L638	9410L638	9410L639	9410L642	9410L642
RFW#:	007 RE	003 RE	006 RE	006 RE	005 RE	010 RE
Re-Prep Dilution	1.00	1.00	1.00	1.00	1.00	1.00
HMX	880 U	880 U	880 U	880 U	880 U	880 U
RDX	430 U	430 U	430 U	430 U	430 U	430 U
1,3,5-Trinitrobenzene	570	560	560	560	550	540
1,3-Dinitrobenzene	100 U	100 U	100 U	100 U	100 U	100 U
Nitrobenzene	100 U	100 U	100 U	100 U	100 U	100 U
Tetryl	300 U	300 U	300 U	300 U	300 U	300 U
Amino DNTs	200 U	200 U	200 U	200 U	200 U	200 U
2,4,6-Trinitrotoluene	680	690	670	670	680	660
2,6-Dinitrotoluene	100 U	100 U	100 U	100 U	100 U	100 U
2,4-Dinitrotoluene	100 U	100 U	100 U	100 U	100 U	100 U
RFW#:	-	-	-	-	-	-
Duplicate D.F.	-	-	-	-	-	-
HMX	-	-	-	-	-	-
RDX	-	-	-	-	-	-
1,3,5-Trinitrobenzene	-	-	-	-	-	-
1,3-Dinitrobenzene	-	-	-	-	-	-
Nitrobenzene	-	-	-	-	-	-
Tetryl	-	-	-	-	-	-
Amino DNTs	-	-	-	-	-	-
2,4,6-Trinitrotoluene	-	-	-	-	-	-
2,6-Dinitrotoluene	-	-	-	-	-	-
2,4-Dinitrotoluene	-	-	-	-	-	-
Hardness (in mg/L)	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-
Iron	-	-	-	-	-	-
Manganese	-	-	-	-	-	-

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	EFFLUENT	EFFLUENT	EFFLUENT	EFFLUENT
DATE:	27-Sep-94	3-Oct-94	6-Oct-94	11-Oct-94
SAMPLE NAME:	EF09271	EF10031	EF10061	EF10111
SAMPLE TIME:	15:45	10:01	9:33	10:10
RFW BATCH #:	9409L426	9410L484	9410L530	9410L603
RFW#:	-	-	-	-
Re-Prep Dilution	-	-	-	-
HMX	-	-	-	-
RDX	-	-	-	-
1,3,5-Trinitrobenzene	-	-	-	-
1,3-Dinitrobenzene	-	-	-	-
Nitrobenzene	-	-	-	-
Tetryl	-	-	-	-
Amino DNTs	-	-	-	-
2,4,6-Trinitrotoluene	-	-	-	-
2,6-Dinitrotoluene	-	-	-	-
2,4-Dinitrotoluene	-	-	-	-
RFW#:	-	-	-	017
Duplicate D.F.	-	-	-	1.00
HMX	-	-	-	6.9 U
RDX	-	-	-	3.4 U
1,3,5-Trinitrobenzene	-	-	-	0.78 U
1,3-Dinitrobenzene	-	-	-	0.78 U
Nitrobenzene	-	-	-	0.81 U
Tetryl	-	-	-	2.3 U
Amino DNTs	-	-	-	1.6 U
2,4,6-Trinitrotoluene	-	-	-	0.78 U
2,6-Dinitrotoluene	-	-	-	0.81 U
2,4-Dinitrotoluene	-	-	-	0.78 U
Hardness (in mg/L)	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-
Iron	-	-	-	-
Manganese	-	-	-	-

APPENDIX C

BENCH-SCALE REPORTS

PURIFICS

BENCH-SCALE REPORT

BENCH-SCALE TEST REPORT FOR ROY F. WESTON/ USAEC

Revision 2

Photocatalytic Treatment System for the Destruction of Explosives Contaminated Ground Water

Submitted by:
Purifics Environmental Technologies Inc.
161 Mallard Road, Hyde Park
Ontario, N0M 1Z0
(519) 473-5788

April 5, 1995

Test Report on Treatment of 2,4,6-TNT Contaminated Groundwater

Introduction:

Five series of tests were performed on the explosives contaminated groundwater from the Savannah Army Depot Activity (SADA) using the Purifics' TiO_2 Photocatalytic technology. Prior to testing, the sample was mixed well in the drums prior to syphoning sample. The initial groundwater sample was clear and amber in colour. No odors were observed.

Purpose:

The purpose of the treatability testing was to determine the destruction removal rates (DRE) of 2,4,6-TNT and 1,3,5-TNB from the groundwater sample and thus determine the level of treatment required to achieve non-detect levels. From this information, life cycle treatment costs will be calculated.

Test Methodology

There are four main factors which were investigated. The effectiveness of:

1) direct photocatalysis with no chemical additives.
2) H_2O_2 addition throughout treatment.
3) direct photocatalysis followed by H_2O_2 addition.
4) addition of a proprietary additive followed by H_2O_2 addition.

The only pretreatment performed to the groundwater sample was removing the carbonate and bicarbonate ions (alkalinity) before testing (performed before all tests). These ions directly compete for the hydroxyl radicals ($^{\bullet}OH$) generated in the process and thus reduce system efficiency. The initial alkalinity of the groundwater sample was measured to be approximately 170 ppm as $CaCO_3$. For this study, the alkalinity was removed by adding sulphuric acid until the pH was approximately 4. At this point, the $CaCO_3$ evolves as CO_2. Prior to each test, the alkalinity was measured in order to verify that it was totally removed.

Bench-Scale Results:

The purpose of the first set of tests (labelled Test Group A) were to investigate factor numbers 1 and 3 listed in the test methodology. The following depicts the major operating conditions for each set of samples, flow rates were 1.1 gpm, 2P model reactor power is 1.2 kW:

Sample Set	Conditions
A1	One pass through a 2P model photocatalytic system, no chemical additives.
A2	Using treated sample collected from Test A1, an additional pass through a 2P model system with no additives.
A3	Using treated sample collected from Test A1, an additional pass through a 2P model system with 100mg/L H_2O_2 addition.

Results Test Group A:

Contaminant	Initial	A1	A2	A3
2,4,6-TNT	0.770	0.108	0.096	0.094
1,3,5-TNB	0.244	0.038	0.040	0.037

Note: All units are in ppb.

The second set of tests (labelled Test Group B) were to investigate factor number 2 listed in the test methodology. The following depicts the major operating conditions for each set of samples, flow rates were 1.1 gpm:

Sample Set	Conditions
B1	One pass through a 2P model system with 100mg/L H_2O_2 addition.
B2	Using treated sample collected from B1, an additional pass through a 2P model system with 100mg/L H_2O_2 addition.

Results Test Group B:

Contaminant	Initial	B1	B2
2,4,6-TNT	0.770	0.112	0.114
1,3,5-TNB	0.244	0.112	0.042

Note: All units are in ppb.

The third set of tests (labelled Test Group C) were to investigate factor number 4 listed in the test methodology. The following depicts the major operating conditions for each set of samples, flow rates were 1.1 gpm:

Sample Set	Conditions
C1	One pass through a 2P model system with the addition of 25 mg/L of the proprietary additive.
C2	Using treated sample collected from C1, an additional pass through a 2P model system with 100mg/L H_2O_2 addition.

Results Test Group C:

Contaminant	Initial	C1	C2
2,4,6-TNT	0.770	0.102	0.164
1,3,5-TNB	0.244	0.038	0.049

Note: All units are in ppb.

Discussion:

As shown in the results of Test Group A, after the first pass of treatment with no chemical additives, destruction removal efficiencies (DRE) of 86% 2,4,6-TNT and 85% 1,3,5-TNB were obtained. However, the same level of destruction was not obtained after an additional pass as shown in Tests A2 and A3. The data here suggests possible contamination since the same level of destruction obtained in Test A1 was expected for Test A2.

The results shown in Test Group B are similar to that of Test A. The level of destruction after a single pass with H_2O_2 addition (Test B1) is similar to that obtained after a single pass without H_2O_2 addition (Test A1). However, as observed in Test Group A after a second pass, the levels of 2,4,6-TNT did not reduce any further than the levels observed after the first pass. Similar results are seen in Test Group C. The results of Test Group C show that the levels of the second pass (C2) were greater than the first pass (C1).

The data supports the theory that there is contamination occurring in the pilot system. After learning of the test results, it was concluded by Purifics that the contamination is probably due to the plastic components of the pilot system and on the sides of the batch processing tanks (also plastic). Corrective measures have therefore been issued to ensure that only stainless steel components are used downstream of the pilot reactor for treatment on-site.

The data shows that a minimum DRE of 85% and 86% was obtained for 1,3,5-TNB and 2,4,6-TNT respectively. However, it seems that the contamination which occurred in the system restricted the treatment to the 100 ppb level for 2,4,6-TNT and to the 40 ppb level of 1,3,5-TNB. It appears that below these levels, the rate of 2,4,6-TNT and 1,3,5-TNB destruction was not seen due to the desorption of these contaminants from the plastic components of the system.

In order to prove this theory and to show that the technology will destroy the contaminants down to non-detect levels, a batch experiment was performed on another pilot system constructed of stainless steel with similar batch processing tanks. The methodology was to continually destroy the contaminants in a batch operation until all of the contamination was removed and thus, non-detect levels would be obtained. The results were monitored by a DTECH kit. After 10 minutes of treatment with no chemical additives the 2,4,6-TNT level was below 60 ppb. After 15 minutes of treatment, the levels were down to 5 ppb, thus demonstrating the treatment objective.

Purifics believes that the contamination in the system is due to the recirculating of the initial sample which is performed before testing in order to pretreat the sample for alkalinity and to mix the TiO_2 with the sample. Continual operation on-site and stainless steel components downstream of the reactor will remedy the problems associated with the bench-scale tests.

Due to the contamination encountered, it is possible that a single pass of treatment generated greater destruction rates than what was observed and that it was the contamination in the system which was measured rather than the actual performance of the system.

It was also shown that the same DRE was achieved without the use of H_2O_2 as the DRE obtained with the use of H_2O_2. The use of the proprietary additive did not seem to help or hinder treatment. Thus it appears that the most cost effective method for treating the explosives is through direct

photocatalysis with no additives. As well, it was shown that the DRE of 2,4,6-TNT and 1,3,5-TNB were virtually the same (86% per pass).

Two additional tests were performed prior to our knowledge of the contamination problem. However, the same pattern of results were obtained where the contamination levels of the second pass were greater than the levels of the first pass.

Conclusions/Recommendations:

Further testing is required to confirm the required equipment size for treatment. Because the stainless steel system which is to be used on-site was not completed at the time of the bench-scale study, Purifics will continue testing during the initial two week start-up period in order to verify our conclusions. based on the data available, Purifics feel that the following equipment will be required for on-site testing:

- equipment size = 4P model pilot unit.
- power = 2.25 kW
- flow rate = 6 L/min.
- chemical additives = none.
- pretreatment - acidification to pH 4 using H_2SO_4 (for alkalinity removal).
  - 5 micron bag filter.
- post treatment - neutralization via NaOH addition.

Utilizing this treatment scheme, life cycle operating costs have been calculated based on the specifications listed in the RFP and are listed in the following table.

Table 1: Life Cycle Costs

Cost	1000 gal.
Power	$1.37
H_2SO_4	$0.69
NaOH	$0.01
TiO_2 catalyst	<$0.01
Maintenance/ Replacement	$2.32
Total Capital	$695,230
Total O&M	$4.40

Note: These are anticipated estimates. A pessimistic estimate would see these numbers double.

A schematic of the full scale system is shown in Figure 1. The life span of the equipment is projected to be 30 years. Due to the modularity of the technology, the equipment can be redeployed at other site(s). Purifics suggests that two labor hours per week be allocated for visual inspections. No filtration was performed before any of the bench-scale testing. However, in order to keep inorganic solids out of the process, Purifics will be incorporating a bag filter to remove the inorganic suspended solids.

Full-Scale Process Description

Referring to Figure 1, groundwater is pumped through the filtration equipment to remove the solids. Downstream of the filtration is the pH adjustment which will remove the alkalinity (pH 3-4). The acidification also performs two other jobs: it will also keep the iron is solution and prevent it from oxidizing and collecting on the catalyst, and second, other work in TNT destruction show that destruction rates are greater at the lower pH levels. The influent groundwater then enters the slurry photocatalytic system. In order to obtain a flow rate of 50 gpm, additional racks are plumbed in parallel. The equipment sizing spreadsheet is shown in Figure 2. After treatment in the photocatalytic system, the groundwater is neutralized by NaOH addition.

Major Component List

1) Power distribution cabinet
2) Photocatalytic system

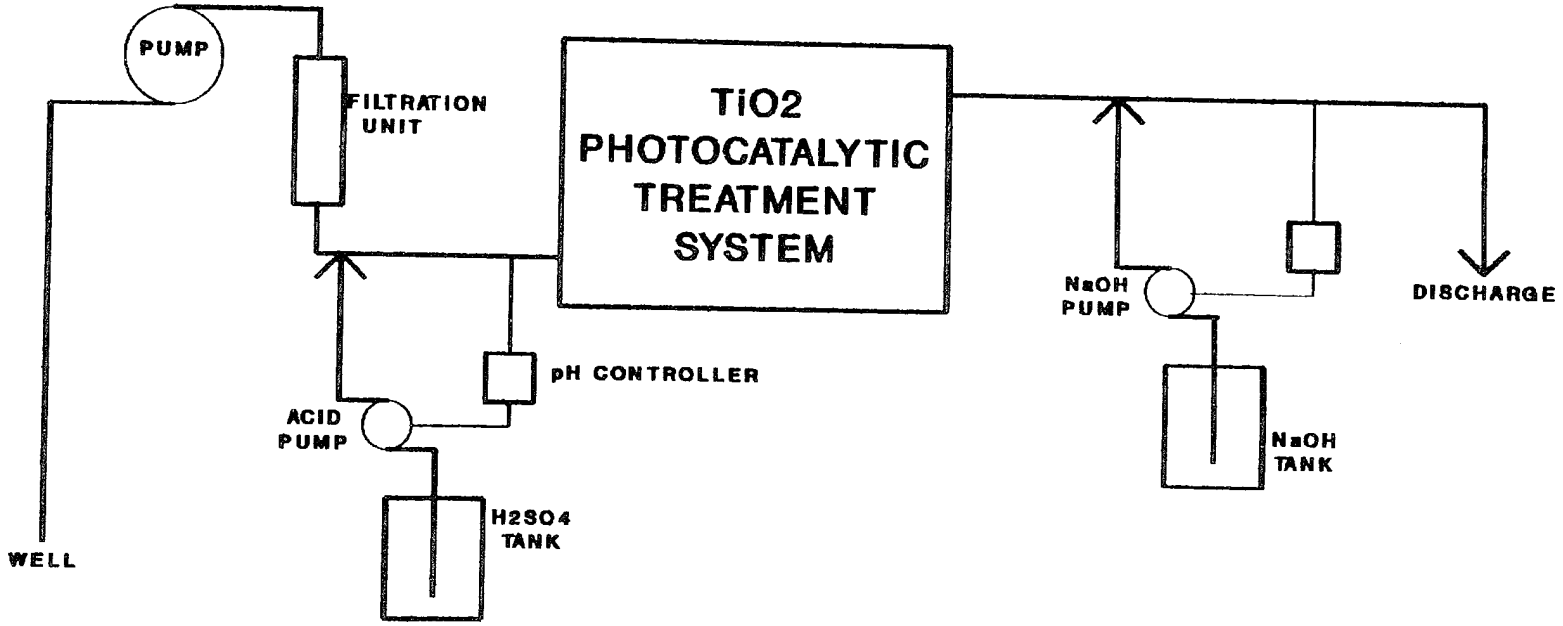
Spare Parts Inventory

1) UV lamps
2) pH probes

O&M Checklist

The entire process can be controlled by PLC control. Diagnostics can be performed by a modem. System flow rates and pressures should be checked weekly or bi-weekly. Lamp replacement should be considered after 8000 hours of operation (an hour totalizer is located on the power distribution cabinet to measure the run time on the lamps).

FIGURE 1: FULL-SCALE SYSTEM SCHEMATIC



PURIFIC ENVIRONMENTAL TECH.

Figure 2

Purifics Environmental Technologies Inc. 05-Apr-95
Photocatalytic Equipment Sizing and Treatment Costs Calculation

Company: **Roy F. Weston Inc. - Savanna Army Depot Activity**

TREATMENT OBJECTIVES:

Contaminants	Initial Concentration	Final Concentration
TNT	1200 ppb	<7 ppb
TNB	600 ppb	<7 ppb

SYSTEM SPECIFICATIONS:

Flow Rate	192	L/min
	50.7	USGPM
Treatment Time	1.9	min
Total Power	69.6	kW

COST DATA:

Costs (US$)	Hourly	m3	1000 gallons
Power	4.18	0.36	1.37
Additives	0.00	0.00	0.00
Total Operating	4.18	0.36	1.37
Maintenance	5.76	0.50	1.89
Total O&M	$9.94	$0.86	$3.27

Power Cost $0.06 per kWh

SOLARCHEM

BENCH-SCALE REPORT

Draft Report on the

Rayox® Design Test to Treat Groundwater at the

Savanna Army Depot Activity (SADA), Savanna, Illinois

Prepared for

Roy F. Weston Inc.

by

Solarchem Environmental Systems

SEPTEMBER 23, 1994

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1.0 SUMMARY

This report outlines the testing results for the first phase of bench scale **Rayox®** treatability testing of groundwater from the Savanna Army Depot Activity (SADA) in Savanna, Illinois.

The objectives of this phase of the design test were:

- to fully characterize the water sample and determine the need, if any, of pretreatment prior to UV/Oxidation treatment
- confirm the effectiveness of the **Rayox®** processes for destruction of TNT, TNB, and other contaminants in order to meet the specified discharge criteria
- determine the operating and capital costs to meet discharge limits for a full scale flowrate of 50 gpm

The bench scale test work completed has confirmed that:

- direct UV photolysis and UV/peroxide treatment both resulted in a net increase in TNB, so they were rejected as treatment options
- lower UV/Ozone ratios are more efficient in destroying TNT and TNB to the required discharge levels
- based on the limited data so far, the estimated capital and operating costs to meet the treatment objectives at a flowrate of 50 gpm are $600,000 and $7.56/1000 gallons respectively

The results from this testing have been used to modify our plan for the next phase of on-site testing. The objective of these tests will be to optimize the treatment to reduce overall costs.

2.0 THEORY

2.1 Advance Oxidation Processes (AOP)

In advanced oxidation processes, the primary treatment mechanism involves the reaction of UV light with hydrogen peroxide or ozone to generate highly reactive hydroxyl radicals (•OH) as shown below:

$$H_2O_2 + \text{UV light} \longrightarrow 2\ \bullet OH \qquad [1]$$

The OH radical initiates a rapid cascade of oxidation reactions which, if allowed to proceed to completion, result in carbon dioxide and water as end products. This oxidation can be greatly enhanced by the addition of homogenous catalysts which increase the efficiency of the UV light reactions.

In some cases, other mechanistic pathways can also be identified such as direct photolysis of the contaminants by UV light or direct reaction of ozone or oxygen radicals with the target contaminants or their intermediate byproducts.

UV Light

The formation of hydroxyl radicals relies on the absorbance of UV light in the range of 200 to 240 nm. In the **Rayox®** system, this light is provided by high intensity medium pressure mercury vapor lamps. The lamps are housed in quartz tubes and a patented device is used to prevent fouling of the quartz tubes. Solarchem's medium pressure UV lamps have been designed to give out significantly more UV light in the 200 to 240 nm range than any other UV light source. While UV light is needed for the formation of hydroxyl radicals from hydrogen peroxide, it may also serve to break or weaken the chemical bonds of many organic compounds by direct photolysis. This is important for compounds that react slowly which hydroxyl radicals.

Hydrogen Peroxide

Hydrogen peroxide is a commonly used chemical oxidant in advanced oxidation processes. It is normally supplied in concentrations of 35 or 50% in water and is metered into the flow line upstream of the UV lamps. The combination of high intensity UV light and hydrogen peroxide produces an oxidative environment that is effective for the treatment of a broad range of organic compounds.

Ozone

Ozone is a strongly oxidizing gas that may react directly with organic compounds or react to form hydroxyl radicals. There are three mechanisms for generation of hydroxyl radicals with ozone: (i) reaction under high pH conditions, (ii) reaction with hydrogen peroxide, or (iii) direct photolysis. Ozone is normally created on site by an ozone generator which requires either clean dry air or oxygen as its feed source. Ozone is produced at a concentration of 2% from air feed and 4 to 7% from oxygen feed. The amount of ozone that is consumed in the treatment process will vary with system geometry, ozone dispersion, UV power and UV/ozone ratio. In previous Solarchem studies with 2% ozone, only 10 to 40% of added ozone reacted during the treatment process. The highest ozone uptake values were observed when ozone was applied in combination with UV light while ozonation without UV resulted in ozone uptake values near 10%. The residual ozone is destroyed by passing the process offgas through a destruction catalyst.

2.2 AOP Treatment of TNT

In the past, process water from the manufacture of TNT has been tested by Solarchem to determine the most promising AOP for the destruction of high levels of TNT. As UV/peroxide is well known as an efficient treatment method for other aromatic compounds such as substituted benzenes and phenols, this treatment regimen was the first AOP tested for the treatment of TNT process water.

The UV/peroxide based **Rayox®** treatment of high concentration TNT process water was successful at removing the TNT but toxicity testing (96 hour LC50 rainbow trout) demonstrated that although the TNT was removed, the water was still not detoxified. A refractory byproduct from the hydroxyl radical decomposition of TNT , identified as trinitrobenzene (TNB), was detected in the treated water. Hydroxyl radical reaction with TNT is postulated to proceed through a series of reaction steps beginning with UV activation of the TNT molecule and resulting in the production of TNB as an intermediate byproduct.

Testing was also done on TNT groundwater and results confirmed an increase in TNB concentration during the UV/peroxide treatment run. The TNB is destroyed very slowly by UV/peroxide treatment, requiring prohibitively high UV doses for complete detoxification of the TNT contaminated water.

The next AOP to be considered was the UV/Ozone based **Rayox®-O** process. Although the removal of organic compounds by UV/Ozone systems is conventionally believed to proceed through formation and photolysis of hydrogen peroxide generating hydroxyl radicals, additional mechanistic

pathways for destruction of TNT and its byproducts (esp. TNB) might allow for more cost effective treatment. These additional pathways may include the reaction of ozone or oxygen radicals with TNT or with an intermediate compounds, or the direct photolysis of TNT by UV light.

Testing of both groundwater and process water, with **Rayox®-O**, demonstrated that efficient TNT removal could be achieved without the buildup of TNB. This indicates that hydroxyl radical attack is not the sole reaction mechanism present in the UV/Ozone TNT treatment system.

The application of ozone under high pH conditions and without UV light, was also found effective, especially for removal of high concentrations (> 10 ppm) of TNT. At the lower concentrations, normally seen in groundwaters, a UV/Ozone polishing step was required to economically remove the final trace contaminants. UV/Ozone was also found more effective for removal of overall TOC and therefore was the preferred process both for treatment of TNT and for removal of potentially undesirable byproducts. A full scale **Rayox®** system using the UV/Ozone process for TNT destruction is currently in place.

2.3 Design Parameters

UV Dose

In the UV oxidation process, a high powered lamp emits UV radiation through a quartz sleeve into the contaminated water. The photons of light activate hydrogen peroxide, ozone or a catalyst and generate highly reactive radicals which destroy the organic contaminants. The destruction of organic contaminants is therefore dependent upon the amount of UV light which is applied to the contaminated water.

Solarchem's design parameter for the scale-up of UV oxidation systems is the "UV dose" which is defined as the amount of UV lamp power (in kWh) applied to 1000 gallons of water. This design parameter can be calculated from either flow through or batch situations as follows;

$$\text{UV Dose (Batch)} = \frac{\text{Lamp Size(kW)} \times \text{Time(min)} \times 3785\ \text{(L/1000gal)}}{\text{Volume (L)} \times 60\ \text{(min/hr)}}$$

and

$$\text{UV Dose (Flow)} = \frac{\text{Lamp Size (kW)} \times 1000\ \text{(gal/ 1000gal)}}{\text{Flow Rate (gpm)} \times 60\ \text{(min/h)}}$$

The UV Dose is used to determine the number of lamps required for a full scale system from data obtained in bench scale testing. For full scale systems using 30 kW lamps, the calculation uses the 27.5 kW nominal running power instead of the 30 kW maximum power.

Electrical Energy per Order (EE/O)

The destruction of a contaminant by a UV/Oxidation process involves a complex series of chemical reactions. However, experience has shown that this destruction generally follows a first order relationship with the amount of energy input into a unit volume of water. A simple design parameter, which incorporates the energy input to the system and the number of orders of contaminant destruction, can be used to compare and scale-up processes. This design parameter is known as the Electrical Energy per Order or the EE/O and its units are in kWh/1000gal/order.

For example, if it takes 10 kWh of electrical energy to reduce the concentration of a target compound from 10 ppm to 1 ppm (1 order of magnitude or 90% destruction) in 1000 gallons of water, then the EE/O is 10 kWh/1000gal/order for this compound.

The EE/O values obtained in a batch system can be applied directly to a full scale flowthrough system. The equation for the EE/O which applies to both batch and flow through situations is:

$$EE/O = \frac{\text{UV Dose}}{\log (C_i/C_f),}$$

where C_i is the initial concentration and C_f is the final concentration.

In scaling up from bench scale results to a full scale system the EE/O value is calculated. In systems with more than one compound of interest the EE/O for each compound must be determined in the batch testing. The compound that treats the slowest will have the largest EE/O value and will determine the minimum requirements for a full scale system. The effluent concentration for each compound can then be calculated for the full scale design.

UV/Ozone Ratio

In this report, UV/Ozone ratio is expressed in terms of kWh of electrical energy used to power the UV lamps per pound of ozone fed to the system. For the purpose of estimating operating costs, it is assumed that 10 kWh are required to generate 1 pound of ozone.

3.0 EXPERIMENTAL TESTING

3.1 Groundwater Characterization

Five 25 gallon drums of groundwater were received on August 11, 1994. The water was blended into a composite by transfering to a 200 gallon tank. The water was mixed with a recirculation pump before sampling. Analysis of the composite water in the Solarchem laboratory gave the following results:

Appearance:	light yellow color
pH:	6
COD:	90 mg/L
Alkalinity:	150 mg/L
Iron:	ND (< 1 ppm)
Chloride:	23 ppm
Nitrate:	775 ppm
TNT:	1200 ppb
TNB:	1500 ppb
RDX:	< 50 ppb

Analysis of the UV absorbance of the water showed optical densities of 1.6 at 200 nm, 1.9 at 220 nm, 1.3 at 240 nm and 0.51 at 260 nm. In general, a high UV absorbance indicates that non-target water constituents are competing for UV light energy against the target contaminants and hydrogen peroxide or ozone thus decreasing treatment efficiency. The absorbance levels of the groundwater in this case were unusually high due to the high level in nitrate in the water.

Over the course of testing, several samples of the groundwater were sent to PACE for full analysis of ordnance compounds by EPA 8330. The PACE analytical reports are contained in the Appendix. The PACE analysis of the initial composite water gave the results shown in Table 1.

Table 1: Analysis of Untreated Groundwater Samples

Parameter	Samples		
	08/13/94	08/13/94 duplicate	08/25/94
HMX	< 10	< 10	< 16
RDX	20	48	76
1,3,5 TNB	470	490	570
1,3 DNB	19	18	20
NB	< 10	< 10	< 16
Tetryl	< 10	< 10	< 16
Amino-DNTs	16	26	103
TNT	760	690	710
2,6 DNT	< 10	< 10	38
2,4 DNT	< 10	< 10	< 16

Solarchem UV reactors are equipped with transmittance controllers which are designed to prevent fouling of the quartz tube during system operation. Therefore, there is no need to pretreat the water for removal of suspended solids or metals.

Because TNT and TNB are present in the highest concentrations in the groundwater samples, the bench test program focussed on these contaminants. Periodic analyses were conducted to confirm that concentrations of other ordinance compounds were also reduced in the treated samples. Previous tests on destruction of TNT by UV/Peroxide resulted in the formation of TNB as an oxidation product, while the combination of UV/Ozone was found to successfully destroy both TNT and TNB without formation of toxic oxidation products. For this reason, most bench test work was conducted using the UV/Ozone process. The application of UV light alone, UV light in combination with hydrogen peroxide, and direct ozonation without UV light were also investigated for completeness.

3.2 Procedure for UV and UV/Peroxide Tests

Design testing of the UV/Peroxide process at Solarchem was performed using a 1 kW Bench unit shown in Figure 1. This unit consists of a 27 L batch tank, a recycle pump and a 1 kW **Rayox®** reactor. The total volume of the system is 33 L. The 1 kW lamp used has an identical UV output to the 30 kW lamps which are used in a full scale system so that scale-up using the design parameter, UV Dose, is extremely accurate. The unit also has a transmittance controller which is activated by the operator at regular intervals to wipe the quartz sleeve to ensure that the quartz sleeve remains clean throughout the entire run.

For the experiments, 29L of sample water was charged to a holding tank and then circulated through the reactor at 18 gpm. An initial sample was taken and then hydrogen peroxide was added to the holding tank and the lamp was ignited at time = zero. Samples were taken at periodic intervals corresponding to increasing UV doses and were analyzed for TNT and TNB. Results were compared by plotting contaminant concentration as a function of UV dose (calculated as total lamp energy per thousand U.S. gallons of water).

3.3 Procedure for Ozone and UV/Ozone Tests

Testing of the UV/Ozone process at Solarchem was carried out in a UV/Ozone bench scale batch reactor, shown in Figure 2. The 100 L stainless steel vessel is equipped with a stainless steel sparger for introduction of ozone, and houses a 1 kW Solarchem lamp. The volume of the water treated was approximately 60 L.

Ozone is generated as a 2% (by weight) solution in air from a PCI Model G-14 ozone generator. Ozone is introduced to the bench scale batch reactor at flow rates between 20 and 200 scfh. An attempt was made to determine ozone concentrations in the off-gas by impingement/iodometric titration following the standard International Ozone Association procedure (IOA 001/87). This would allow determination of ozone consumption as the difference between the ozone inlet concentration and the ozone off-gas concentration. Unfortunately, the ozone titration measurements gave erroneous results during the test runs, with a faulty flow meter being the likely source of error, and true ozone consumption values could not be determined. Previous studies on TNT containing waters have shown that the ozone consumption varies with UV power and the UV/Ozone ratio. Ozone alone has the lowest ozone consumption with values around 10% or lower. The ozone consumption rises to 30 - 40 % when UV light is applied.

In a typical experiment, the water is added to the reactor and the ozone flow is started. The lamp is ignited and allowed to warmup for 45 seconds. Once the lamp is warmed up, a run timer is started. Water and ozone samples are then taken at intervals measured from the run start time. For ozone only test runs, the same procedure was followed without the use of the UV lamp. Results were compared by plotting contaminant concentration as a function of total power applied (calculated as electrical energy for both UV light and ozone generation per thousand U.S. gallons of water).

3.4 *Sample Analysis*

Samples were analyzed by Solarchem for 2,4,6-trinitrotoluene (TNT) and 1,3,5-trinitrobenzene (TNB) using a Water's HPLC equipped with a 30 cm x 0.46 cm C-18 column with detection using UV spectrophotometry at 225 nm. For the optimum test runs, samples were submitted to an MRD-certified analytical laboratory, PACE Inc., for analysis using certified USATHAMA methods.

3.5 *Experimental Results*

A total of 12 runs were conducted in this design test. Results of these test runs are presented in the Appendix and discussed in the following sections.

Direct Photolysis and UV/Peroxide

Results of direct photolysis and UV/Peroxide tests are shown in Figure 3. As expected from Solarchem's previous experience in the treatment of ordnance compounds, TNT was successfully treated by direct photolysis and with a combination of UV light and peroxide. However, in both these cases, levels of TNB were shown to increase over the test run. Because of these poor results, subsequent test work focused on ozone based AOP treatment.

Ozonation

Two tests were conducted on direct ozonation of the groundwater sample without UV light. Results from the first test indicated that ozonation at neutral pH would not provide adequate treatment of either TNT or TNB. However, treatment efficiency was found to be greatly improved under higher pH conditions. Figure 4 illustrates the improvement in ozone treatment of TNT and TNB with pH adjustment. Samples from the higher pH ozonation run were submitted for analysis by PACE and the results are shown in Table 2.

Table 2: Byproduct formation during ozonation treatment

O3 Dose kWh/kgal	TNT ppb	TNB ppb	2-NT ppb	4-NT ppb
0	710	570	ND	ND
17	140	44	49	ND
68	ND	ND	ND	15

UV/Ozone

Both UV/Ozone ratio and sample pH were expected to have a significant impact on treatment efficiency. UV/Ozone runs were carried out at three different ratios of UV to ozone: 10, 2.5 and 1.3 kWh of UV light per pound ozone. In all three runs, TNT was found to oxidize faster than TNB, so that the treatment system requirements are controlled by TNB which is the rate limiting compound. Figure 5 compares the destruction of TNB at the three different UV/Ozone ratios as a function of total power applied (UV dose and Ozone added). The most effective treatment was found with the lower UV/Ozone ratios and the ratio of 2.5 was found to be nominally more effective that the ratio of 1.3.

Using a UV/Ozone ratio of 2.5 kWh/lb, further tests were then conducted to examine the effect of pH on destruction efficiency. Three runs were conducted by adjusting the sample pH by addition of caustic before initiating the test run. Results of these tests are illustrated in Figure 6. Addition of caustic was observed to provide a dramatic improvement in TNB destruction with TNB now treating more rapidly than the TNT. Treatment performance with respect to TNT was also improved by pH adjustment.

Split samples from the two higher pH runs were submitted to PACE for analysis by EPA method SW8330 for explosives in liquid. Concentrations of TNT and TNB were found to be lower than values obtained in the Solarchem laboratory, possibly due to co-elution on the Solarchem HPLC. The data did however confirm that when levels of TNT and TNB are reduced to below the MDL value of 10 ppb, all other organics compounds were also successfully treated to levels below their MDL values. The report of the laboratory analysis conducted by PACE is included in the Appendix.

3.6 *Discussion of Results*

The test work confirmed that direct photolysis and UV/peroxide treatment do not effectively treat TNT and TNB in groundwater. Ozonation under high pH conditions was found to be effective for TNT and TNB removal.

In the tests of the UV/Ozone process, all the EPA SW8330 compounds were successfully treated. This result agrees with previous Solarchem test work that indicated that UV/Ozone treatment was more effective than direct ozonation for TOC removal. UV light is also known to enhance ozone up take in the process water and thereby improve the efficiency of sample ozonation.

Based on these bench scale tests, it was decided that UV/Ozone treatment should be employed in subsequent pilot testing. To select the most promising conditions for UV/Ozone testing, the EE/O value is calculated. From the EE/O parameter, the lamp requirements for a given application can be calculated. Table 3 lists the EE/O values for the six UV/Ozone test runs. By comparing EE/O values from each run one can easily see the reduction in electrical power required for treatment as the UV/Ozone ratio and the sample pH is varied. The numbers of lamps that would be required to reduce 1500 ppb of TNT to 2 ppb at a flowrate of 50 GPM are also shown in Table 3. The most effective treatment was obtained under higher pH conditions and low UV/Ozone ratios. Therefore, pilot testing and full scale design estimates will be based on the conditions tested and EE/O values obtained in UV/Ozone Runs 4 and 6.

Table 3: Calculated EE/O Values for ***Rayox®*** *UV/Ozone Treatment*

Run Type No.	UV/O_3 Ratio	pH	Limiting compound	EE/O	No. of 30 kW Lamps Required
1	10	7	TNB	234	74
2	2.5	7	TNB	25	8
3	1.3	7	TNB	27	9
4	2.5	8.5	TNT	15	5
5	2.5	7	TNB	48	15
6	2.5	9	TNT	14	5

4.0 PILOT PLANT DESIGN

Solarchem's pilot plant comprises of a UV/Ozone reactor with a vertical tower containing three 1kW UV lamps and a 21 lb/day ozone generator. By applying the EE/O value of 14 obtained in the bench scale testing to the pilot scale flow through system, the recommended process conditions can be calculated as follows:

$$\text{UV Dose} = \text{EE/O} \times \log (Ci/Cf)$$

To reduce 1500 ppb of TNT to 2 ppb, the required UV Dose is 40 kWh/1000 gal.

$$\text{Flow rate (gpm)} = \frac{\text{Lamp Size (kW)} \times 1000 \text{ (gal/ 1000gal)}}{\text{UV Dose (flow)} \times 60 \text{ (min/h)}}$$

Based on a total of 3 kW of lamp power, the pilot plant should be operated at a flow rate of 1.25 gpm to ensure adequate removal efficiency of the target organic compounds.

The optimal UV to ozone ratio identified in the bench scale tests was 2.5 kWh/lb. At this ratio, an ozone dose of approx. 11 lb/1000 gal or 19 lb/day would be required in the pilot unit. However, much higher ozone uptake is expected in the pilot unit due to improved reactor geometry and ozone dispersion. The 21 lb/day ozone generator should therefore be more than adequate for the pilot plant testing conducted at a groundwater flow rate of approx. 1 gpm. The actual ozone consumption will be measured in the pilot scale tests by an ozone monitor as well as the titrimetric procedure.

5.0 PRELIMINARY FULL SCALE DESIGN

5.1 Rayox® System

The analysis of the results indicated that a 5 x 30 kW **Rayox®** reactor system with a 350 lb/day ozone generator would be required to destroy the ordnance compounds to the discharge requirements outlined. Expected performance is shown in Table 4.

Table 4: Predicted Destruction Removal Efficiency

Compound	Influent Conc. (ppb)*	Effluent Conc. (ppb)
HMX	< 11	< 10
RDX	5.4	< 10
1,3,5 TNB	870	< 10
1,3 DNB	47	< 10
NB	58	< 10
Tetryl	< 3.8	< 10
Amino-DNTs	< 1.2	< 10
TNT	1500	< 10
2,6 DNT	79	< 10
2,4 DNT	110	< 10

* based on maximum values from monitoring of Well 302124 by Dames & Moore and Weston from May to August 94.

A breakdown of the operating costs for the **Rayox®** process is shown in Table 5. The estimated selling price for the system is $600,000.

*Table 5: Operating Cost Breakdown for **Rayox®***

Component	Operating Costs ($/1000 gal)	Annual Costs ($/yr)
Power (at $0.06/kWh)		
- UV lamps	$3.00	$75,000
- Ozone generator	3.00	75,000
Replacement UV lamps	1.39	35,000
Caustic consumption	0.17	4,000
Annual repair costs		
Total	**$7.56**	**$189,000**

O&M labor hours are roughly estimated at 500 hrs/year.
Estimated lifespan or the equipment is 30 years.

APPENDIX

Results of Bench Scale Design Testing

Runs 1 & 2: Test Data from Direct Photolysis and UV/Peroxide Runs

UV Dose	Direct Photolysis		UV/Peroxide	
kWh/kgal	TNT ppb	TNB ppb	TNT ppb	TNB ppb
0	1100	1400	1200	1400
12.5	810	1600	300	1500
25	100	1600	70	1500
37.5	20	1800	ND	1600
50	ND	1700	ND	1800

Run 4: Test data from UV/Ozone Ratio Run at 10 kWh/lb

UV Dose kWh/kgal	Ozone Dose kWh/kgal	Total Power In kWh/kgal	TNT ppb	TNB ppb
0	0	0	1100	1500
5.3	4.5	9.8	540	1350
10.5	9.0	19.5	180	1380
15.8	13.5	29.3	90	1260
21	18.0	39.1	na	1190
26.3	22.6	48.8	26	1240
31.5	27.1	58.6	10	1100

Run 5: Test Data from UV/Ozone Run at Ratio 2.5 kWh/lb

UV Dose kWh/kgal	O3 Dose kWh/kgal	Total Power In kWh/kgal	TNT ppb	TNB ppb
0	0	0	1100	1500
5.3	20.7	25.6	430	1230
10.5	41.4	51.9	110	870
15.8	62.0	77.8	20	660
21	82.7	103.7	ND	510
26.3	103.4	129.7		320
31.5	124.1	155.6		260
42	165.4	207.5		130
63	248.1	311.2		ND

Run 6: Test data from UV/Ozone Run at Ratio 1.3 kWh/lb

UV Dose kWh/kgal	O3 Dose kWh/kgal	Total Power In kWh/kgal	TNT ppb	TNB ppb
0	0	0	1200 (760)*	930 (470)
2.6	20.0	22.6	530	820
5.3	40.0	45.3	330	600
7.9	60.0	67.9	190 (< 10)	520 (< 10)
13.1	99.9	113.0	60	340
15.8	119.9	135.7	40	300
21.0	159.9	180.9	9	na
26.3	199.9	226.2	ND	120
42.1	319.8	361.9		18
52.6	399.7	452.3		10

* values in brackets from PACE laboratories

Run 7: Test data from UV/Ozone Run at Ratio 2.5 kWh/lb and pH 8.5

UV Dose kWh/kgal	O3 Dose kWh/kgal	Total Power In kWh/kgal	TNT ppb	TNB ppb
0	0	0	820	1020
10.5	40.0	50.5	150	50
21.0	79.9	99.9	30	1
31.5	119.9	151.4	ND	ND

Run 9: Test Data from UV/Ozone Run at, Ratio 2.5 kWh/lb and pH 7

UV Dose kWh/kgal	O3 Dose kWh/kgal	Total Power In kWh/kgal	TNT ppb	TNB ppb
0	0	0	920	720
10.5	42.2	52.7	900	520
15.8	63.3	79.1	430	340
31.5	126.6	158.1	53	180
47.3	189.9	237.2	43	95
63.1	253.1	316.2	2	34

Run 10: Test Data from UV/Ozone Run at, Ratio 2.5 kWh/lb and pH 9

UV Dose kWh/kgal	O3 Dose kWh/kgal	Total Power In kWh/kgal	TNT ppb	TNB ppb
0	0	0	713 (690)	910 (490)
5.3	21.0	26.2	388	100
10.5	41.9	52.4	131 (150)	21 (26)
15.8	62.9	78.6	58	8
21.0	83.8	104.9	22 (<10)	ND (<10)
31.5	125.7	157.3	ND	

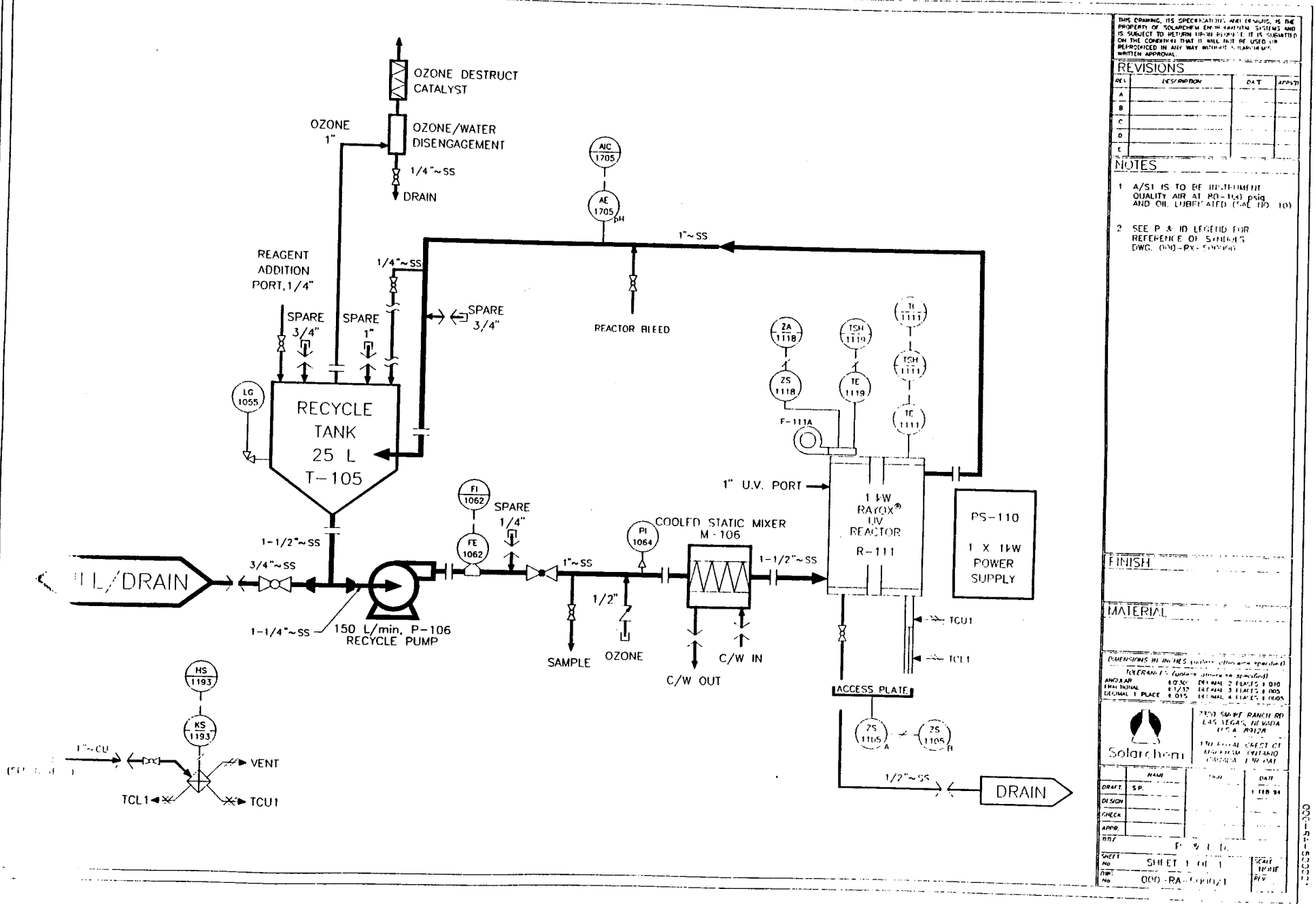
* values in brackets from PACE laboratories

Run 13: Test Data from Ozonation Run

O3 Dose (kWh/kgal)	TNT (ppb)	TNB (ppb)
0	1010	1250
21	890	1200
42	760	1010
63	640	920
84	560	790
105	460	810
126	400	750

Run 12: Test Data from Ozonation Run at pH 8.5

O3 Dose kWh/kgal	TNT ppb	TNB ppb
0	714 (710)	782 (570)
4.3	646	749
8.5	622	672
17.0	379 (140)	34 (44)
25.5	170	12
34.0	87	7
42.5	57	ND
51.0	21	
59.5	8	
68.0	ND (<10)	(< 10)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DRAIN
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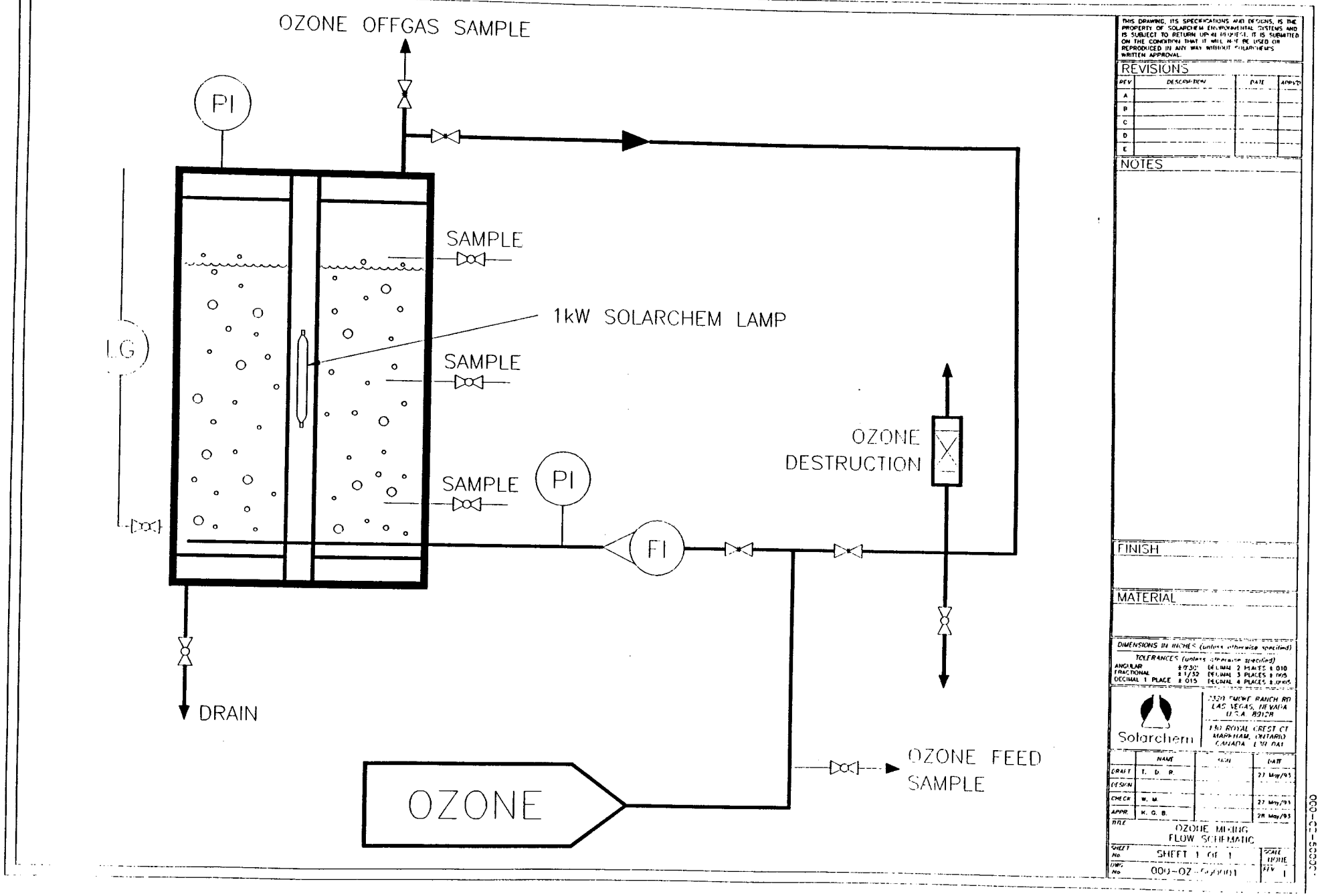
AE 1705 pH
1"~SS
REAGENT ADDITION PORT, 1/4"
1/4"~SS
SPARE 3/4"
SPARE 1"
SPARE 3/4"
REACTOR BLEED
LG 1055
RECYCLE TANK 25 L T-105
ZA 1118
TSH 1119
TI 1111
TSH 1111
ZS 1118
TE 1119
TE 1111
F-111A
1" U.V. PORT
1 kW RAYOX® UV REACTOR R-111
PS-110 1 X 1kW POWER SUPPLY
FI 1062
FE 1062
SPARE 1/4"
COOLED STATIC MIXER M-106
PI 1064
1-1/2"~SS
3/4"~SS
1"~SS
1/2"
TCU1
TCL1
ACCESS PLATE
ZS 1105 A
ZS 1105 B
1/2"~SS
DRAIN
1-1/4"~SS
150 L/min, P-106 RECYCLE PUMP
SAMPLE
OZONE
C/W OUT
C/W IN
HS 1193
KS 1193
1"~CU
VENT
TCL1
TCU1
REVISIONS
NOTES
1 A/S1 IS TO BE INSTRUMENT QUALITY AIR AT 80-100 psig AND OIL LUBRICATED (SAE 10 TO 10)
2 SEE P & ID LEGEND FOR REFERENCE OF SYMBOLS DWG. 000-PX-
FINISH
MATERIAL
Solarchem
DRAFT S.P.
DESIGN
CHECK
APPR.
DWG
SHEET No SHEET 1 OF 1
DWG No 000-RA-
SCALE NONE
REV

Figure 1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LG
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OZONE
DESTRUCTION
DRAIN
OZONE
OZONE FEED
SAMPLE
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NOTES
FINISH
MATERIAL
DIMENSIONS IN INCHES (unless otherwise specified)
TOLERANCES (unless otherwise specified)
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FRACTIONAL ± 1/32
DECIMAL 1 PLACE ± .015
DECIMAL 2 PLACES ± .010
DECIMAL 3 PLACES ± .005
DECIMAL 4 PLACES ± .0005
Solarchem
2320 PAIGE RANCH RD
LAS VEGAS, NEVADA
U.S.A. 89128
190 ROYAL CREST CT
MARKHAM, ONTARIO
CANADA L3R 9X1
NAME
SIGN
DATE
DRAFT T. D. R. 27 May/93
DESIGN
CHECK W. M. 27 May/93
APPR. K. G. B. 28 May/93
TITLE
OZONE MIXING
FLOW SCHEMATIC
SHEET No SHEET 1 OF 1
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REV 1
000-02-1

Figure 2

Figure 3

Direct Photolysis (Run 1) and UV/Peroxide (Run 2) Treatment of TNT and TNB

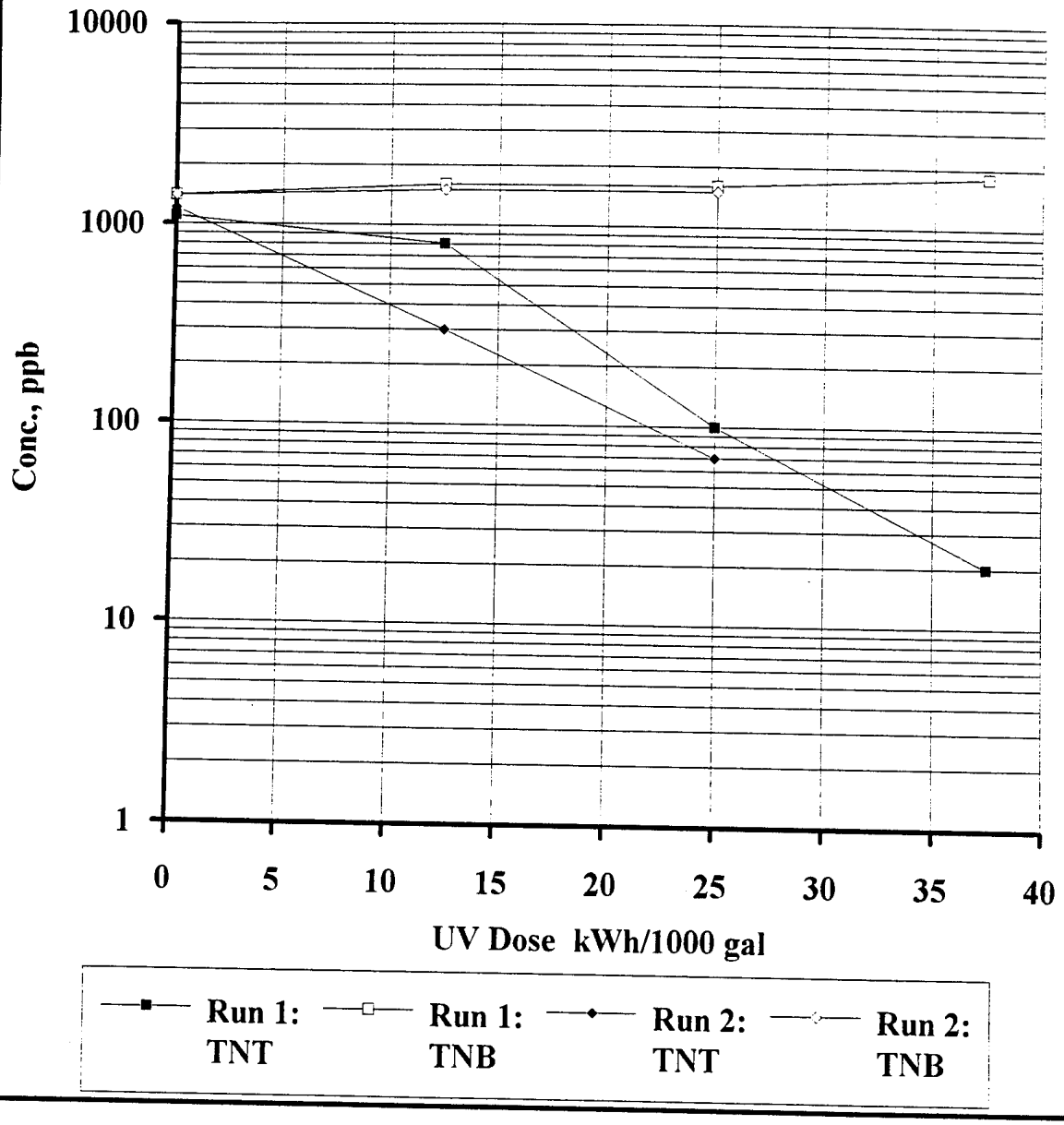


Figure 4

Ozonation of TNT and TNB

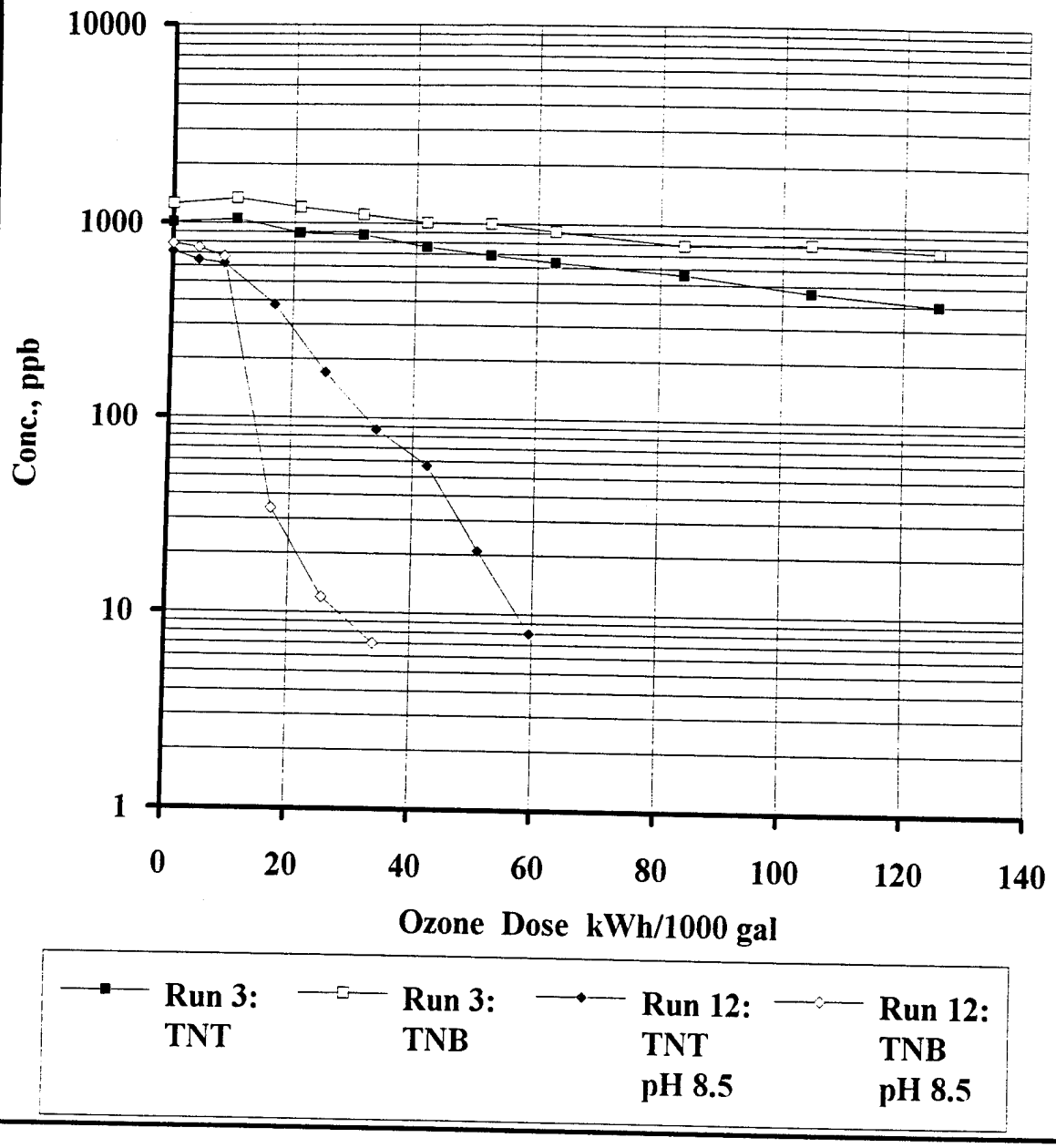


Figure 5

TNB Destruction At Different UV/O3 Ratios at pH 7

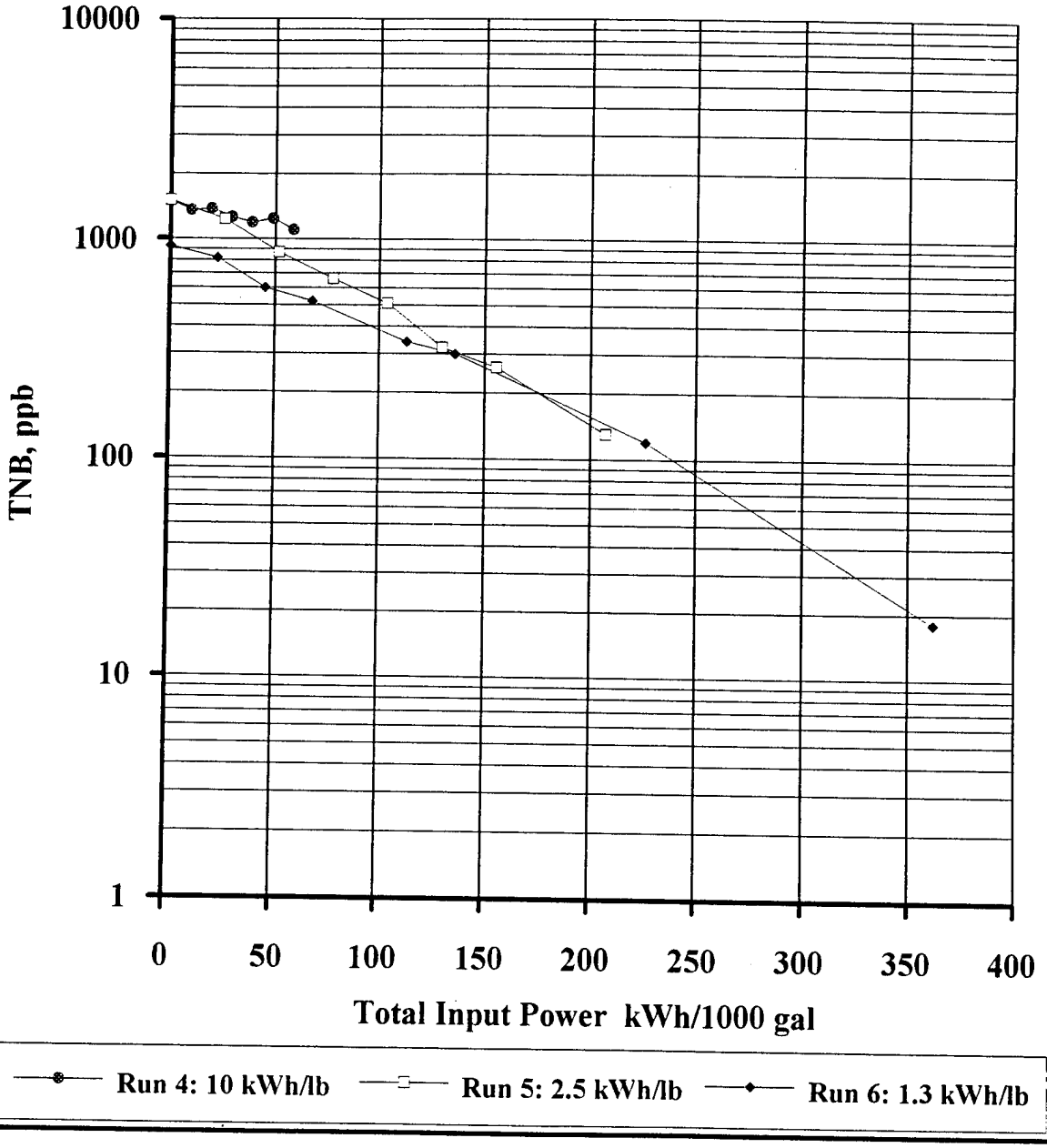
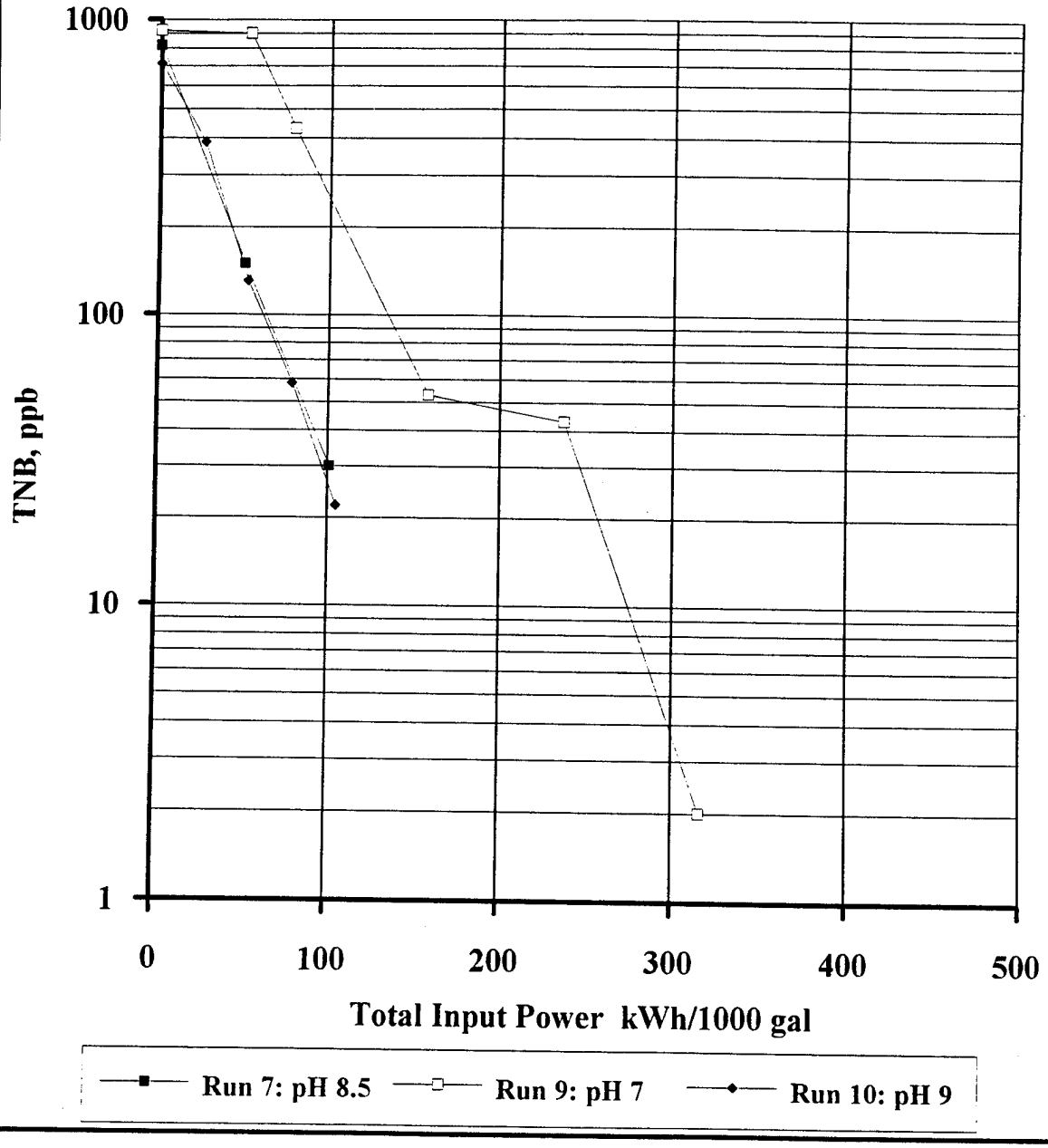


Figure 6

TNB Destruction Versus Sample pH



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REPORT OF LABORATORY ANALYSIS

Mr. Steve Cater
Page 2

September 01, 1994
PACE Project Number: 940825509

Client Reference: P432

Parameter	Units	MDL			
PACE Sample Number:			10 0195561	10 0195570	10 0195588
Date Collected:			08/13/94	08/13/94	08/13/94
Date Received:			08/25/94	08/25/94	08/25/94
Client Sample ID:			432-10-2	432-10-4	432-10-6
ORGANIC ANALYSIS					
SW8330: EXPLOSIVES IN LIQUID					
Date Extracted			08/29/94	08/29/94	08/29/94
Date Analyzed			30AUG94 2	30AUG94 2	30AUG94 2
HMX	ug/L	10	ND	ND	ND
RDX	ug/L	10	ND	ND	ND
1,3,5-Trinitrobenzene	ug/L	10	26 CO	ND	ND
1,3-Dinitrobenzene	ug/L	10	ND	ND	ND
Tetryl	ug/L	10	ND	ND	ND
Nitroglycerin	ug/L	50	ND	ND	ND
2,4,6-Trinitrotoluene	ug/L	10	150 CO	ND	ND
2,6-Dinitrotoluene	ug/L	10	ND	ND	ND
2,4-Dinitrotoluene	ug/L	10	ND	ND	ND
2-Nitrotoluene	ug/L	10	ND	ND	ND
4-Nitrotoluene	ug/L	10	ND	ND	ND
3-Nitrotoluene	ug/L	10	ND	ND	ND
Nitrobenzene	ug/L	10	ND	ND	ND
4-amino-2,6-Dinitrotoluene	ug/L	10	ND	ND	ND
2-amino-4,6-Dinitrotoluene	ug/L	10	ND	ND	ND
1,4-Dinitrobenzene (Surrogate)	%		79	103	81

These data have been reviewed and are approved for release.

Todd R. Mitchell
Project Manager

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FROM :612-525-3377 TO : 305 477 4511 1994.09-01 15:11 #668 P.03/07

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THE ASSURANCE OF QUALITY

REPORT OF LABORATORY ANALYSIS

Solarchem Enterprises Inc.
130 Royal Crest Court
Markham, Ontario
Canada, . L3R-0A1

September 09, 1994
PACE Project Number: 940831501

Attn: Mr. Steve Cater

DRAFT

Client Reference: P432

PACE Sample Number:			10 0200980	10 0200999	10 0201006
Date Collected:			08/25/94	08/25/94	08/25/94
Date Received:			08/31/94	08/31/94	08/31/94
			432-12-0	432-12-4	432-12-10
Parameter	Units	MDL			
ORGANIC ANALYSIS					
SW8330: EXPLOSIVES IN LIQUID					
Date Extracted			08/31/94	08/31/94	08/31/94
Date Analyzed			07SEP94	2#27SEP94 #	07SEP94 2#
HMX	ug/L	16	ND #	ND #	ND #
RDX	ug/L	16	76 #	ND #	ND #
1,3,5-Trinitrobenzene	ug/L	16	570 # E	44 #	ND #
1,3-Dinitrobenzene	ug/L	16	20 #	ND #	ND #
Tetryl	ug/L	16	ND #	ND #	ND #
Nitroglycerin	ug/L	80	-	-	ND #
2,4,6-Trinitrotoluene	ug/L	16	710 # E	140 #	ND #
2,6-Dinitrotoluene	ug/L	16	38 #	ND #	ND #
2,4-Dinitrotoluene	ug/L	16	ND #	ND #	ND #
2-Nitrotoluene	ug/L	16	ND #	49 #	ND #
4-Nitrotoluene	ug/L	16	ND #	ND #	15 #
3-Nitrotoluene	ug/L	16	43 #	ND #	ND #
PETN	ug/L		-	-	ND #
Nitrobenzene	ug/L	16	87 #	ND #	ND #
4-amino-2,6-Dinitrotoluene	ug/L	16	53 #	ND #	ND #
2-amino-4,6-Dinitrotoluene	ug/L	16	50 #	ND #	ND #
1,4-Dinitrobenzene (Surrogate)	%		83 #	97 #	107 #

These data have been reviewed and are approved for release.

Todd R. Mitchell
Project Manager

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THE ASSURANCE OF QUALITY

REPORT OF LABORATORY ANALYSIS

Solarchem Enterprises Inc.
130 Royal Crest Court
Markham, Ontario
Canada, . L3R-0A1

September 01, 1994
PACE Project Number: 940825509

Attn: Mr. Steve Cater

Client Reference: P432

Parameter	Units	MDL			
PACE Sample Number:			10 0195537	10 0195545	10 0195553
Date Collected:			08/13/94	08/13/94	08/13/94
Date Received:			08/25/94	08/25/94	08/25/94
			432-7-0	432-7-3	432-10-0
ORGANIC ANALYSIS					
SW8330: EXPLOSIVES IN LIQUID					
Date Extracted			08/29/94	08/29/94	08/29/94
Date Analyzed			30AUG94 2	30AUG94 2	30AUG94 2
HMX	ug/L	10	ND	ND	ND
RDX	ug/L	10	20 CO	ND	48 CO
1,3,5-Trinitrobenzene	ug/L	10	-	ND	490 CO
1,3,5-Trinitrobenzene	ug/L	20	470 CO	-	-
1,3-Dinitrobenzene	ug/L	10	19 CO	ND	18
Tetryl	ug/L	10	ND	ND	ND
Nitroglycerin	ug/L	50	ND	ND	ND
2,4,6-Trinitrotoluene	ug/L	10	-	ND	-
2,4,6-Trinitrotoluene	ug/L	20	760 CO	-	690 CO
2,6-Dinitrotoluene	ug/L	10	ND	ND	ND
2,4-Dinitrotoluene	ug/L	10	ND	ND	ND
2-Nitrotoluene	ug/L	10	ND	ND	ND
4-Nitrotoluene	ug/L	10	ND	ND	ND
3-Nitrotoluene	ug/L	10	ND	ND	ND
Nitrobenzene	ug/L	10	ND	ND	ND
4-amino-2,6-Dinitrotoluene	ug/L	10	ND	ND	ND
2-amino-4,6-Dinitrotoluene	ug/L	10	16 CO	ND	26 CO
1,4-Dinitrobenzene (Surrogate)	%		74	62	74

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ULTROX

BENCH-SCALE REPORT

ULTROX

A Division of Zimpro Environmental, Inc.

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ULTROX DIVISION OF ZIMPRO ENVIRONMENTAL, INC.

LABORATORY TREATABILITY STUDY REPORT

FOR THE

UV/OXIDATION SYSTEM
PILOT SCALE DEMONSTRATION PROGRAM
SAVANNA ARMY DEPOT ACTIVITY
SAVANNA, ILLINOIS

DACA31-91-D-0079/0006
WORK ORDER NO. 02281-012-006

Submitted by:

William S. Himebaugh
Ultrox Division of Zimpro Environmental, Inc.
September 2, 1994

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1.0 INTRODUCTION

Ultrox division of Zimpro Environmental, Inc. was contracted by Roy F. Weston, Inc. (Weston) to conduct a laboratory treatability study and field pilot demonstration on representative groundwater from the Savanna Army Depot Activity in Savanna, Illinois. This report addresses the requirements and results of the bench scale testing alone.

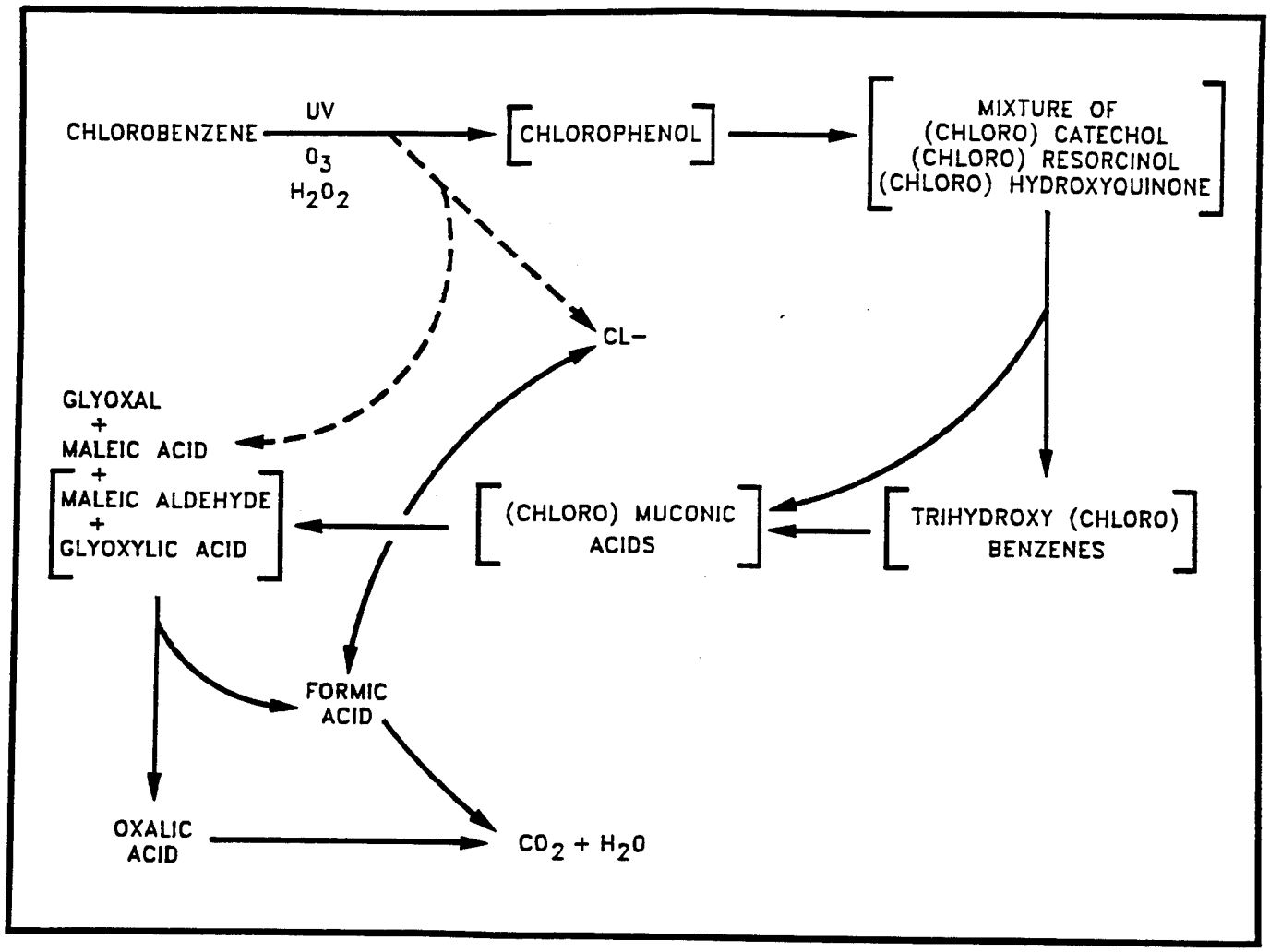
The Ultrox® technology is an Advanced Oxidation Process (AOP) which utilizes the optimum combinations of three primary oxidizers. These include ozone (O_3), hydrogen peroxide (H_2O_2), and ultraviolet light (UV) which combined to destroy organic compounds in water. This process has the distinct advantage of on site destruction of organic compounds. This is in contrast to other treatment methods such as granular activated carbon adsorption (GAC) where compounds are captured and transferred to disposal sites or air stripping which merely transforms the problem compounds from the water phase to the vapor phase. Compounds are attacked by the UV light, chemical oxidants alone and by free radicals which are produced by combing ozone with hydrogen peroxide and/or with UV. The oxidation strength of these species is detailed in comparison to others in Table 1. The ultimate result of this destruction is carbon dioxide, water, and in the case of chlorinated compounds, salts (see Figure 1). Because different compounds in various groundwaters oxidize with varying efficiencies, (depending upon oxidant dosages, combinations, and UV exposure times) laboratory treatability studies are conducted to optimize these conditions.

The full scale and pilot Ultrox® UV/Oxidation systems consist of a UV treatment tank containing highly efficient UV lamps. Hydrogen peroxide is water soluble and is metered into the treatment tank influent line. Ozone is produced on-site from air and diffused into the UV treatment tank through spargers located in the bottom of the tank. Any residual ozone or VOCs which may collect in the vapor area within the UV treatment tank are destroyed by the D-TOX™/Decompozon™ catalytic air treatment unit. The result is water meeting discharge requirements without toxic byproducts or air emissions. What's more, the operating and maintenance costs are typically significantly lower than GAC or other UV/Oxidation technologies which utilize high intensity UV lamps.

TABLE 1		
Relative Oxidation Potential (C12 = 1.0)	**Species**	**Oxidation Potential (Volts)**
2.23	fluorine	3.03
2.06	hydroxyl radical	2.80
1.78	atomic oxygen (single)	2.42
1.52	ozone	2.07
1.31	hydrogen peroxide	1.78
1.25	perhydroxyl radical	1.70
1.24	permanganate	1.68
1.15	chlorine dioxide	1.57
1.07	hypoiodous acid	1.45
1.00	chlorine	1.36
0.80	bromine	1.09
0.39	iodine	0.54

FIGURE 1 - REACTION PATHWAY

Oxidation of Chlorobenzene



2.0 LABORATORY TREATABILITY STUDY OBJECTIVES

2.1 The objectives were as follows:

- To determine the effectiveness of UV/Oxidation as an alternative for reducing the concentration of explosive compounds in the groundwater from Well No. 302124.

- To obtain information necessary to determine pretreatment requirements, optimized oxidant dosages and UV exposure times required for a full-scale treatment UV/Oxidation system capable of reducing the explosives in the groundwater from Well No. 302124 to below the objective concentrations listed in Table 2.

TABLE 2 - TREATMENT OBJECTIVES

Discharge Limits for Treated Groundwater from the UV/Ox Pilot-scale Demonstration Program

Parameter	Monthly Average (mg/L)	Daily Average (mg/L)
2,4,6-Trinitrotoluene	-	0.007
2,4-Dinitrotoluene	0.003	0.006
2,6-Dinitrotoluene	-	0.009
1,3,5-Trinitrobenzene	-	0.007
Tetryl	-	0.044
HMX	-	0.013
1,3-Dinitrobenzene	-	0.004
2-Amino-4,6-Dinitrotoluene	-	0.036
Nitrobenzene	-	0.010
RDX	-	0.014
pH	-	6 - 9

3.0 EXPERIMENTAL PROCEDURES

3.1 Materials

The bench scale test included the following equipment and materials:

- A Ultrox® bench-scale batch reactor
- A Ultrox® UV radiation lamp
- A 35% solution of H_2O_2
- A 2 lb/day O_3 generator

The Ultrox® batch reactor (Figure 2) is a cylindrical, glass vessel with a capacity of 2.4 liters (l). The UV radiation was provided by an Ultrox® UV lamp located inside a quartz sheath which was positioned in the center of the bench-scale reactor.

For each oxidation test performed, a two liter sample of the water to be treated was poured into the bench-scale reactor. For those tests involving hydrogen peroxide, a predetermined dosage of H_2O_2 (35% by weight) was added and stirred by a magnetic stirrer. The magnetic stirrer was active throughout the tests to simulate flow dynamics of a full scale system. Ozone was generated by a 2 pound/day Model GL-1 PCI ozone generator. Ozone was introduced as a mixture of 2% ozone in oxygen using a coarse frit gas dispersion tube (sparger) at the bottom of the reactor.

3.2 Sample Handling

Eight (8) gallons of sample groundwater were received on August 8, 1994 in eight one gallon glass bottles which were packed with ice in two coolers. Upon receipt, the samples were logged in and chain of custody was maintained. Samples were immediately transferred to the walk-in cooler (4°C) until used in oxidation tests. Prior to use in oxidation tests, the untreated sample groundwater was removed from the walk in cooler and allowed to warm to room temperature. Two liters of the untreated were poured from their 1-gallon bottles into the Ultrox® bench scale reactor. Any sample ground water not utilized for analytical purposes was stored in the original glass bottles which were labeled as "Partially Treated Groundwater (Well 302124 SADA Demonstration)". Unless otherwise directed, this water will be returned at the completion of the demonstration to Roy F. Weston at the SADA facility.

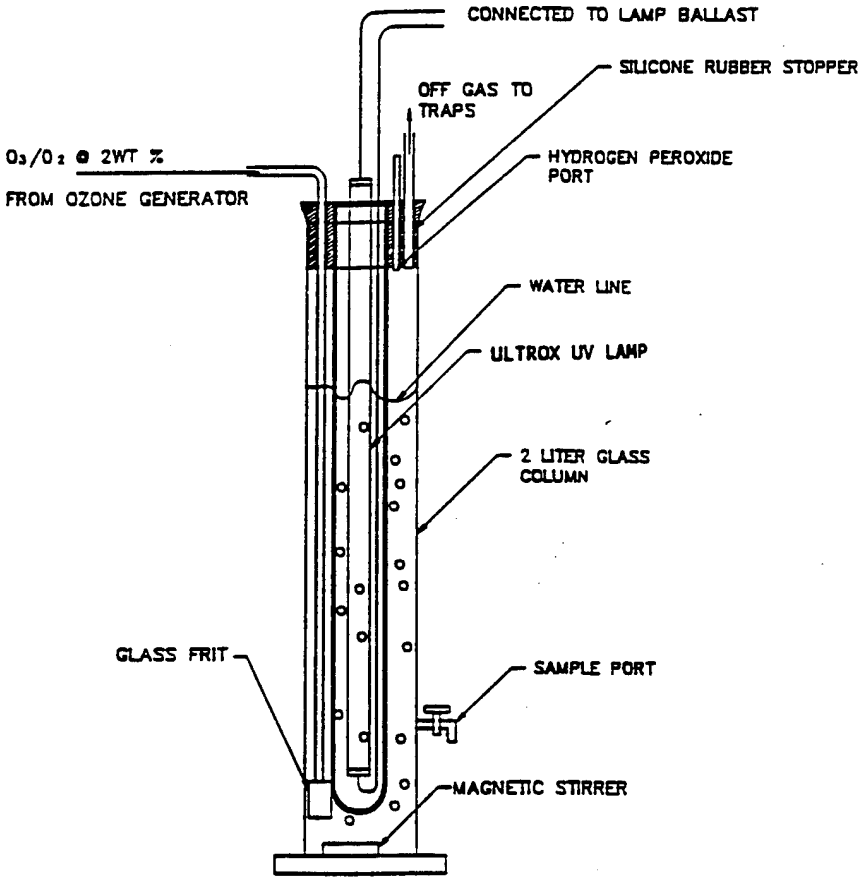


FIGURE 2

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TOLERANCES (EXCEPT AS NOTED)	ULTROX	2400 SO. ANNE ST. SANTA ANA, CA. 92704	
DECIMAL ±	BENCH SCALE UV/OXIDATION TREATMENT ASSEMBLY		
FRACTIONAL ±	DRAWN BY M.OLGUIN	SCALE NONE	MATERIAL
ANGULAR ±	CHK'D	DATE 12-07-90	DRAWING NO. 3242
NEXT ASSY / USED ON	1 OF 1	APP'D	

3.3 Preparation and Calibration Procedures

Prior to oxidation testing, the eight 1-gallon samples were combined to insure consistency of characterization. After combining, sample groundwater was analyzed for parameters which can affect the oxidation process. These parameters and analytical methods are listed in Table 3.

At the beginning of each working period, the O_3 output of the ozone generator was determined according to the following procedure:

- The O_3 generator was set at the predetermined power level estimated to produce 2 percent O_3 by weight;
- One liter/minute of the generated O_3 was passed through 300 ml of 2 percent potassium iodide (KI) solution in a 500 ml graduated cylinder for 30 to 60 seconds;
- A 50 ml aliquot of the KI solution was acidified with sulfuric acid then titrated with 0.02 Molar (M) sodium thiosulfate solution to a starch endpoint;
- The O_3 concentration was calculated from the volume of the sodium thiosulfate consumed.
- The calculated concentration of hydrogen peroxide (35% solution) was added by a pipette at predetermined times during each test run.

TABLE 3		
PARAMETER	**ANALYSIS**	**METHOD**
Alkalinity	Titration	SM 4500
Iron	AAS	EPA 236.1
Manganese	AAS	EPA 244.1
Hardness	Titration	EPA 130.1
Total Suspended Solids (TSS)	Gravimetric	EPA 160.2
Total Dissolved Solids (TDS)	Gravimetric	EPA 160.1
pH	Electrometric	SM 4500H
Chlorides	Titration	EPA 300
Chromium	AAS	EPA 218.1
Total Organic Carbon (TOC)	Combustion-Infrared	EPA 415.1

3.4 Oxidation Test Procedures

A total of nine (9) batch oxidation tests were conducted on the groundwater from Well 302124. All oxidation tests were conducted by pouring two liters of the combined groundwater from the appropriate bottle into the bench scale reactor.

The first oxidation test was performed using UV and ozone without pretreatment. Ozone was introduced at the rate of 0.5 mg of ozone per liter of groundwater water per minute. Ozone was diffused into the bench scale reactor at a continuous rate during 120 minutes of UV irradiation. After 120 minutes of UV and ozone treatment, a sample was collected and analyzed for explosives, pH, and total organic carbon (TOC).

The second oxidation test was conducted using ozone in combination with hydrogen peroxide and no UV light. Based upon previous work performed by Ultrox and others, ozone/hydrogen peroxide in dark reactions is enhanced by an elevated pH and an oxidant ratio of 3:1 favoring ozone. To compare the effectiveness of ozone/hydrogen peroxide with that of UV/ozone, the total oxidant dosage of 60 minutes was maintained. As in the first test, samples were collected after 120 minutes of treatment and analyzed for explosives and TOC.

The third oxidation test was performed with conditions identical to those in the first test (UV/ozone), except that the pH was reduced from 7.0 to 4 by addition of concentrated sulfuric acid. It was postulated that by reducing the pH, the carbonate and bicarbonate level would be reduced. Since carbonate and bicarbonate are scavengers of both hydroxyl radicals and oxidants, reduction in these parameters would assist in the oxidation process. Again, samples were collected after 120 minutes of treatment analyzed for explosives, TOC and pH.

Tests 4 and 5 involved UV with ozone at the elevated ozone dosing rate of 1 mg of ozone per liter of groundwater per minute. Again, the ozone was introduced at a continuous rate during 120 minutes of UV irradiation. However, the sample groundwater for test 5 was pretreated by adding sufficient sulfuric acid to reduce the pH from 7.0 to 9.0. Samples were collected after the 120 minutes of treatment and analyzed for explosives, TOC and pH.

Test 6 was conducted with the high ozone dosage (120 mg/l) as in tests 4 and 5, but UV exposure time was reduced to 90 minutes. Again the pH was adjusted to 4 to reduce the carbonate and bicarbonate in the groundwater.

The seventh oxidation test was performed with 120 minutes of UV exposure and 90 mg/l of ozone. Again, the pH was reduced to 4 to reduce the carbonates and bicarbonates. This provided an intermediate data point between Tests 3 and 5 in optimizing the ozone dosage.

The eighth oxidation test was performed to determine if the addition of hydrogen peroxide during the last 60 minutes of the test would aid in oxidation. The total oxidant dosage was 120 mg/l and UV exposure was 120 minutes.

The ninth and final test was conducted with the same conditions as test 7 (120 minutes of UV with 90 mg/l of ozone) except the pH was reduced to 5 instead of 4.

3.5 Analytical Procedures

Besides the characterization analyses performed (Table 3), the untreated and treated samples were analyzed for explosives using EPA method 8330.

4.0 RESULTS

The results of the first two oxidation tests indicate that ozone and hydrogen peroxide without UV results in reductions in 2,4-DNT and increases in 1,3-DNB. This is likely due to the cleaving of the methyl groups of the 2,4-DNT resulting in 1,3-DNB as a byproduct. However, the reduction of 2,4,6-TNT did not result in increases in 1,3,5-TNB. Since the projected costs associated with treatment based on Test 2 would be higher than those with UV/ozone, the latter approach was determined to be more applicable.

A comparison of the results from Tests 1 and 3 indicate that pH has a significant affect on the oxidation process for this groundwater. The relatively high hardness indicates sufficient carbonates and bicarbonates to warrant pretreatment investigation. By reducing the pH to 4, the oxidation process was improved significantly. Addition of acid reduces the carbonates and bicarbonates which are scavengers of oxidants and the hydroxyl radicals produced for destruction of organics. Reduction of pH to 5 did not provide as efficient destruction per oxidant dosage and UV exposure. This is supported by a comparison of Tests 7 and 9.

Examination of the results from Test 6 indicates that all treatment objectives were achieved for all compounds except 2,4,6-TNT. This is considered an anomaly since the oxidation of 2,4,6-TNT results in the byproduct of 1,3,5-TNB and none was detected. Duplication of these conditions is planned during the optimization period of the pilot demonstration. If in fact, all treatment objectives are met, a lower UV exposure time may apply.

SAVANNA ARMY DEPOT ACTIVITY
Treatability Study
Job # 11-3895-500
06-Sep-94

TABLE 4 - TEST RESULTS

Ultrox,
Division of Zimpro Env.

TEST No.	DATE	CONDITION	TIME (mins.)	O3 (mg/L)	H2O2 (mg/L)	pH	TC (mg/L)	TOC (mg/L)	1,3,5-TNB (ug/L)	1,3-DNB (ug/L)	NB (ug/L)	2,4-DNT (ug/L)	2,6-DNT (ug/L)	2,4,6-TNT (ug/L)
Feed	7/12/94	Analyzed by Weston	0	0	0	N/A	N/A	N/A	590.0	47.0	0.1	110.0	10.0	1,200.0
	8/17/94	Analyzed by Pyramid	0	0	0	7.0	61	7	798.0	33.0	< 20.0	140.0	< 41.0	1,515.0
(1)*	8/9/94	UV/O3	0	0	0	7.0	58	7	798.0	33.0	< 20.0	140.0	< 41.0	1,515.0
			120	60	0	7.3	57	10	917.0	381.0	< 20.0	< 20.0	< 41.0	< 25.0
Destruction Removal Efficiency									(14.9)	(1,054.5)	na	85.7	na	98.3
(2)	8/11/94	O3/H2O2	0	0	0	9.0	60	6	798.0	33.0	< 20.0	140.0	< 41.0	1,515.0
			120	45	15	7.6	66	8	721.0	23.0	< 20.0	42.0	< 41.0	1,185.0
Destruction Removal Efficiency									9.6	30.3	na	85.7	na	85.7
(3)	8/22/94	UV/O3	0	0	0	4.0	36	9	798.0	33.0	< 20.0	140.0	< 41.0	1,515.0
			120	60	0	4.0	7	4	800.0	< 11	< 20.0	< 20.0	< 41.0	< 25.0
Destruction Removal Efficiency									(0.3)	66.7	na	85.7	na	98.3
(4)*	8/22/94	UV/O3	0	0	0	6.9	61	7	798.0	33.0	< 20.0	140.0	< 41.0	1,515.0
			120	120	0	7.6	49	4	500.0	< 11	< 20.0	< 20.0	< 41.0	< 25.0
Destruction Removal Efficiency									37.3	66.7	na	85.7	na	98.3

* A dark brown precipitate, likely manganese oxide, formed during the oxidation.

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SAVANNA ARMY DEPOT ACTIVITY
Treatability Study
Job # 11-3895-500
06-Sep-94

Table 4 (continued)

Ultrox,
Division of Zimpro Env.

TEST No.	DATE	CONDITION	TIME (mins.)	O3 (mg/L)	H2O2 (mg/L)	pH	TC (mg/L)	TOC (mg/L)	1,3,5-TNB (ug/L)	1,3-DNB (ug/L)	NB (ug/L)	2,4-DNT (ug/L)	2,6-DNT (ug/L)	2,4,6-TNT (ug/L)
(5)*	8/22/94	UV/O3	0	0	0	4.0	36	9	798	33.0	< 20.0	140.0	< 41.0	1,515.0
			120	120	0	3.6	4	4	< 19	< 11.0	< 20.0	< 20.0	< 41.0	< 25.0
Destruction Removal Efficiency									97.6	66.7	na	85.7	na	98.3
(6)*	8/26/94	UV/O3	0	0	0	4.0	29	10	798	33.0	< 20.0	140.0	< 41.0	1,515.0
			90	120	0	3.7	6	5	< 19	< 11.0	< 20.0	< 20.0	< 41.0	169.0
Destruction Removal Efficiency									97.6	66.7	na	85.7	na	88.8
(7)*	8/26/94	UV/O3	0	0	0	4.0	39	15	798	33.0	< 20.0	140.0	< 41.0	1,515.0
			120	90	0	3.6	5	4	< 19	< 11.0	< 20.0	< 20.0	< 41.0	< 25.0
Destruction Removal Efficiency									97.6	66.7	na	85.7	na	98.3
(8)	8/29/94	UV/O3	0	0	0	4.0	39	14	798	33.0	< 20.0	140.0	< 41	1,515.0
			60	45	0	3.9	14	12	-	-	-	-	-	-
		UV/O3/H2O2	120	90	30	3.9	13	12	292	< 11.0	< 20.0	< 20.0	< 41.0	37.0
Destruction Removal Efficiency									63.4	66.7	na	85.7	na	97.6
(9)	8/29/94	UV/O3	0	0	0	5.0	39	14	798	33.0	< 20.0	140.0	< 41.0	1,515.0
			120	90	0	5.5	9	8	1045	243.0	< 20.0	< 20.0	< 41.0	< 25.0
Destruction Removal Efficiency									-30.95	(636.4)	na	85.7	na	98.3

* A dark brown precipitate, most likely manganese oxide, formed during the oxidation.

INORGANICS

ANALYTE	METHOD EPA	UNIT	RESULTS
Alkalinity	130.1	mg CaCO3/L	182
Chloride	325.5	mg/L	< 5.0
Dissolved Solids	160.1	mg/L	966
Hardness	SM 2340B	mg eq CaCO3/L	569
Iron	236.1	mg/L	0.89
Manganese	243.1	mg/L	3.36
Suspended Solids	160.2	mg/L	11.8
Turbidity	180.1	NTU	6.6

5.0 CONCLUSIONS

Results indicate that Ultrox® UV/Oxidation is successful in reducing the explosives to below their appropriate treatment objective concentrations (Table 2). Due to the high carbonate/bicarbonate concentration in the sample groundwater, the oxidation process was significantly improved by reduction of pH to 4. The addition of hydrogen peroxide did not aid the oxidation process and will therefore not be used in the pilot demonstration. UV with hydrogen peroxide was not evaluated because historical data indicates that this is not an economical approach when treating explosives with Ultrox® UV/Oxidation. Based upon the data from this laboratory study, the optimum UV exposure time is between 117 minutes and 156 minutes for a full scale flow through system. The laboratory data indicates that the optimum ozone dosage is between 60 and 90 mg/l depending upon UV exposure (retention) time with a pH of 4.

6.0 COMMERCIAL

The following estimated treatment conditions and costs are for an Ultrox® UV/Oxidation system design based upon the treatment conditions represented in Tests 6 and 7 of this study. Performance is based upon the reduction of explosives as shown in Table 4.

6.1 Design Assumptions (Test 6)

- Flow Rate ..... 50 gpm
- Ozone Dosage ..... 120 mg/l
- Hydrogen Peroxide Dosage ..... 0 mg/l
- Retention Time* ..... 103 minutes
- UV Lamp Life ..... 9,000 hours

* Full scale retention time is increased by 15% over the laboratory retention time to account for flow through characteristics of a full scale system (as opposed to the batch treatment conducted in the laboratory).

6.2 Design Assumptions (Test 7)

- Flow Rate ..... 50 gpm
- Ozone Dosage ..... 90 mg/l
- Hydrogen Peroxide Dosage ..... 0 mg/l
- Retention Time* ..... 138 minutes
- UV Lamp Life ..... 9,000 hours

* Full scale retention time is increased by 15% over the laboratory retention time to account for flow through characteristics of a full scale system (as opposed to the batch treatment conducted in the laboratory).

6.3 Cost Assumptions

- Power Cost $0.06/kwh
- UV Lamp Cost $60/lamp

6.4 System Equipment (Based on Test 6)

The estimated Ultrox oxidation system consists of the following major components:

- Ultrox® F-3900/1300 UV/Oxidation Treatment Tanks
- 100 lb/day ozone generator
- Air Preparation System consisting of:
  - Air Filter
  - Air Dryer

- Decompozon Air Treatment System
- Programmable Logic Control Panel

6.5 System Equipment (Based on Test 7)

The estimated Ultrox oxidation system consists of the following major components:

- Ultrox® 2 F-3900 UV/Oxidation Treatment Tanks
- 50 lb/day ozone generator
- Air Preparation System consisting of:
  - Air Filter
  - Air Dryer
- Decompozon Air Treatment System
- Programmable Logic Control Panel

6.6 Estimated System Capital Cost

The estimated capital cost for the Ultrox® UV/Oxidation system described in Section 6.4 (Test 6) is **$583,000**. Estimated cost is F.O.B. Rothschild, Wisconsin and does not include any applicable federal, state or local taxes.

The estimated capital cost for the Ultrox® UV/Oxidation system described in Section 6.5 (Test 7) is **$601,800**. Estimated cost is F.O.B. Rothschild, Wisconsin and does not include any applicable federal, state or local taxes.

6.7 Additional Costs

Additional costs are itemized for the appropriate system on subsequent pages entitled "Roy F. Weston Life Cycle Cost Comparison" for each of the alternative treatment conditions.

6.8 Additional Required Information

Volume of Groundwater Treated ..... 20 liters
Estimated Power Usage (Based on Test 6) ..... 70 KW
Estimated Power Usage (Based on Test 7) ..... 81 KW
Estimated Annual Chemical Usage
. Sulfuric Acid ..... 54.5 Liters/Day
. Sodium Hydroxide ..... 7.08 Liters/Day
Pretreatment Requirements ..... See Life Cycle Cost Comparison
Estimated Annual Repair/Replacement Costs for System Components:
. Based on Tests 6 & 7 ..... See Life Cycle Cost Comparison
Estimated Annual O&M Labor Hours ..... 104 Hours
Typical Full Scale System Design Life Span ..... 35-40 Years

Estimated Total Treatment Cost Per Gallon Groundwater:

- Based on Test 6 ..... $6.65/1000 gallons
- Based on Test 7 ..... $7.83/1000 gallons

APPENDIX

LIFE CYCLE COST COMPARISONS

TERMS & CONDITIONS

LIFE CYCLE COST COMPARISONS

Roy F. Weston
LIFE CYCLE COST COMPARISON

5 Year Project Life (Based upon Test 7)

COST CATEGORY	ULTROX	Vendor A	Vendor B
Electrical Costs Ultraviolet Lamps (# of lamps x KW/lamp x 24 hrs/day x 365 days/yr x $0.06/KWH)	$29,517.70		
Ozone Generator (# of lbs of Ozone/day x 11 KWH/lb x 365 days/yr x $0.06/KWH)	$1,447.81		
Ultraviolet Lamp Replacement (# of lamps x # of times replaced/yr x cost/lamp)	$51,840.00		
Chemical Costs Hydrogen Peroxide (lbs. req'd/day x $0.70/lb x 365 days/yr)	$0.00		
Acid (lbs. req'd/day x cost/lb x 365 days/yr)	$664.30		
Base (lbs. req'd/day x cost/lb x 365 days/yr)	$273.75		
Catalyst (lbs. req'd/day x cost/lb x 365 days/yr)	$0.00		
Maintenance Labor (Average hrs/week x $40/hr x 52 wks/yr	$4,160.00		
Amortized Capital (Installed equipment cost / 5 yrs)	$120,360.00		
TOTAL ANNUAL COST	$208,263.56		

Roy F. Weston
LIFE CYCLE COST COMPARISON

5 Year Project Life (Based upon Test 6)

COST CATEGORY	ULTROX	Vendor A	Vendor B
Electrical Costs Ultraviolet Lamps (# of lamps x KW/lamp x 24 hrs/day x 365 days/yr x $0.06/KWH)	$19,678.46		
Ozone Generator (# of lbs of Ozone/day x 11 KWH/lb x 365 days/yr x $0.06/KWH)	$1,447.81		
Ultraviolet Lamp Replacement (# of lamps x # of times replaced/yr x cost/lamp)	$34,560.00		
Chemical Costs Hydrogen Peroxide (lbs. req'd/day x $0.70/lb x 365 days/yr)	$0.00		
Acid (lbs. req'd/day x cost/lb x 365 days/yr)	$664.30		
Base (lbs. req'd/day x cost/lb x 365 days/yr)	$273.75		
Catalyst (lbs. req'd/day x cost/lb x 365 days/yr)	$0.00		
Maintenance Labor (Average hrs/week x $40/hr x 52 wks/yr	$4,160.00		
Amortized Capital (Installed equipment cost / 5 yrs)	$116,600.00		
TOTAL ANNUAL COST	$177,384.32		

TERMS & CONDITIONS

ZIMPRO PASSAVANT

TERMS AND CONDITIONS OF SALE

This offer is made expressly subject to the following terms and conditions. Terms and conditions appearing in any order based on this offer which are in conflict with the following shall not be binding on Zimpro Passavant Environmental Systems, Inc. (Seller), unless specifically agreed to in writing by an authorized officer of Seller.

1. **GENERAL TERMS**—A. Written quotations are void after ninety (90) days. Prices and quotations are subject to change without written notice, unless specified otherwise. Acceptance of this offer is expressly limited to the exact terms contained herein and any attempt by Purchaser to alter or omit any of such terms shall be deemed a rejection or counter-offer. All orders are received subject to acceptance by Seller at Seller's main office in Rothschild, Wisconsin.

   B. This Agreement includes only the equipment specified herein, and does not include erection, installation, accessory or associated materials such as controls, piping, etc., not specifically listed.

   C. If applicable laws, ordinances, regulations or conditions require anything different from or in addition to that called for by Seller's drawings and specifications, Seller will satisfy such requirements at Purchaser's written request and expense upon receipt of proper specifications. Purchaser hereby agrees to indemnify and hold harmless Seller from any claims or losses arising due to alleged or actual insufficiency or inadequacy of the safety devices offered or supplied hereunder, whether specified by Seller or Purchaser, and from any damage resulting from use of the equipment supplied hereunder.

   D. In addition, Purchaser shall be responsible for the installation of safety devices or guards which may be necessary as a result of any modification to the equipment or any change of any operating procedure by Purchaser, and Purchaser hereby agrees to indemnify and save the Seller harmless from any claims, liabilities, obligations, costs and expenses incurred by Seller resulting from any claim by any person injured directly or indirectly in connection with the operation of the equipment sold hereunder because of the lack of safety devices or guards on the equipment necessitated by any such modification or change or operating procedure.

   E. There are no rights, warranties or conditions, express or implied, statutory or otherwise, other than those contained herein. This Agreement contains the entire agreement between Purchaser and Seller and can be modified or rescinded only by a writing signed by both parties. No waiver of any provisions of this Agreement shall be binding unless in writing signed by an authorized representative of the party against whom the waiver is asserted and unless expressly made generally applicable shall only apply to the specific case for which the waiver is given. Failure of either party to insist upon strict performance of this Agreement shall not be construed as a waiver of any terms or conditions hereof.

2. **PAYMENT**—A. Net amount of invoice shall be due in full within thirty (30) days of the date of invoice. If, in the opinion of Seller, the financial condition of Purchaser at any time does not justify continuance of production or shipment on the above payment terms, full or partial payment in advance may be required. All payments, unless otherwise specified, shall be in U.S. currency.

   B. In the event Purchaser defaults in making any payment due and payable hereunder, Purchaser agrees to pay a late payment charge on the amount of said payment from and after the date of default at a rate of one-and-one-half percent (1½%) per month of the unpaid balance.

   C. Final payment by Purchaser to Seller after settlement of contract back charges, if any, shall be prima facie evidence of Purchaser's acceptance of the equipment and products purchased hereunder and satisfactory performance by Seller of all of its obligations under this Agreement.

3. **TITLE AND OWNERSHIP**—Title to the equipment specified herein and any replacements or substitutes therefor, and the right of repossession remains with Seller until final payment is made by Purchaser. Said equipment or any part thereof shall not be considered fixtures or be incorporated into realty by reason of attachment thereto and may be separated from realty for the purpose of repossession. Purchaser agrees to do all things necessary to protect Seller's title and interest in and to such equipment. From date of shipment until full payment of invoice, Purchaser agrees to provide and maintain at its expense, but for the benefit of Seller, adequate insurance on the equipment against any loss of any nature whatsoever. In the event of default on any payment, the full amount unpaid shall become due and payable at any time during the continuance of the default, and Seller may repossess the products and retain the rights to collect the balance of the contract price.

4. **DELIVERY AND DELAYS**—A. Delivery dates are based on Seller's prompt receipt of all necessary information from Purchaser regarding the order. Seller shall not be liable for any delay in the performance of orders or contracts or in the delivery or shipment of goods or damages caused by such delay when such delay is directly or indirectly caused by or arises from fires, floods, accidents, acts of God, government requests, orders and regulations, labor disputes or strikes, fuel or materials shortages, delays in transportation, delays or failure to deliver by any of Seller's suppliers or subcontractors, or any other similar or dissimilar cause or causes beyond the control of Seller, and Seller's time for performance hereunder shall be extended accordingly. Such delay shall not be cause for cancellation of this Agreement.

   B. Seller shall have the right to make partial shipments. Invoices covering same shall be due and payable by Purchaser in accordance with the payment terms described herein.

5. **SHIPMENT**—The equipment specified herein shall be delivered F.O.B. Seller's factory or its supplier's shipping points. Method and route of shipment are at the discretion of Seller, unless Purchaser furnishes explicit instructions. All shipments are to be insured at Purchaser's expense and made at Purchaser's risk. Claims for damages during transit shall be filed by Purchaser with the carrier.

6. **TAXES**—Prices on the equipment specified herein are exclusive of all taxes. The amount of the present or future sales, revenue, excise or other taxes applicable to said equipment shall be added to the purchase price and shall be paid by Purchaser. In lieu thereof, Purchaser shall provide a tax exemption certificate acceptable to the taxing authorities.

7. **PATENTS**—Seller will defend and hold Purchaser harmless against any charges of infringement of claims of United States patents issued at the time of acceptance of the order; provided such charges are based exclusively on infringement by equipment designed and manufactured by Seller, and Seller is notified promptly in writing of the institution or threatened institution of any suit or proceeding and is given full control of the defense, settlement or compromise of any such action; and Purchaser agrees to give Seller any and all needed information, assistance and authority to enable Seller to do so. Should the use of said equipment be enjoined in such suit or should Seller otherwise deem it advisable, Seller shall, at its own expense, either procure for Purchaser the right to continue using said equipment or replace same with non-infringing equipment or modify it so it becomes non-infringing or remove equipment and refund the purchase price, less freight charges and depreciation. Seller shall not be liable for use of said equipment in the conduct of any process not inherent therein nor for infringement resulting from compliance with designs furnished by Purchaser. The foregoing states the sole liability of Seller for patent infringement with respect to said equipment.

   As to any equipment furnished by the Seller to the Purchaser and/or manufactured in accordance with the specifications supplied by the Purchaser or on behalf of the Purchaser, the Purchaser assumes full responsibility for the design, specifications and end-use of such equipment and hereby agrees to indemnify and hold Seller harmless against all claims, costs and expenses (including attorneys' fees) arising out of any claim initiated against Seller alleging infringement of any patent, trademark or copyright.

8. **CHANGES, DELAYS AND UNUSUAL COSTS**—A. Should Purchaser request or cause changes to be made in design or construction of the equipment, or if Purchaser delays the progress of work covered by this Agreement, the contract price and time shall be adjusted to reflect any increase or decrease. Additional charges may be made to cover any unforseen or unusual cost elements which have not been contemplated by Seller or Purchaer, and special packing, engineering and documentation.

   B. If delivery is postponed by Purchaser or prevented by strike, accident or other cause beyond Seller's control, and occurring at a location other than Seller's factory or its supplier's shipping point, Seller may tender delivery at Seller's factory or its supplier's shipping point. If Purchaser refuses such delivery for any such cause, Purchaser shall be responsible for all costs and expenses incurred by Seller resulting from such failure to accept delivery, including charges to its suppliers and subcontractors, and Seller may store the equipment at Purchaser's expense and risk, and if such storage is on the premises of the Seller, Seller may charge at a rate similar to that charged by a public warehouse. For all purposes of this Agreement, such tender of delivery or storage shall constitute delivery.

9. **SUPERVISION OR INSPECTION**—A. Service of a factory representative to supervise or inspect installation and/or operation of the products specified herein will be furnished by Seller upon the request of Purchaser, upon the following conditions:

   1. Supervision or inspection within the continental limits of the United States; per eight (8) hour day, Monday through Friday inclusive.
   2. Overtime worked Monday through Friday in excess of eight hours but less than twelve hours and up to eight hours on Saturday at time-and-one-half.
   3. Time worked in excess of twelve (12) hours on any one day or Sunday and holiday work, at double time.
   4. Traveling, living and incidental expenses at cost, including shipping charges on tools and other equipment which the factory representative has shipped to the construction site.
   5. Travel time will be charged to and from Purchaser's construction site, and overtime, weekend or holiday travel requested or required by Purchaser will be charged at the appropriate rates.

   B. Except for the direct acts or omission of the factory representative, the responsibility for the installation and/or first operation shall be Purchaser's. Seller will assume responsibility for worker's compensation coverage of Seller's employees only. All other insurance coverage and necessary materials and labor to accomplish installation shall be provided by Purchaser.

10. **WARRANTY**—A. Seller warrants the equipment specified herein to be free from defects in material and workmanship. Subject to the provisions of Paragraph 10B., Seller shall replace or repair F.O.B. point of manufacture, parts which Seller's examination shall show to have failed under normal use and service by the original user within one (1) year from date of delivery; provided Purchaser gives prompt written notice of each defect to Seller. Such repair or replacement shall then be subject to a pro-rata charge based upon Seller's estimate of the percentage of normal service life realized from the part. Decomposition by chemical action and wear caused by the presence of abrasive materials shall not constitute defects. Liability of Seller under this warranty is limited to repair or replacement of the defective part, all damage claims of whatever nature, including without limitation Purchaser's labor costs, being excluded.

    Correction by Seller of non-conformities whether patent or latent, in the manner and within the period of time provided above shall constitute fulfillment of all liabilities of Seller for such non-conformation, whether based on contract, warranty, negligence, indemnity, strict liability or otherwise with respect to or arising out of the sale or use of such equipment.

    B. Commodities not manufactured by Seller are warranted or guaranteed to the extent and in the manner they may be warranted or guaranteed to Seller by the manufacturer thereof, and to the extent such warranty or guarantee may reasonably be enforced without litigation by Seller.

    C. If Purchaser makes any modification to the equipment without Seller's prior written approval, or uses any spare part not manufactured or sold to the Purchaser by the Seller, which causes or contributes to a defect, then Seller shall be relieved of its warranty obligations hereunder.

    D. THERE ARE NO WARRANTEES OF MERCHANTABILITY AND FITNESS FOR ANY PARTICULAR PURPOSE OF SAID EQUIPMENT OR ANY OTHER WARRANTEES (EXPRESS, IMPLIED OR STATUTORY) CONCERNING THE PERFORMANCE CAPABILITY THEREOF, OR ANY OTHER REPRESENTATIONS AND GUARANTEES, OTHER THAN THE WARRANTEES, REPRESENTATIONS AND GUARANTEES SET FORTH IN THIS SECTION, OR WHICH SHALL BE SPECIFICALLY DESIGNATED AS A GUARANTEE BY THE LEGEND "PERFORMANCE GUARANTEE" APPEARING THEREON.

11. **LIMITATION OF LIABILITIES**—Seller shall not be liable to Purchaser for any indirect, incidental, special or consequential damages arising out of or in connection with this Agreement, including any claim in tort, contract, strict liability, warranty or otherwise, including but not limited to, damages in the nature of:
    1. loss of profits or revenues resulting from the failure of the equipment to meet specifications or warrantees;
    2. damages suffered by Purchaser as a result of downtime, overhead, labor, loss of use of or damage to machinery, equipment or structures, spoilage or loss of production or profit;
    3. cost of replacement equipment;
    4. damages suffered by customers of Purchaser; or
    5. any fines or penalties assessed for failure to comply with any law or governmental regulations.
12. **DESIGN CHANGE**—Seller reserves the right to change, discontinue or modify the design and construction of any product or to substitute materials equal to or superior to that originally specified.
13. **CANCELLATION**—This Agreement is not subject to cancellation unless requested by Purchaser and accepted in writing by Seller. In the event of any such cancellation, Purchaser shall pay to Seller, within 30 days of such cancellation, all reasonable costs and other expenses incurred by Seller prior to receipt of the request for cancellation (including but not limited to engineering, manufacturing expenses, all commitments to suppliers, subcontractors and others) plus 25% of the foregoing to compensate Seller for overhead and profit. No order may be cancelled after shipment.
14. **CONFIDENTIAL INFORMATION**—All information and data herein or furnished to Purchaser hereunder relating to price, size, type and design is submitted with the understanding that it is for Purchaser's own confidential use and is not to be shown or otherwise made known or available to any third party at any time without Seller's written consent.
15. **CLAIMS FOR SHORTAGES AND DAMAGES**—All claims for shortages and damaged equipment must be made in writing within 90 days after delivery or 30 days after arrival at destination, whichever is later. Purchaser shall file all claims within the same time periods with the transporting common carrier and with its insurance company. If the shortage is due to failure to ship, Seller's only obligation will be to make good the shortage F.O.B. its plant.
16. **SOFTWARE**—If the equipment purchased by Purchaser includes software, it is acknowledged that such software, together with all documentation provided by Seller in connection therewith, are proprietary to Seller, and that the license to use such software is personal to the Purchaser. Therefore, Purchaser agrees (a) not to reproduce, distribute or disclose to others such software and to maintain same in confidence, (b) to use same only in connection with Purchaser's business and not to allow third parties to use it without Seller's prior written consent and (c) not to make any modifications to the software for any reason whatsoever.
17. **GOVERNING LAW**—This Agreement shall be construed in accordance with the laws of the State of Wisconsin. The courts of such state shall have exclusive jurisdiction over all controversies arising out of or in connection with this Agreement. The parties hereto consent to personal jurisdiction in the courts of such state and agree that process may be served upon them in any such action by registered mail at the address stated at the head of this Agreement personally within or without such state. If service is made in any manner other than personal within such state, the defendant shall be entitled to a period of twenty additional days to answer over and above the time limited by law.
18. **SEVERABILITY**—Each paragraph and provision of this Agreement is severable from the entire Agreement and if any provisions of this Agreement are held to be invalid, the remainder of this Agreement shall nevertheless remain in full force and effect.
19. **RIGHTS**—The parties hereto covenant and agree that if either acquires any right or rights to bring any action, suit or proceeding against the other for or as a result of any breach of this Agreement, except for non-payment of the purchase price, the party acquiring such right or rights shall be conclusively deemed to have waived and relinquished the same unless such action, suit or proceeding is commenced within one year after such right or rights arose.
20. **BACK CHARGES**—In no event shall any installation, erection, modification or corrective work be done by Purchaser for the account of Seller until after full particulars (including an estimate of material cost, amount and rate of labor required) have been submitted in writing to and approved in writing by Seller. Return items will not be accepted unless Seller has previously agreed to such return in writing and supplied written shipping instructions.
21. **EQUAL OPPORTUNITY**—Seller hereby certifies that it does not and will not maintain or provide for its employees any segregated facilities at any of its establishments and it is in compliance with the requirements of executive order 11246, dated September 24, 1965, as amended and the rules, regulations and relevant orders issued thereunder.

ZIMPRO PASSAVANT
ENVIRONMENTAL SYSTEMS, INC.

301 W. Military Rd.
Rothschild, WI 54474
Telephone (715) 359-7211
Telecopier (715) 355-3219

ADDITIONAL LIMITS OF LIABILITY

22. **In no event shall either party be liable to the other for any indirect, special, incidental or consequential damages arising out of the performance or non-performance by such party of its obligations under this Agreement, including without limitation, loss of profits.**

23. **Except for claims for personal injury, the total liability of Subcontractor to Contractor arising under this Agreement, whether arising by causes of action in contract, tort, warranty (expressed or implied), performance guarantee, strict liability, delay or otherwise shall not exceed 10% of the contract price in the aggregate.**

VPSI

BENCH-SCALE REPORT

CONFIDENTIAL PROCESS ASSESSMENT

ASSESSMENT OF THE perox-pure™ PROCESS FOR THE DESTRUCTION OF ORGANIC CONTAMINANTS IN GROUNDWATER

prepared for

Roy F. Weston, Inc.
West Chester, Pennsylvania
Purchase Order No. P-0569-F1
VPSI Project No. 424

by

Vulcan Peroxidation Systems, Inc.
5151 East Broadway, Suite 600
Tucson, Arizona 85711

October 18, 1994

The information contained in this report includes descriptions and procedures which are confidential to Vulcan Peroxidation Systems, Inc. The report shall not be copied nor released to third parties without prior approval from Vulcan Peroxidation Systems, Inc.

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ATTACHMENT A - Specifications for **perox-pure™** Equipment
ATTACHMENT B - Process Flow Diagram

EXECUTIVE SUMMARY

Vulcan Peroxidation Systems, Inc. (VPSI) has performed a bench-scale evaluation for Roy F. Weston, Inc. (Weston) to determine the effectiveness of the **perox-pure™** Process in destroying the organic contaminants in the groundwater from the Savanna Army Depot Activity (SADA) site. The organic contaminants of concern include approximately 1,900 μg/l of volatile and semi-volatile organic compounds including 1000 μg/l trinitrotoluene (TNT) and 600 μg/l of trinitrobenzene (TNB).

The **perox-pure™** system provides effective treatment of the contaminated groundwater at the SADA site. Destruction of the target contaminants to the treatment objective was demonstrated. The unique difference between the **perox-pure™** organic destruction process and other treatment technologies is its ability to actually destroy organics to non-detectable levels. It does this by combining the effects of ultraviolet light (UV) and hydrogen peroxide (H_2O_2) in a closed reactor. The UV light cleaves the H_2O_2, thereby forming the powerful hydroxyl radicals. The hydroxyl radicals oxidize the organics to carbon dioxide and water. Any halogens present are converted to halides.

Successful full-scale treatment of the groundwater at the specified flow rate of 50 gpm is projected to occur with a power requirement of 600 kW. Including electricity, H_2O_2, acid, catalyst, and maintenance (parts & labor), the treatment cost is estimated to be $12.54 1000/gal.

The **perox-pure™** Process offers the advantages of a proven, cost-effective treatment system that creates no air emissions, or generation of secondary waste products and is backed by the security of more than 80 successful full-scale installations world-wide.

1.0 INTRODUCTION

The **perox-pure™** Process destroys dissolved organic contaminants in water by means of chemical oxidation. Ultraviolet (UV) light catalyzes the chemical oxidation of organic contaminants in water by its combined effect upon the organic contaminants and its reaction with hydrogen peroxide (H_2O_2). Many organic contaminants absorb UV light and may undergo a change in their chemical structure or may become more reactive with chemical oxidants. More importantly, UV light at less than 400 nm wavelength reacts with H_2O_2 molecules to form hydroxyl radicals. These powerful chemical oxidants then react with the organic contaminants in the water. If carried to completion the reaction products of hydrocarbon oxidation with the **perox-pure™** Process are carbon dioxide and water.

Vulcan Peroxidation Systems, Inc. (VPSI) was contracted by Roy F. Weston, Inc. (Weston) to perform a bench-scale study on contaminated groundwater using the **perox-pure™** Process. The groundwater contained approximately 1000 μg/l of TNT and 600 μg/l of TNB as expected. The treatment objective specified by Weston was the destruction of 1200 μg/l TNT and 590 μg/l TNB to less than 7 μg/l each at a flow rate of 50 gpm.

A bench-scale **perox-pure™** study was performed on the groundwater during August of 1994 at the VPSI Testing Laboratory in Tucson, Arizona. These tests were designed to provide a range of data from which full-scale treatment criteria and costs would be projected.

2.0 BENCH-SCALE LABORATORY TESTING

2.1 Testing Procedures

2.1.1 Description of Groundwater

On August 12, 1994, approximately 30 gallons of groundwater were received warm from Weston at the VPSI Laboratory in Tucson, Arizona. The water was contained in a plastic barrel with little headspace.

Characterization of the "as received" raw water sample was performed by VPSI to determine parameters of importance for **perox-pure™** treatment. The analytical results are shown in Table 1.

Table 1
Characterization Results
for the SADA Groundwater

Visual Color:	orange/brown
Visual Appearance:	Cloudy
pH:	7.0
Iron (mg/l):	0.40
Chloride (mg/l):	4.5
Chemical Oxygen Demand (mg/l):	16
Total Organic Carbon (mg/l):	5.0
Total Dissolved Solids (mg/l):	740
Total Suspended Solids (mg/l):	918
Hardness (mg/l as $CaCO_3$):	837
Alkalinity (mg/l $CaCO_3$):	176
Nitrate (mg/l NO_3):	1,232

The high concentration of suspended solids and turbidity present in the SADA groundwater would severely inhibit the effectiveness of the **perox-pure™** Process. Therefore, the as received water was pretreated to remove solids and turbidity prior to **perox-pure™** treatment. The pretreatment is discussed in Section 2.1.2.

2.1.2 Pretreatment

To remove solids and turbidity the raw water was treated with 30 mg/l of H_2O_2 and then filtered through a 3 micron cartridge filter. The resulting water was clear and free of solids. Characterization results for the pretreated water are shown in Table 2. In this case only those parameters directly affected by the pretreatment were analyzed.

Table 2
Characterization Results
for the Pretreated SADA Groundwater

Visual Color:	Yellow
Visual Appearance:	Clear
pH:	7.3
Total Iron (mg/l):	0.17
Total Organic Carbon (mg/l):	4.8
Total Dissolved Solids (mg/l):	710
Total Suspended Solids (mg/l):	<5
Turbidity (NTU):	1.7
Nitrate (mg/l as $N0_3$):	396

In addition to the reduction in solids and turbidity, the pretreated water contained one-third the nitrate level present in the raw water (Table 1). It is believed that the raw water nitrate concentration was affected by either analytical inference due to turbidity or by the presence of adsorbed nitrates on the solids.

2.1.3 **perox-pure™** Testing Protocol

The bench-scale **perox-pure™** test unit was charged by placing an aliquot of the water into a recycle reservoir. A pump was started which circulated the solution through the reactor and back into the reservoir providing continual mixing in the closed system. The UV lamp was illuminated to start the test. Catalyst formula and H_2O_2 were then added as required. Hydrogen peroxide was fed into solution during the entire test period in order to maintain a constant residual H_2O_2 concentration. All materials in contact with the solution were glass, quartz, stainless steel, viton or teflon.

After the appropriate retention times, samples of the treated water were collected in 40-ml septum vials and 500 ml bottles. An untreated sample was also collected the same way. The 40 ml samples were analyzed by VPSI for total organic carbon (TOC) using EPA Method 415.1. The 500 ml samples were sent to Hercules Environmental Testing Laboratories (HETL) for analysis of ordnance compounds using EPA Method 8330.

Because the ordnance analysis results required a two week turnaround time, VPSI utilized the TOC results to aid in optimizing the **perox-pure™** process variables.

2.2 Testing Results

Ten (10) **perox-pure™** treatment tests were performed by VPSI on the SADA groundwater. These tests were designed to determine the effects of the oxidant type and dosage, pH, and catalyst addition on the rate of contaminant destruction. The test conditions are shown in Table 3. All testing was performed on pretreated groundwater.

Table 3
Bench-Scale **perox-pure™** Treatment Conditions
for the SADA Groundwater

Test	Oxidant Dose (Type; mg/l)	Initial pH	Catalyst (formula; mg/l)
1	H_2O_2; 70	7.3	None
2	H_2O_2; 70	4.7	None
3	H_2O_2; 70	4.7	I;1
4	H_2O_2; 70	4.0	I;6
5	H_2O_2; 70	3.8	IV; 5
6	H_2O_2; 100	4.2	I; 20
7	H_2O_2; 100	4.0	I; 12
8	H_2O_2; 70, O_3; 65[1]	8.0	None
9	H_2O_2; 100	4.0	VI; 6
10	H_2O_2; 100	4.0	VII; 6

[1] Total applied Ozone dose after 4 minutes of oxidation time.

The test results are shown in Table 4.

The influent water contained the expected TNT and TNB concentrations of approximately 1000 µg/l and 600 µg/l, respectively. TNB was determined to be the rate limiting compound. As expected, TNB was generated initially and then destroyed after 2 minutes of oxidation time. The other ordnance compounds present were destroyed to the treatment objectives with 2 minutes of oxidation time or less. The best destruction rates were obtained in Test 7 performed using Catalyst Formula I at a dose of 12 mg/l.

The TOC results are also shown in Table 4. The TOC destruction rates are in good agreement with the ordnance compound destruction rates in that the TOC destruction rates achieved in Test 7 were also among the best.

Table 4
Bench-Scale **perox-pure™** Treatment Results
for the SADA Groundwater

Contaminant (μg/l)	Oxidation Time (min.)			
	0	1	2	4
Test 1				
TNT	1030	<8	<8	<8
1,3,5-TNB	585	798	951	1160
1,3-DNB	56	283	507	739
2 AMD	22	<8	<8	<8
TOC (mg/l)	4.7	4.08	3.7	3.1
Test 2				
TNT	1030	<8	<8	<8
1,3,5-TNB	580	895	1160	960
1,3-DNB	56	327	500	<11
2 AMD	29	<8	<8	<8
TOC (mg/l)	4.58	3.9	3.28	1.13
Test 3				
TNT	1040	<8	<8	<8
1,3,5-TNB	577	896	1310	1000
1,3-DNB	51	317	228	<11
2 AMD	28	<8	<8	<8
TOC (mg/l)	4.62	3.76	2.5	0.95
Test 4[1]				
TNT	1033	<8	<8	<8
1,3,5-TNB	581	807	766	85
1,3-DNB	54	56	<11	<11
2 AMD	26	<8	<8	<8
TOC (mg/l)	4.64	3.7	2.4	1.0

Table 4 (cont'd)
Bench-Scale **perox-pure™** Treatment Results
for the SADA Groundwater

Contaminant (μg/l)	Oxidation Time (min.)			
	0	1	2	4
Test 5				
TNT	1033	<8	<8	<8
1,3,5-TNB	581	954	1360	778
1,3-DNB	54	253	156	<11
2 AMD	26	<8	<8	<8
TOC (mg/l)	4.64	3.7	2.4	1.0
Test 6				
TNT	1033	NA	<8	<8
1,3,5-TNB	581	NA	231	148
1,3-DNB	54	NA	<11	<11
2 AMD	26	NA	<8	<8
TOC (mg/l)	4.64	3.2	1.6	0.64
Test 7				
TNT	1033	<8	<8	<8
1,3,5-TNB	581	262	53	<8
1,3-DNB	54	<11	<11	<11
2 AMD	26	<8	<8	<8
TOC (mg/l)	4.3	1.4	0.6	0.3
Test 8				
TNT	961	<8	<8	<8
1,3,5-TNB	552	687	807	1062
1,3-DNB	45	356	631	57
2 AMD	18	<8	<8	<8
TOC (mg/l)	8.3	7.7	6.8	2.6

NA = Not analyzed (sample container broken)

Table 4 (cont'd)
Bench-Scale **perox-pure™** Treatment Results
for the SADA Groundwater

Contaminant (µg/l)	Oxidation Time (min.)			
	0	1	2	4
Test 9				
TNT	959	<8	<8	<8
1,3,5-TNB	555	157	82	<8
1,3-DNB	44	<11	<11	<11
2 AMD	31	<8	<8	<8
TOC (mg/l)	8.6	1.52	0.79	0.36
Test 10				
TNT	966	<8	<8	<8
1,3,5-TNB	547	173	78	<8
1,3-DNB	48	<11	<11	<11
2 AMD	31	<8	<8	<8
TOC (mg/l)	7.8	2.1	0.94	0.47

(1) Influent data for Tests 4, 5 and 6 is an average of the influent results from Tests 1 through 3.

2.3 Discussion

The primary objective of the bench-scale study discussed herein was to determine the best **perox-pure™** treatment conditions for rapid destruction of ordnance compounds in the groundwater and to establish treatment parameters for the on-site testing phase of the project. The effect of each treatment parameter is discussed below, with the focus being on the rate limiting compound TNB.

Pretreatment

Pretreatment for solids and turbidity removal was necessary to improve the treatment efficiency of the **perox-pure™** Process and to prevent fouling of the UV reactor over long periods of continuous operation. Pretreatment is recommended for full-scale equipment operation.

pH Adjustment

The effect of pH adjustment on the rate of contaminant destruction was evaluated in Tests 1 and 2 and is shown in Figure 1. The TNB objective was not met in either test, however, the TNB did begin to degrade between 2 and 4 minutes of oxidation time in Test 2 (pH 4.5) as compared to Test 1 (pH 7) where the TNB was still being generated even after 4 minutes of oxidation time. The DNB destruction was also much better in Test 2 as compared to Test 1. pH adjustment is recommended for improved contaminant destruction rates.

Oxidant Dosage

The primary oxidant evaluated for the treatment of the SADA groundwater was H_2O_2. However, a combination of H_2O_2 and ozone (O_3) was evaluated in Test 8. As shown in Table 3, the two H_2O_2 dosages utilized during testing were 70 and 100 mg/l. The O_3 dose was 65 mg/l after four (4) minutes of oxidation time.

A direct comparison of the effects of H_2O_2 dosage on contaminant destruction rates was not performed. Instead the H_2O_2 dosage was optimized relative to the type and dose of catalyst used in each test. This approach was followed because based on previous experience with treating ordnance contaminated groundwater, the optimization of catalyst usage has a more significant benefit in enhancing destruction rates than H_2O_2 dosage alone. Additionally, optimization of H_2O_2 dosage can be more easily performed during on-site testing than can catalyst usage.

The effect of using ozone (O_3) in combination with H_2O_2 is shown in Figure 2 by comparing results from Tests 1 and 8. The use of ozone showed no significant benefit compared to using H_2O_2 alone.

Catalyst Formula and Dosage

Catalyst formula addition is typically applied to groundwaters and wastewaters which contain high concentrations of interfering background contaminants. The background contamination can scavenge hydroxyl radicals directly, or reduce the efficiency in generating radicals by absorbing available UV light. In general both processes occur. The use of a catalyst can overcome these effects by generating hydroxyl radicals and thus speeding up target contaminant destruction rates.

In the case of the SADA groundwater, the most significant background contaminant was the high nitrate levels (396 mg/l). Nitrate absorbs UV light thus reducing the amount available for hydroxyl radical generation. To try to overcome the effect of the nitrate concentration a total of four different catalyst formulations were evaluated in the bench-scale treatment study. The results are summarized below.

Catalyst Formula I

The effects of Catalyst Formula I dosage was evaluated in Tests 3, 4, 6, and 7. The TNB results for these tests are shown in Figure 3. A Catalyst Formula I dose of 12 mg/l, (Test 7) achieved the best TNB destruction rates. Results from Test 6 were not plotted due to a lack of a 1 minute data point. However, it is clear from the results in Table 4 that the Catalyst Formula I dosage of 20 mg/l used in Test 6 did not produce TNB destruction rates as good as a dosage of 12 mg/l used in Test 7.

Catalyst Formulas IV, VI, & VII

Tests 5, 9, and 10 were performed to evaluate the effects of catalyst formulas IV, VI, and VII, respectively, on the destruction rate of TNB. Figure 4 compares the TNB results from Tests 5, 7, 9 and 10 and shows the effects of using each of the catalyst formulas IV, I, VI, and VII, respectively. As shown, catalyst formulas IV and VII (Tests 9 and 10) generated TNB destruction rates similar to TNB rates achieved using Catalyst Formula I (Test 7). However, catalyst formulas VI, and VII are more expensive formulations relative to Catalyst Formula I, and therefore their use is not warranted.

Recommendations

Based on a comparison of the treatment results, the optimum treatment conditions for destruction of ordnance compounds in the SADA groundwater include pretreatment for removal of solids and turbidity, pH adjustment to approximately 4, a H_2O_2 dosage of 100 mg/l, and a Catalyst Formula I dosage of 12 mg/l.

FIGURE 1

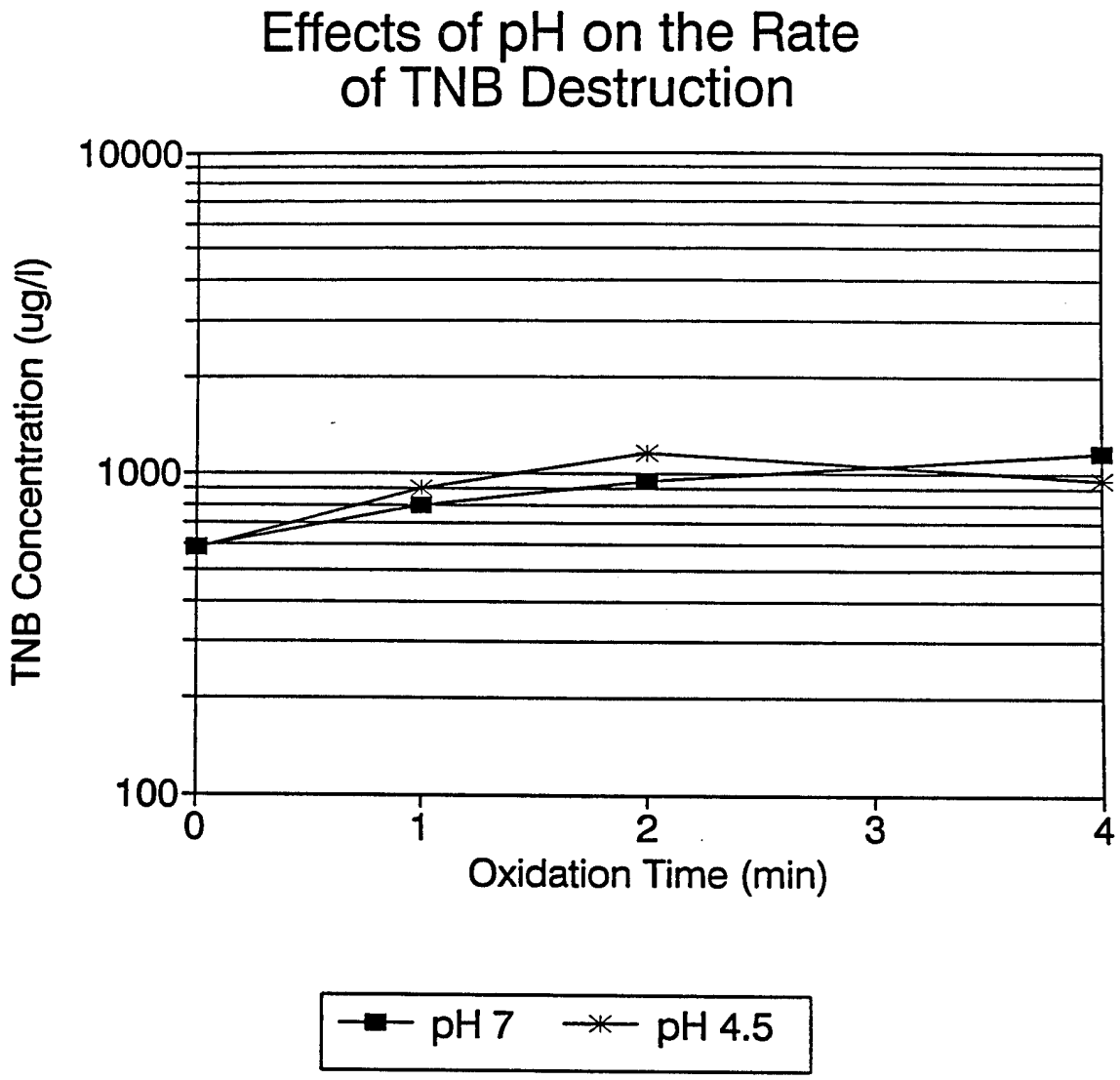

Effects of pH on the Rate of TNB Destruction
10000
1000
100
TNB Concentration (ug/l)
0
1
2
3
4
Oxidation Time (min)
pH 7
pH 4.5

FIGURE 2

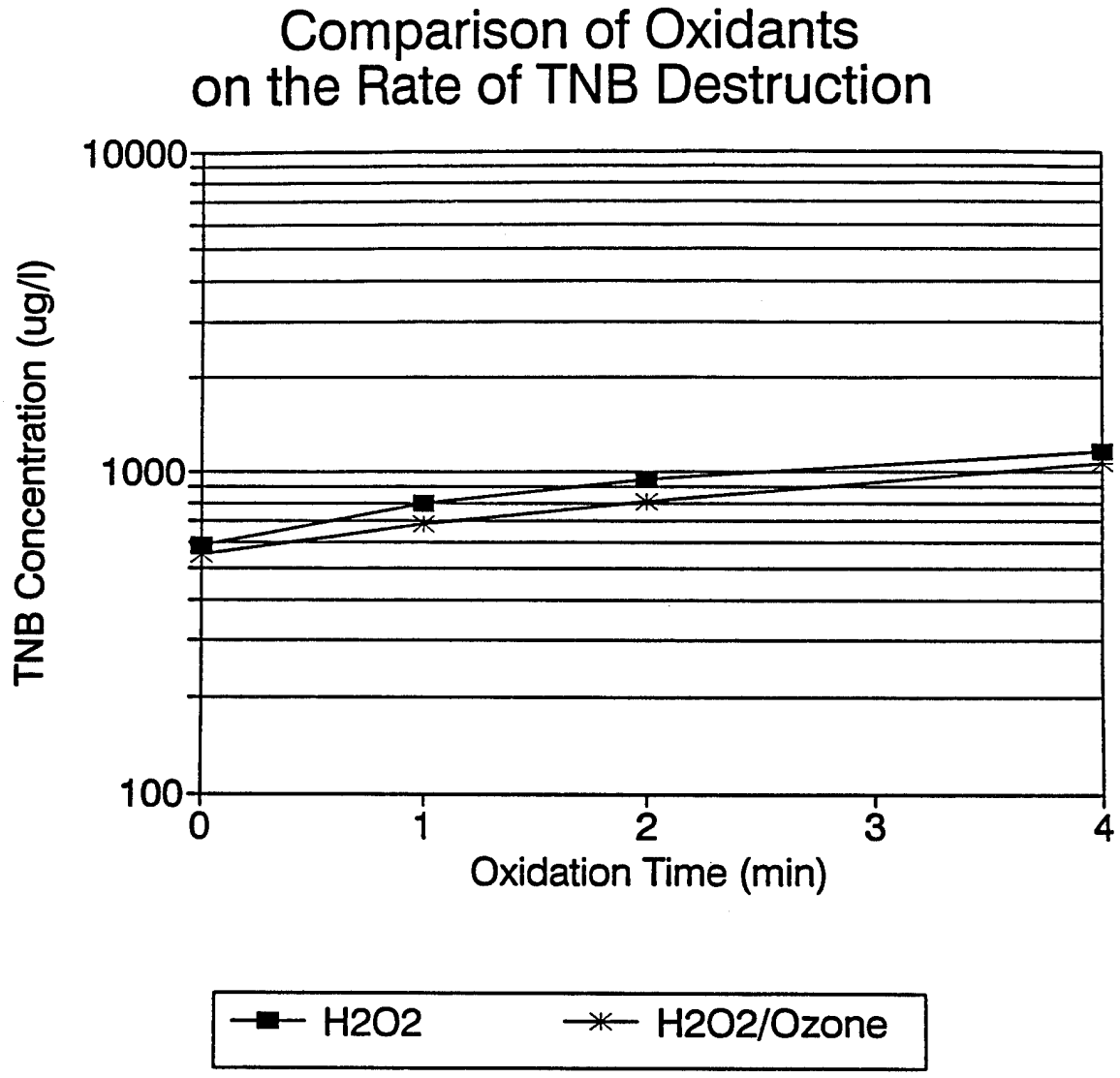

Comparison of Oxidants
on the Rate of TNB Destruction
TNB Concentration (ug/l)
10000
1000
100
0
1
2
3
4
Oxidation Time (min)
H2O2
H2O2/Ozone

FIGURE 3

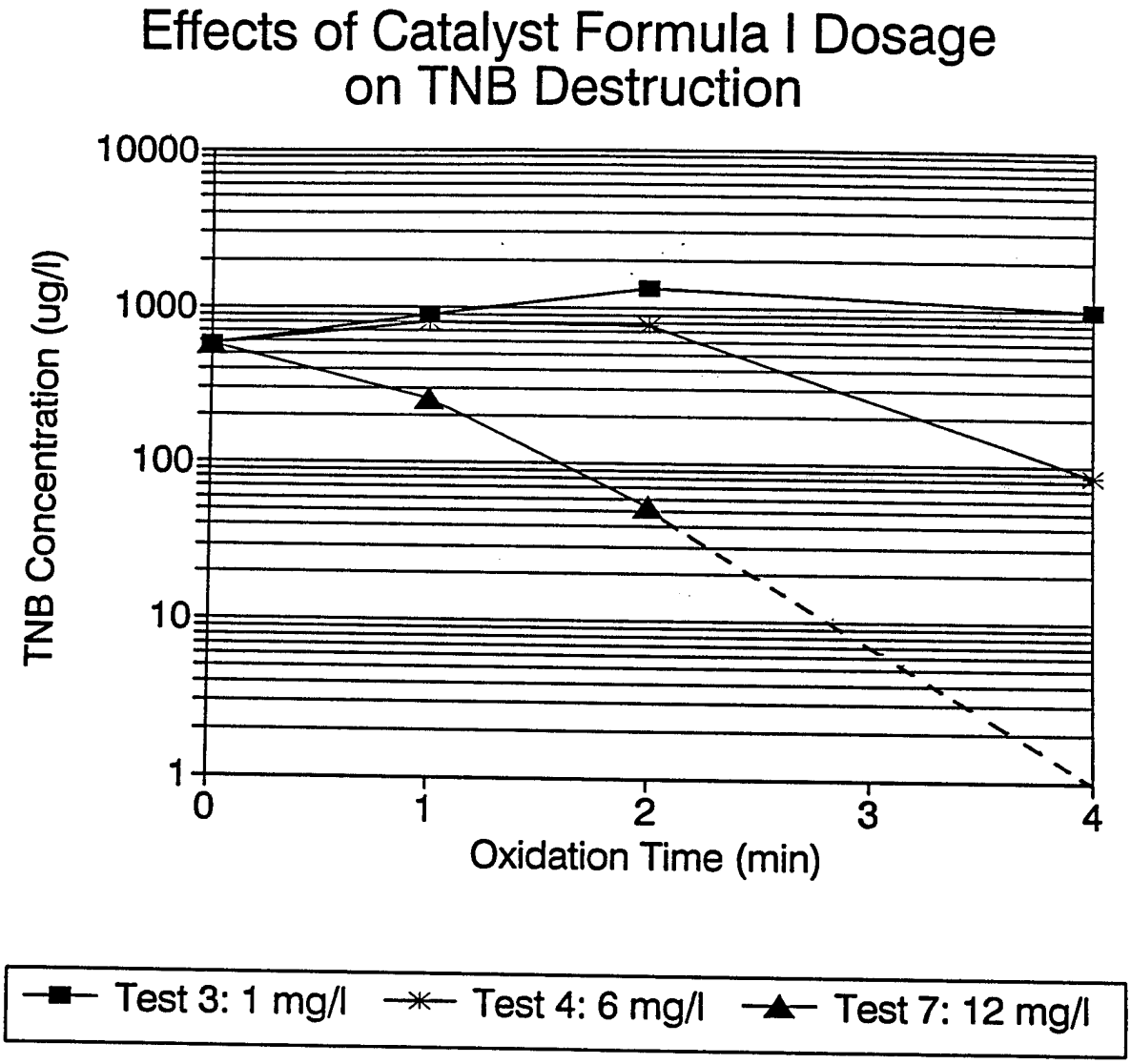
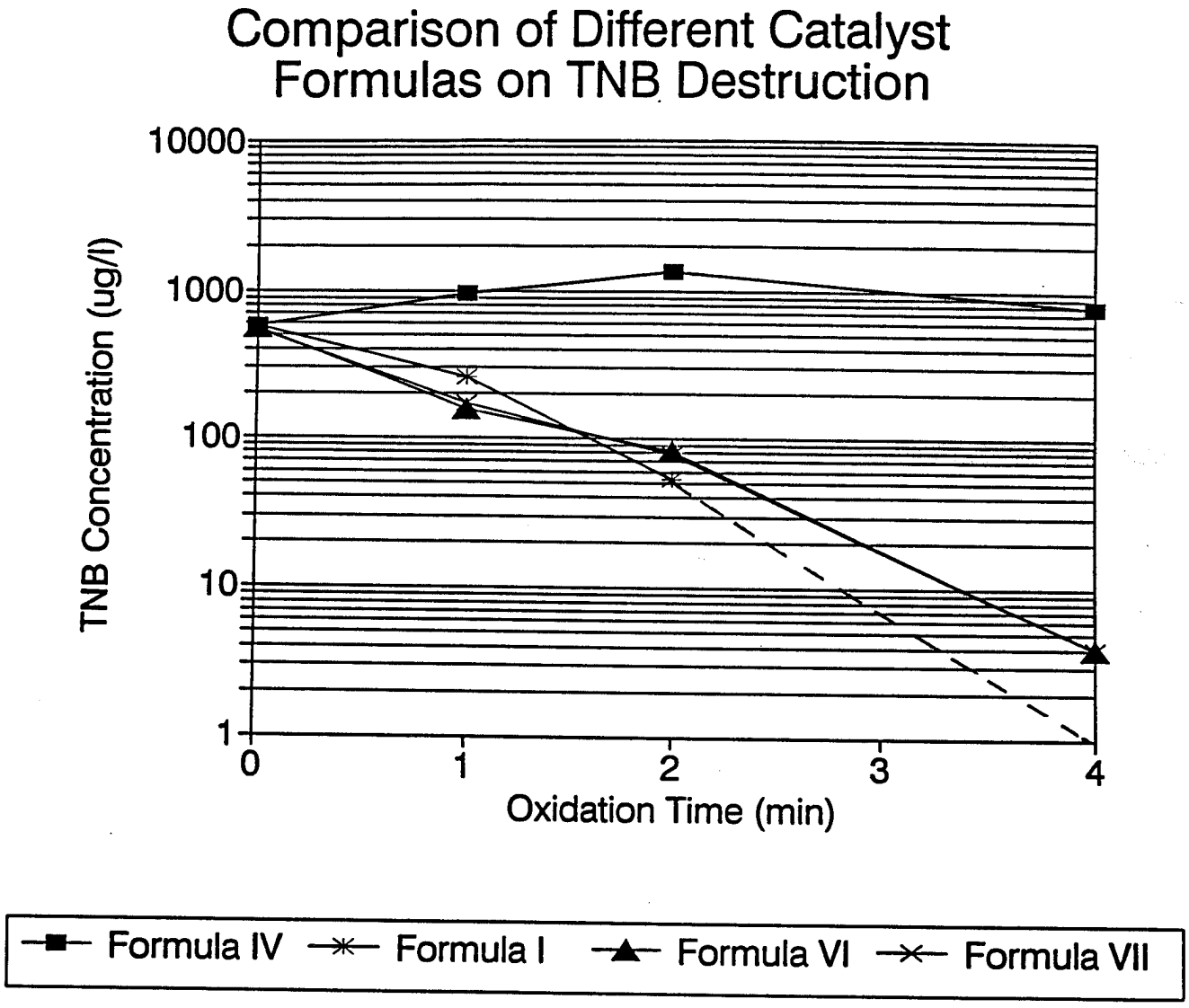

Effects of Catalyst Formula I Dosage on TNB Destruction
TNB Concentration (ug/l)
10000
1000
100
10
1
0
1
2
3
4
Oxidation Time (min)
Test 3: 1 mg/l
Test 4: 6 mg/l
Test 7: 12 mg/l

FIGURE 4


Comparison of Different Catalyst Formulas on TNB Destruction
TNB Concentration (ug/l)
10000
1000
100
10
1
0
1
2
3
4
Oxidation Time (min)
Formula IV
Formula I
Formula VI
Formula VII

2.4 Laboratory Testing Summary

This bench-scale testing program has demonstrated that the **perox-pure™** Process is an effective method of treating the contaminated groundwater to meet the required treatment objectives. Specific test results and treatment observations are as follows.

1) The as-received SADA groundwater contained approximately 581 μg/l of TNB, 1030 μg/l of TNT and 56 μg/l of DNB as expected. Other ordnance compounds present were at levels below the analytical detection limit.

2) A total of ten (10) bench-scale tests were performed on the groundwater evaluating the effects of oxidant dosage (H_2O_2 and Ozone), pH adjustment, and catalyst type and dosage on the rate of contaminant destruction.

3) The groundwater was pretreated to remove solids and turbidity prior to testing. The pretreatment consisted of preoxidation with H_2O_2 and filtration through a 3 micron cartridge filter.

4) The best condition and recommended parameters for full-scale treatment are pH reduction from 7 to approximately 4, a H_2O_2 dosage of 100 mg/l and a Catalyst Formula I dosage of 12 mg/l, as was demonstrated in Test 7.

3.0 PROCESS ASSESSMENT

3.1 Full-Scale Treatment Conditions

3.1.1 Treatment Criteria

The treatment criteria and design flow rate specified by Weston are shown in Table 5. Only those compounds detected in the water were listed in the treatment criteria.

Table 5
Criteria for Full-Scale Treatment
of the SADA Groundwater

Flow rate (gpm)	50
Influent Contaminants (μg/l)	
2,4,6-Trinitrotoluene	1200
1,3,5-Trinitrobenzene	590
1,3-Dinitrobenzene	47
2-Amino-4,6-Dinitrotoluene	26
Effluent Contaminants (μg/l)	
2,4,6-Trinitrotoluene	7
1,3,5-Trinitrobenzene	7
1,3-Dinitrobenzene	9
2-Amino-4,6-Dintrotoluene	36

3.1.2 Recommended Process Conditions

Full-scale **perox-pure™** Process conditions are projected in Table 6. The full-scale oxidation time was calculated from the treatment criteria in Table 5 using the contaminant destruction rate data derived from Test 7. Becuase the final data point in Test 7 was below the detection limit, the overall TNB destruction was projected down to 1 μg/l (Figure 3). This projection is based on the assumption that the TNB destruction rate will increase with time, as it did between 1 minute and 2 minutes of oxidation time. Based on this projection the treatment objective of 7 μg/l is achieved with 3.0 minutes of oxidation time. The oxidation time was then used along with the flow rate from Table 5 to determine the necessary power demand. The H_2O_2 dosage listed in Table 6 was calculated from the H_2O_2 concentration used in Test 7.

Table 6
Full-Scale **perox-pure™** Process Conditions
for Treatment of the SADA Groundwater

Oxidation Time (min.)	3
Power Demand (kW)	600
50% H_2O_2 dosage (lbs/1000 gal)	1.7
Concentrated Acid (lbs/1000 gal)	2.7
Catalyst (lbs/1000 gal)	0.1

3.2 Discussion of Equipment

The bench-scale testing indicates that the target contaminants in the groundwater are oxidized to below the effluent levels specified by Weston with 3.0 minutes of oxidation in an SX reactor using 600 kW of power to the UV lamps at the specified flow rate of 50 gpm.

A 50% H_2O_2 dosage of 1.7 pounds per 1,000 gallons is projected from the bench-scale testing. This results in a 50% H_2O_2 usage of approximately 370 gallons per month. An additional 110 gallons per month of 50% H_2O_2 is recommended for pretreatment. VPSI therefore recommends that a 1000 gallon H_2O_2 storage and feed module be used to support the **perox-pure™** system.

The only utilities required include potable water for the safety shower, and 1200 amps of 3 phase, 60 cycle, 480 volt electrical power.

VPSI's **perox-pure™** system is a complete skid mounted system with all required controls enclosed. Only a minimal foundation with containment dike, and electrical and plumbing connections are necessary. The equipment can operate with infrequent attention from the operator. It does require occasional servicing which VPSI can provide under several service agreement options.

4.0 TESTING SUMMARY AND COST ESTIMATES AS REQUESTED BY WESTON

4.1 Testing Summary

- Contaminant Concentrations

	Influent (mg/l)	Effluent (μg/l)
2,4,6-TNT	1,030	<8
2,4-DNT	BDL	BDL
2,6-DNT	BDL	BDL
2,A-4,6-DNT	26	<8
1,3,5-TNB	581	<8
1,3-DNB	54	<11
NB	BDL	BDL
RDX	BDL	BDL
HMX	BDL	BDL
Tetryl	BDL	BDL

BDL = Below the detection limit.

- Estimated destruction removal efficiency (DRE) >98.8% 1,3,5-TNB destruction.

- **Volume of groundwater treated**
  Approximately 30 gallons of groundwater was used for the bench-scale testing.

- **Detention Time**
  As discussed in Section 3.1.2, the projected oxidation time required to meet the specified treatment objectives is 3.0 minutes.

4.2 Estimated Treatment Costs

1. Estimated Pretreatment Requirements

• H_2O_2 13,017 lb/yr @ $0.50/lb.	$6,508/yr.
• Filtration (see capital costs)	

2. Estimated Chemical Usage

• H_2O_2 44,064 lb/yr @ $0.50/lb	$28,612
• Acid 69,984 lb/yr @ $0.08/lb	5,599
• Catalyst 2,592 lb/yr @ $5.00/lb	12,960

3. Estimated Power Requirements

• Electricity 5184000 kWh/year @ $0.0425/kWh	220,320

4.	Estimated Annual Repair/Replacement Costs	$51,000
5.	Estimated Full-Scale System Capital Costs (Does not include capital costs for filtration since this is dependent upon type of filtration selected for pre-treatment.)	$650,000
6.	Estimated Total Treatment Cost Per gallon of Groundwater	$0.0125

4.3 Other

1.	Estimated Annual Maintenance Labor Hours	68
2.	Typical Full-Scale System Design Lifespan	> 15 years

5.0 CONCLUSION

The **perox-pure™** Process can provide effective treatment of the contaminated groundwater to the effluent limits specified by Weston as detailed in the process assessment presented herein. The **perox-pure™** Process offers the advantages of a proven, cost-effective treatment system that creates no air emissions, or generation of secondary waste products and is available under purchase or lease arrangements.

ATTACHMENT A

SPECIFICATIONS FOR **perox-pure**™ EQUIPMENT

SPECIFICATION

Ultraviolet Light/Hydrogen Peroxide Oxidation System

1. General

This specification describes the **perox-pure™** ultraviolet light (UV) - hydrogen peroxide (H_2O_2) oxidation system capable of destroying soluble toxic organic contaminants in water. These specifications are subject to change without notice.

Unloading, handling, installation, excavation, concrete work, finish painting, connecting piping, and electrical hookup are the responsibility of others.

2. Principle of Operation

The System utilizes the chemistry of UV/H_2O_2 reactions, which involves generation of hydroxyl radicals, and other reactive species, by the photochemical action of ultraviolet light on hydrogen peroxide. The hydroxyl radicals attack organic species.

The final products of the noted reaction are carbon dioxide, water, and inorganic ions.

3. Applicable Codes - (Latest Editions)

Uniform Building Code	National Electric Code
Uniform Plumbing Code	NFPA
Uniform Mechanical Code	OSHA

Note: Operating pressure is not to exceed 15 psig, ASME Code does not apply.

4. Equipment Description

UV/H_2O_2 Oxidation Module -

Maximum Inlet Pressure: 15 psig
Power Requirement: 3ph/60Hz/480V

Materials of Construction -

UV/H_2O_2 oxidation chamber, fluorocarbon lined 6063-T6 aluminum or 316L stainless steel.
Chemical tubing - type 316 stainless steel with compression fittings.
Process Piping - Sch. 80 CPVC.
Structural Steel Skids and Supports - carbon steel.
ASTM A-36 with chemical and weather resistant paint.
Electrical Enclosures - Enamelled carbon steel.
Wetted non-metallic components - Quartz, fluoroelastomers, or polymers resistant to UV, H_2O_2 and all chemicals present.

Design Features -

Oxidation Chamber

Lamps shall be horizontally mounted and removable without draining the oxidation chamber.

The lamp end enclosures shall be provided with hinged and gasketed doors.

All UV sensitive materials shall be shielded from the UV rays by material reflective of, or resistant to, UV.

The UV lamps shall be protected against contact with the fluid in the event of a leak.

Water shall be separated from contact with the UV lamps by quartz tubes sized for optimimum lamp operating temperature.

The UV oxidation chamber shall be designed to efficiently distribute and collect the process water throughout the entire oxidation chamber in order to eliminate an uneven flow pattern or short-circuiting. Piping connections shall be designed so that the UV oxidation chamber will remain full of fluid after shutdown.

The oxidation chamber shall not have chamber penetrations for automatic quartz tube cleaner actuation mechanism.

Electrical Enclosures

Electrical enclosures shall have hinged and lockable doors.

Electrical enclosure cabinets shall be weatherproof. Lamp drive enclosures will be provided with intake air cooling fans to control the inside temperature. The fans shall operate continuously when the unit is running.

Access doors shall have limit switches to shut the power off should the doors be opened.

Circuitry

All wiring and electrical connections shall be protected against moisture to prevent electrical short or failure. Pressure indicators and temperature switches shall be in weatherproof housings.

All wiring and electrical components within the system shall be designed, constructed and installed in accordance with the latest edition of the National Electrical Code and all applicable State and local electrical codes.

Circuitry within the lamp drive enclosure shall be protected and disconnected by pre-wired circuit breaker rated at 30,000 amp minimum AIC with external ground fault sensor and shunt trip.

Lamp drives shall be of the high-power factor type.

Instrumentation and Controls

The UV system shall be controlled via a touch-screen interface to a programmable logic controller (PLC). Standard PLC is Siemens Model TI 435 or TI 545. The Model of the PLC will vary with the size of the UV system. Controls shall be provided to allow on/off operation of individual UV lamps, on/off operation of (1) chemical feed pump, and shut-down of the UV system.

Alarm contact closures shall be provided on:

1) high temperature in lamp drive enclosure
2) low water flow (adjustable)
3) high water temperature
4) moisture in lamp end enclosure
5) access door opening
6) remote contact closure (10 amp, 120 VAC)
7) low peroxide pressure
8) low peroxide splitter flow (if splitter is provided)
9) overpressure relief flow
10) low oxidation chamber water level
11) tube cleaning system failure
12) lamp low current detection (shut-down optional)
13) lamp contactor failure
14) Emergency Stop
15) Primary Ground Fault
16) Secondary Ground Fault

Alarm conditions shall be displayed on the touchscreen with "First Out" indicator. Flow indicator calibrated in gpm, with totalizer, shall be provided.
A system to indicate the operating status of each lamp shall be provided.

An elapsed timer meter shall be provided to indicate the number of hours of module operation. Timer shall be resettable with access codes.

H_2O_2 Feed

Connections for injection of H_2O_2 in quantities suitable for the process shall be provided. If required by the process, means for complete mixing of the H_2O_2 and process water, and for variable, staged injection shall be provided.

Automatic Cleaner

The UV oxidation system shall incorporate an automatic quartz tube cleaning system, programmable by the user for variable operation period frequency and duration dependent upon the requirements of the installation. Cleaner shall be constructed of stainless steel and/or UV resistant materials. The tube cleaner control system shall be capable of changes in both frequency of operation cycles and duration of each cycle. It shall also be capable of automatic variation of these cycles in response to changes in flow rate or signals from a remote control system based on, for example, effluent contaminant concentration.

The tube cleaner mechanism shall not require sliding shaft seals through the wall of the oxidation chamber. It shall effectively wipe the lamp tube to prevent accumulation of deposits that interfere with transmittance of UV light from the lamp. To prevent accumulation of deposits on the wall of the oxidation chamber the wiper shall also clean the inside of the oxidation chamber. The interior of the oxidation chamber shall be finished in a manner to minimize deposits of material.

The wiper mechanism shall wipe any point opposite the UV lamp a minimum of 4 times per pass. For extended tube wiper life, the wiper shall be retained in a recess away from the UV lamps so that it is shielded from UV light during the period between cycles. For even wiper wear distribution, the wiper shall be free to rotate around the longitudinal axis of the quartz tube.

Assembly

Oxidation chamber, control enclosures, instrumentation, controls, and piping shall be shop assembled on a skid and disassembled only as necessary for shipment. Lamps and supports to be shipped separately.

5. Installation, Start-up, and Operator Training

Supplier will supervise initial placement of all equipment provided in this specification.

The mechanical and electrical hookups by others shall be completed per schedule mutually agreed upon by all parties.

Upon completion of installation the equipment supplier shall hydrostatically test all pressure systems provided by this specification. If leaks occur, necessary corrections shall be made and retested until completed without any evidence of leakage. All electrical circuits and equipment shall be tested for continuity and functional performance.

All surfaces to be contacted by H_2O_2 shall be properly passivated by the equipment supplier.

In addition to the above, during a scheduled start-up period of five (5) calendar days, the equipment supplier shall provide start-up operation of the systems furnished by this specification. The Field Service Engineer shall operate the equipment, make all adjustments and calibrations necessary to allow operation at full load for a 24-hour period. Representative samples will be taken as required to determine performance. During this period, the owner's operating personnel are to be trained in the operation and maintenance of this equipment. Any materials deemed defective during this period are to be replaced.

6. Certified Dimension Drawings

Two (2) sets of certified dimension drawings will be furnished.

7. Operation and Maintenance Instructions

Three (3) complete Operation and Maintenance Instruction Manuals will be furnished.

8. Safety

Formal safety policies and procedures for laboratory, manufacturing and field operations activities shall be documented. Supplier shall have a Safety Committee which meets regularly to review and establish safety policies. All equipment shall be designed and constructed to adhere to regulatory requirements and practical consideration. Consideration shall be given to personnel safety during both operation and maintenance of the equipment. The following information outlines the safety features.

1. Changing Lamps and Quartz Tubes. Both lamps and tubes are reliable when handled by proper procedures. However, being quartz they are subject to breakage if dropped or struck on another object. Accordingly, all maintenance on lamps and tubes is done by a technician without the need for ladders, scaffolds or other elevation means.

2. Changing ballasts. Ballasts which may weigh up to 250 pounds are quite reliable and are infrequently changed. If changing is necessary, the unit is to be equipped with a slide out mechanism to eliminate potential personnel problems with moving and securing the ballast.

3. Opening Enclosures. All electrical enclosures are to be built with interlock high voltage position switches which will shut down power to the unit if they are opened.

4. UV Exposure. The units shall be designed such that operators cannot be subjected to UV light.

5. Ground Fault Projection. In addition to conventional grounding and insulation, the unit shall employ an external groundfault sensor and a shunt trip. The shunt trip will activate when the primary or secondary exhibits a electrical short of 4 amps or greater.

6. Hydrogen Peroxide. H_2O_2 is a powerful oxidizing agent which is safe when handled properly. Safety training on handling and use of H_2O_2 is to be provided by Supplier to on-site personnel. In addition, standard H_2O_2 storage and feed equipment is to be equipped with a shower and eyewash station for personnel safety.

7. Equipment Protection. An extensive series or safety interlocks are to be designed into each module to guarantee the safety of the equipment if operating variables should significantly change during operation.

9. Quality

The equipment shall be produced under a versatile quality program that employs resolution inspections and pretested equipment which meets and complies with Quality Assurance/Quality Control Programs.

Supplier shall have a program in compliance with requirements of:

- NQA-1 - Nuclear Quality Assurance
- ANSI/ASME - American National Standard Institute/ American Society of Mechanical Engineers
- AWWS Specifications - American Water Works Standards
- NASA Specifications - National Aeronautics and Space Administration
- Military Specifications

Supplier's program shall be an on-going QA/QC program to satisfy the provisions and requirements of:

- ASQC Q90 - American Society for Quality Control
- ISO 9000 Series - International Standards Organization

Supplier shall have qualified QA/QC personnel and a system of procedures, checks, audits and corrective activities to ensure that all research, design and performance, environmental monitoring, sampling, plus other technical and reporting actions, are of the highest reasonably achievable quality.

SPECIFICATION

Hydrogen Peroxide Storage/Feed Module

Materials of Construction:

Structural Steel Skids & Supports - carbon steel ASTM A-36 or Aluminum
Chemical Storage Vessels - HDPE
Chemical Piping - 316 stainless steel
Wetted non-metallic components - fluoroelastomers

Design Features:

Chemical feed pumps, controls, and piping will be shop assembled on skid and disassembled only as necessary for shipment.

Electrical enclosures will be weatherproof. All controls and indicator lights will be housed in electrical enclosures with hinged and lockable doors.

All wiring and electrical connections will be protected against moisture to prevent electrical short or failure. All electrical components and installation within the system will be designed, constructed and installed in accordance with the latest edition of the National Electrical Code and all applicable State and local electrical codes.

Terminals will be provided for connection of control wiring and interlocks with each UV/H_2O_2 Oxidation Module control panel.

Terminals will be provided for connection of control wiring and interlocks with each UV/H_2O_2 Oxidation Module control panel.

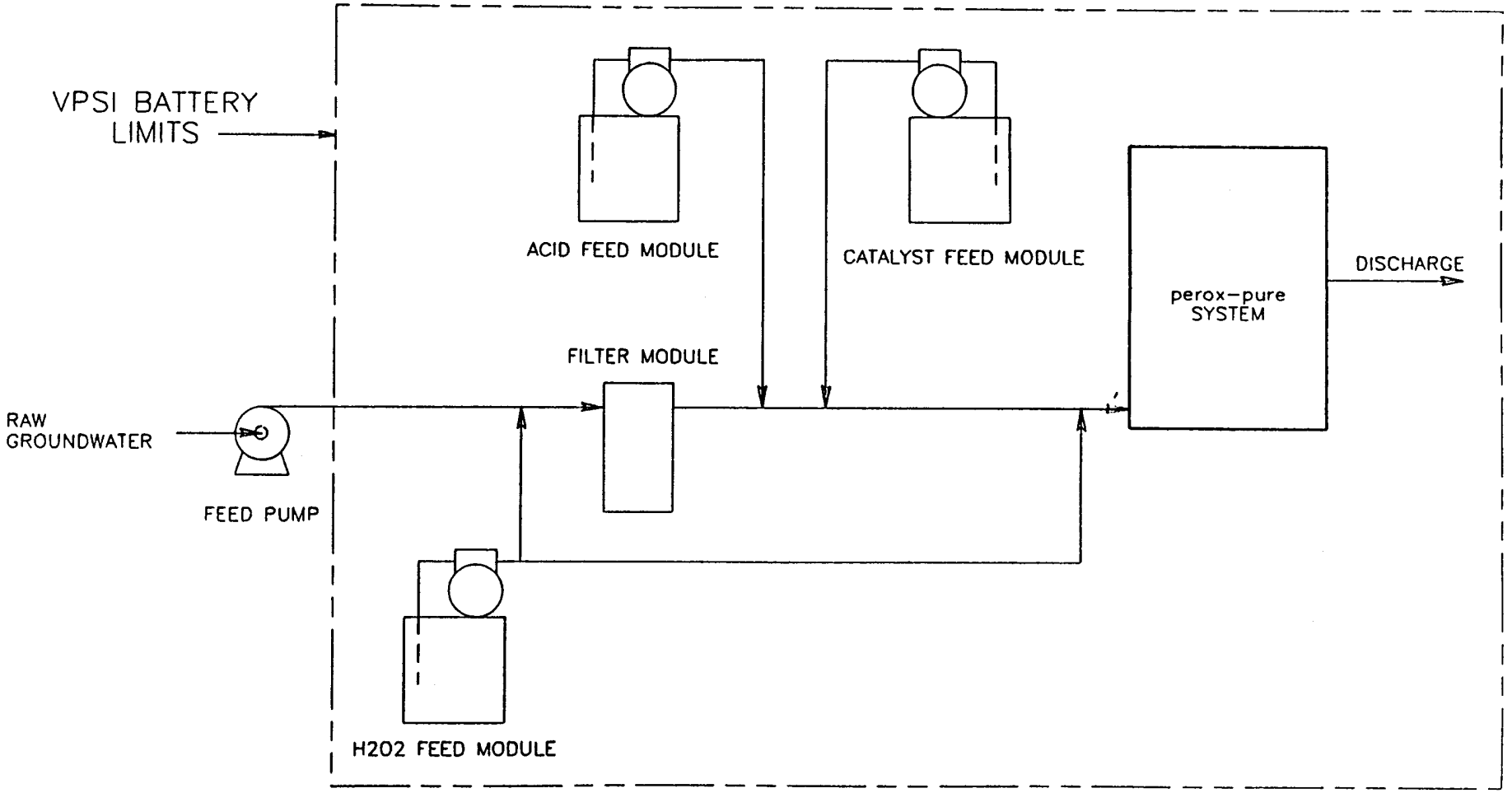
Operating and spare H_2O_2 pumps will be provided. Each pump will be of the positive displacement type, infinitely adjustable from 0 to 100% flow, electric motor driven for 1 ph/60 Hz/120 V power, 10 amp max. Wetted pump materials will be suitable for continuous contact with 50% H_2O_2. Piping and valves will be provided to allow use of pump for continuous injection of H_2O_2 to each UV/H_2O_2 module and to ease pump flow calibration. A pump calibration system is to be included on the skid.

Optional: Chemical storage tank will be provided with access man-way and connections for drain, H_2O_2 fill, outlet to feed pumps, and vent. Safety shower will be provided, mounted on the skid.

ATTACHMENT B

PROCESS FLOW DIAGRAM

PROCESS FLOW DIAGRAM



DOCUMENT NO.:

Vulcan Peroxidation Systems, Inc.
Tucson, Arizona

APPENDIX D

PILOT-SCALE REPORTS

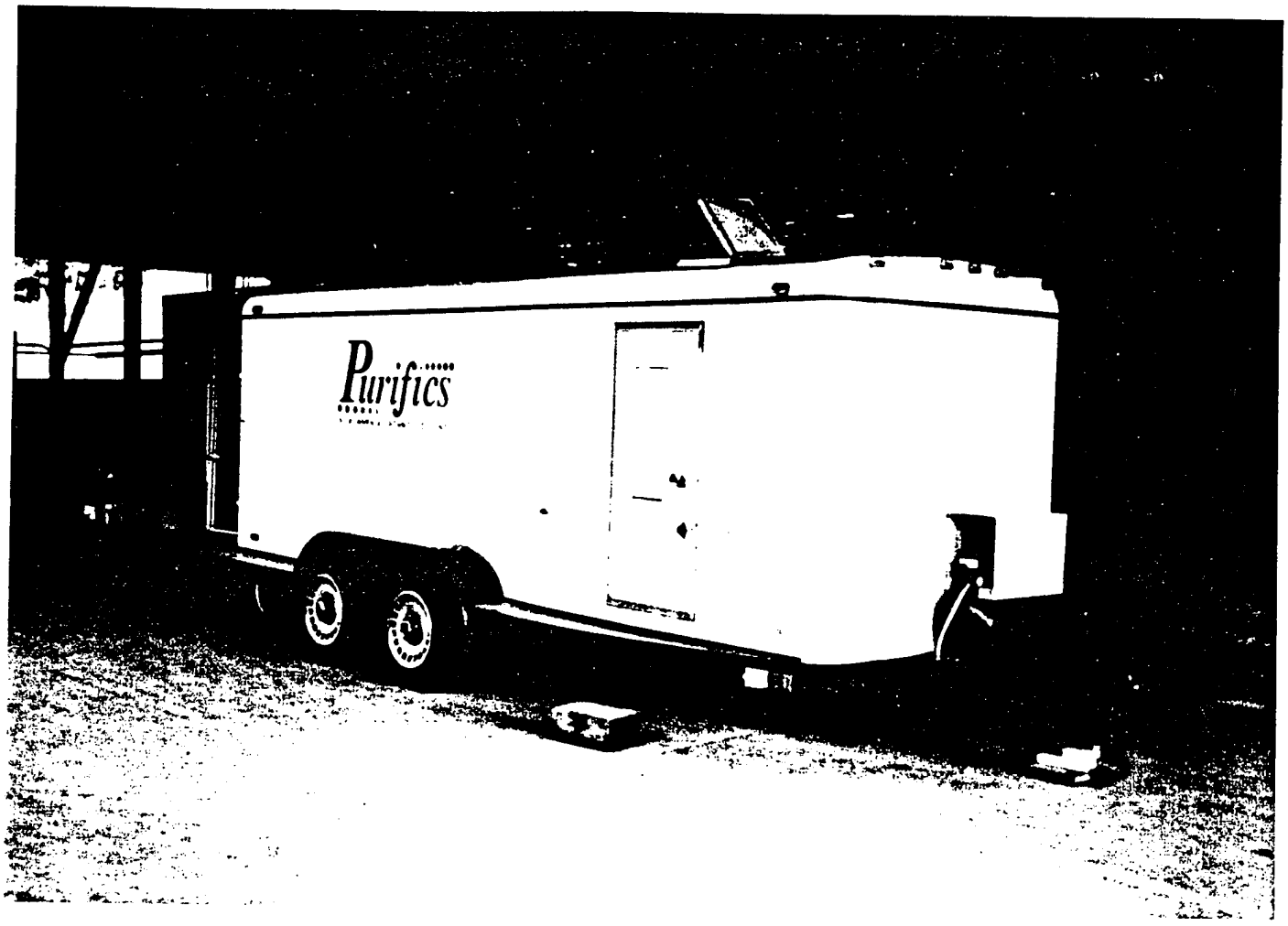
PURIFICS

PILOT-SCALE REPORT

TEST REPORT FOR THE DESTRUCTION OF EXPLOSIVES CONTAMINATED GROUNDWATER AT SAVANNA ARMY DEPOT USING PURIFICS PILOT-SCALE PHOTOCATALYTIC TREATMENT SYTEM (FINAL)

Submitted to:

US ARMY ENVIRONMENTAL CENTER/ ROY F. WESTON



Submitted by:

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1.0 Project Summary

The Purifics patented photocatalytic process treated:

- the 2,4,6-trinitrotoluene (TNT) and 1,3,5-trinitrobenzene (TNB) to less than detection levels on a sustained basis
- and met the requirement for 1,3-dinitrobenzene (1,3-DNB) over a 24 hour period through a more onerous start-up and shut-down situation.

Throughout the entire pilot project, no system components failed, required repair or replacement. There were no routine adjustments made to the process, only supervision of treatment was performed.

It should be clearly realiszed that, no cleaning requirements exist for the glass sleeves in the Purifics' photocatalytic technology. At the end of the test program a glass sleeve was removed and examined by the auditing Engineers and was found to be clear.

No precipitation or flocculation pretreatments were performed and thus no solid wastes, hazardous or otherwise, were generated. No process upsets occurred, no leaks occurred, and the system ran autonomously and continuously with no faults for the entire program. The photocatalytic system was simple to operate, and provided instantaneous start-up and shut-down capability.

The presence of acetone in the treated effluent was identifed after the test program. The presence of this component will be simply eliminated in future by the use of an alternative additive or modification to the treatment process.

For most of the 10 days of the 15 days of audited operation, the photocatalytic treatment system was operated at various conditions of treatment utilizing H_2O_2 (Mode A) from which conflicting results were obtained. However, it was seen that during this treatment mode that the TNT was predominantly treated to the treatment specification, whereas the TNB was moderately treated.

At the end of the second week and for the final five days of the 15 day audited trial, treatment Mode B was utilized. Mode B consistently treated both the TNT and TNB to the discharge levels and did achieve the required ppb discharge level for 1,3 DNB over a 24 hour period. This successful but unoptimized method of treatment (Mode B) did not require H_2O_2 or O_3 addition.

It is important to note that the treatment process of this water continued to improve with time and experience. Also note that much was learned to further reduce treatment requirements and equipment size in furture applications.

2.0 Purpose

This project varied significantly from typical pilot projects in that the main objective for this project was to operate continuously at the treatment specifications. In normal on-site pilot projects, the goal is to optimize the key parameters of treatment such that treatment costs are minimized. Sustained operation at the determined treatment specifications is not usually required.

This project brought about the first experience for Purifics to treat nitro-aromatic (explosives) compounds. Prior to field-scale testing, Purifics conducted an experimental program to determine the optimal treatment conditions for 2,4,6-TNT and 1,3,5-TNB. The results of the bench-scale testing were found to be inconclusive because of contamination carry-over in the bench-scale reactor, and problems encountered with analyses. Inconclusive bench-scale test results (due to a GC problem that took two weeks to detect) made it very difficult to predict accurate treatment costs for full-scale treatment at that time. Consequently, the majority of the optimization work had to be performed onsite.

Purifics utilized a two D style rack system to perform the pilot work at the Savanna Army Depot Activity site in Illinois. The entire treatment system was housed in a 16 foot trailer, and thus was entirely portable. Once the trailer was pulled to the site, the system was virtually ready to operate. No cranes or forklifts were required. The only labor that was required for installation was to connect the influent and effluent lines, and the power supply.

3.0 Optimization Methodology

There were two main treatment modes utilized during the demonstration: Mode A and Mode B.

Mode A
Treatment Mode A consisted of photocatalytic treatment with the addition of acid and base for basic pH control and H_2O_2 addition. The main factor investigated during the optimization period was the effect of H_2O_2 dosage rates.

Mode B
Treatment Mode B consisted of photocatalytic treatment with the addition of acid and base for basic pH control and an additive. This mode did not utilize H_2O_2 addition (or O_3). Instead, a low cost proprietary additive (patents pending) developed at Purifics was added to the treatment system. This proprietary additive (one of a group of additives) will be referred to in this report simply as 'Additive'.

In order to fulfill the requirements of the program, the first objective for Purifics was to determine the optimal treatment conditions which would meet the treatment specifications. At the end of the second week of the demonstration, which was 10 days into the 15 day trial, it was determined that treatment Mode B met the treatment specifications.

In order to comply to the goal of the program as outlined in Section 2.0 of this report, further enhancements were not performed once the treatment specification was obtained during the pilot-testing period because such attempts may have inhibited Purifics from continually meeting the treatment specification. However, at the end of the test period Purifics did successfully conduct an unaudited optimization test using the Dtech test kit with improved results.

Due to turn-around time and cost limitations, duplicate samples were not taken for detailed analysis by Purifics. Instead, Purifics relied on the DTech test kits for total explosives analysis. Consequently, levels of 1,3-DNB were not availabe to Purifics until the Army data was released in the post test period.

4.0 Process Set-up

Figure 1 shows the process set-up in the pilot study used to obtain the treatment specification.

Upstream of treatment, the groundwater was sent through a 4" diameter by 1' long bag filter in order to remove suspended solids. One bag filter was used for the entire project, and it did not require any attention, change-out, or flushing. No precipitation pretreatment was performed and thus no solid waste was generated.

The photocatalytic treatment system consisted of a two D rack system. The total power of the entire treatment system was approximately 2.4 kW. Other than pumps and valves, no moving parts exist. No metal oxide fouling occurs, thus, no wiping mechanisms are required. There are no cooling water requirements for Purifics' systems.

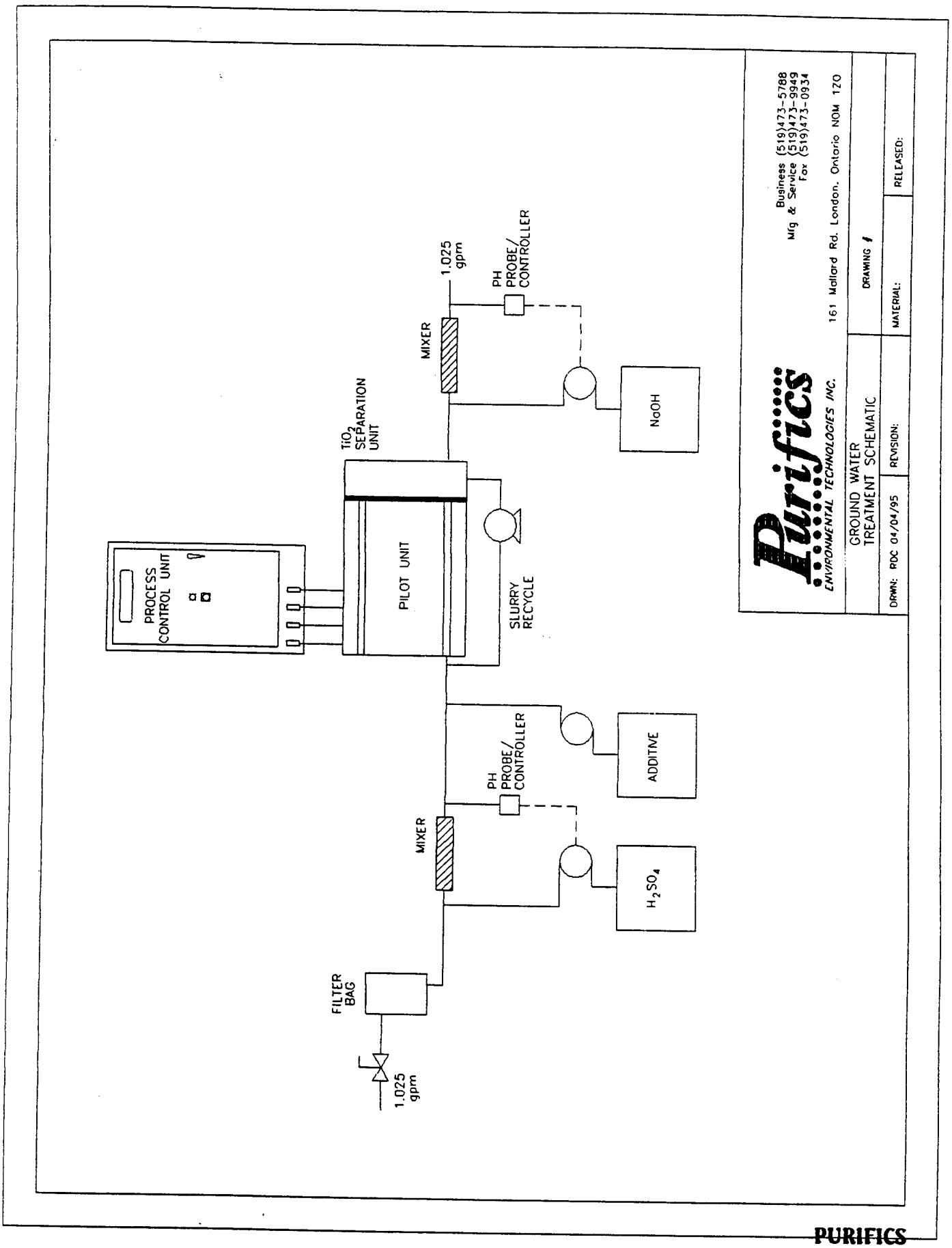
Automatic pH controllers located both upstream and downstream of the photocatalytic reactor continuously adjusted the pH to their preset values. Acid (H_2SO_4) and caustic (NaOH) were used for basic pH control.

Some of the TiO_2 had been changed out during the first two weeks of optimizational work as it was thought to be a potential cause of the fluctuations in performance. However, after the second week of operation this was determined not to be the case. Consequently, the same TiO_2 catalyst was used for the remainder of the demonstration. At the time of this report the longest period of use for TiO_2 is 11 consecutive months with no detectable change in performance.

A more detailed description of the process is described in section 7.0: Full-Scale Process Description.

It should be noted that photocatalytic treatment is frequently confused with established UV destruction technologies better known as photolysis. The differences are many and significant. In photocatalytic treatment a light driven slurry catalyst is used to create a lower energy destruction process. Without the slurry catalyst, water treatment would not occur. The slurry catalyst is always contained within the equipment and it is not lost or consumed in any way.

Figure 1: Process Schematic



5.0 Results

The results of the TNT, TNB, and 1,3-DNB treatment throughout the 3 weeks are shown in the plots of Figures 2 through 4. The raw data are shown in Appendix 1.

Data Analysis

Figures 2 and 3 show that all TNT and TNB samples in the last week of operation (except for the last sample on Oct. 12, 1994) were below the treatment objective. The TNB detection of 74 ppb and the 1,3-DNB detection of 23 ppb on Oct. 12, 1994 were due to the Additive's reservoir running dry. This occured while the system was unattended due to Purifics staff being interviewed by the US Army video team. The sample was taken before the upset was detected. It should be noted that the reservoir used was of size just sufficient to just meet a days requirement.

On the day of Oct. 7, 1994, the Purifics' system was converted from Mode A (oxidation) to Mode B (reduction) at 12:00 noon. After 1 hour and 35 minutes of treatment, a sample was taken by Roy F. Weston and both the TNT and TNB were reduced to 1.7 ppb. Earlier samples that day taken at 11:10AM (while operating under treatment Mode A) were 6.6 and 780 ppb for TNT and TNB respectively. It can be concluded that after the switch from treatment Mode A to treatment Mode B the TNT, and in particular the TNB, were quickly and efficiently reduced below treatment specifications.

Figure 4 is a plot of the influent and effluent concentration of 1,3-DNB during the five and a half days of the audited demonstration when Mode B was utilized. Vertical red lines distinguish the operating days. On the afternoon of Oct. 7, 1994 when the treatment Modes were changed, the effluent concentration of 1,3-DNB increased slightly (from 20 ppb to 27 ppb). The actual levels of 1,3-DNB are increasing significantly do to the rapid reduction of the influent TNB and the elevated existing levels of TNB (780 ppb) in the slurry loop.

On Monday Oct. 10, the 1,3-DNB levels continually lowered during the day. Unlike the instant reduction in TNB levels seen after the change from Mode A to Mode B on the afternoon of Oct. 7, the 1,3-DNB levels took approximately 8 hours of treatment to reach its steady state concentration of less than 4 ppb. This is also seen after the afternoon of Oct. 12 when the Additive reservoir ran dry. It took an additional day of treatment to reduce the 1,3-DNB levels specification within the treatment process.

Purifics attributes this phenomena to adsorption of 1,3-DNB to the polyethlylene (PE) reservoir located downstream of the photocatalytic racks. The general treatment trend during each day (except for Oct. 14) is progressively decreasing levels of 1,3-DNB. The Additive feed pump momentarily lost its prime at 2:35PM on Oct. 14, and consequently attributed to the 1,3-DNB detection at an elevated level (TNB at elevated levels but below the treatment specification). However, due to adsorpton / desorption of 1,3-DNB in the PE reservoir, 1,3-DNB is detected in the effluent but gradually dissipates as desorption is completed. The increasing temperature during the day may of helped desorption as it warmed up. Thus, the rate of 1,3-DNB destruction has been masked by its desorption rate in the PE reservoir. From the data it appears that 8 hours of operation is required to remove it from the reservoir.

A stainless steel reservoir would remove any chance of adsorption of 1,3-DNB and elimated this lag effect. This finding is consistent with the results of the bench-scale testing in which adsorption occurred onto plastic components. All wetted components in the pilot unit at SADA were stainless steel except for the reservoir and a flow meter. The adsorption problem was detected late in the bench-scale testing and consequently, there was not sufficient time to obtain a stainless steel reservoir, thus a PE reservoir was used. This phenomina is clearly seen in Figure 4.

Treatment Criteria

On the day of Oct. 12, Purifics was operating below the treatment specification as shown by the sample analyses taken at 10:50AM and at 1:45PM (average 1,3-DNB concentration was 3.6 ppb). The only reason why the treatment specification was not met at 4:00PM was that the Additive reservoir ran dry while Purifics staff was being interviewed at the request of the US Army. Removing the results of the 4:00PM sample demonstrates compliance to the treatment specifications.

As well, the three consecutive samples taken between Oct. 13 (4:10PM) and Oct. 14 (1:15) demonstrate a 24 hour period (one day) in which the average concentration of all parameters were below the treatment specification. This demonstrates that Purifics has complied with the treatment specifications outlined in the original Request for Proposal.

Acetone Production

Volatile organic compounds were analyzed by GC/MS on Oct. 13 and on Oct. 14 (during treatment mode B). Acetone was detected on both days at 3.7 and 3.4 ppm respectively. The acetone is caused from the Additive used in treatment Mode B. Purifics has a family of Additives which can be used for this purpose, other Additives will not produce acetone. Thus the use of another Additive will remove acetone formation as would process modification.

Flow Data

Table 1 lists the volume of water treated and the power consumed for each of the fourteen days as recorded by Roy F. Weston. The average efficiency (gallons treated per kWh consumed) was 25.5 gallons per kWh.

Table 1: Water Treated Vs. Power Consumed Per Day

Date	Total Flow (gallons)	Power (kWh)	Efficiency (gal./kWh)
27-Sept.-94	454	18	25.2
28-Sept.-94	537	19	28.3
29-Sept.-94	543	20	27.2
30-Sept.-94	533	20	26.7
3-Oct.-94	509	20	25.5
4-Oct.-94	494	19	26.0
5-Oct.-94	533	19	28.1
6-Oct.-94	546	19	28.7
7-Oct.-94	539	20	27.0
10-Oct.-94	492	19	25.9*
11-Oct.-94	443	20	22.2
12-Oct.-94	433	19	22.8
13-Oct.-94	445	20	22.3
14-Oct.-94	409	19	21.5
Totals - Average	6910	271	25.5

Two other key points are:

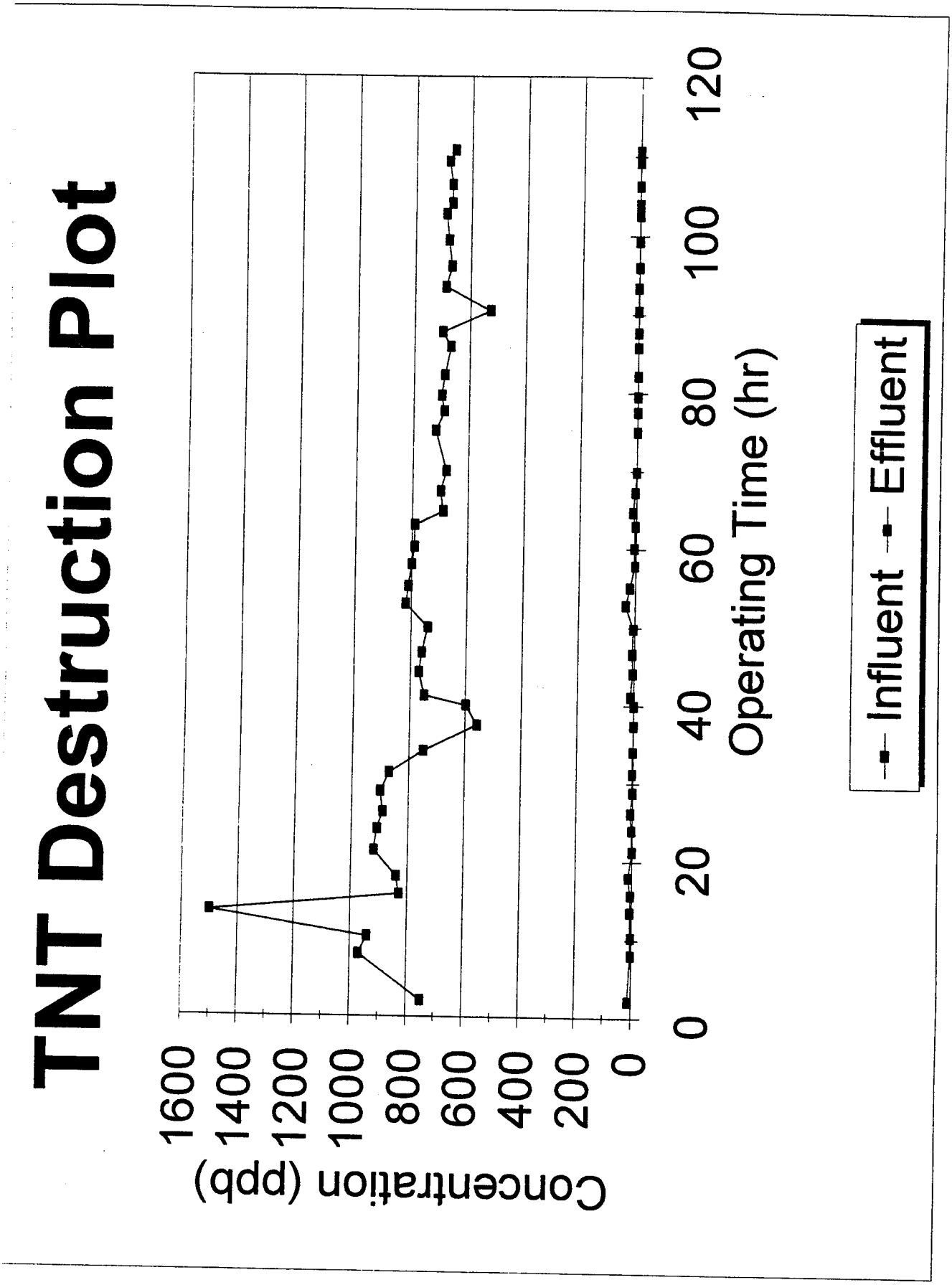
- A fluorescent lamp located inside the trailer and used for illuminating the trailer was on at all times. Its power (60 W) attributed to the total power measured by Weston (ie. nearly 7 kWh for the three weeks which correlates to 2.5%).
- The pilot unit's power supply uses less efficient single phase lamp drivers rather than the more efficient 3 phase lamp drivers. This is typical for smaller systems such as pilot units, and resulted in a power penalty of 6.8%. These savings will be evident in the larger full-scale systems (ie. 50 gpm).

The efficiency obtained on Oct. 10, 1994 was 25.9 gallons per kWh. As shown in Appendix 1, all TNT and TNB analyses on this day were less than the detection limit. However, Dtech monitoring that day identified detections around the treatment specification, which now can be classified as false positives. These false positive detections caused Purifics to lower the flow rate slightly on the subsequent days in order to ensure that the treatment specification was met. Thus, the power efficiencies are lower on those subsequent days. Since the efficiency of 25.9 was demonstrated, Purifics used this efficiency as a basis for full-scale treatment calculations.

Post Testing Optimization

After the final sample was taken by Roy F. Weston on the last day of the pilot program, Purifics shut down 12.5% of the photocatalytic cells. After 30 minutes of operation, the effluent was analyzed by a DTech kit and was found to be non-detect. This post optimization shows the potential for further cost reductions in power costs and capital cost.

Figure 2: TNT Destruction Plot



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Purifics Environmental Technologies Inc.

Figure 3: TNB Destruction Plot

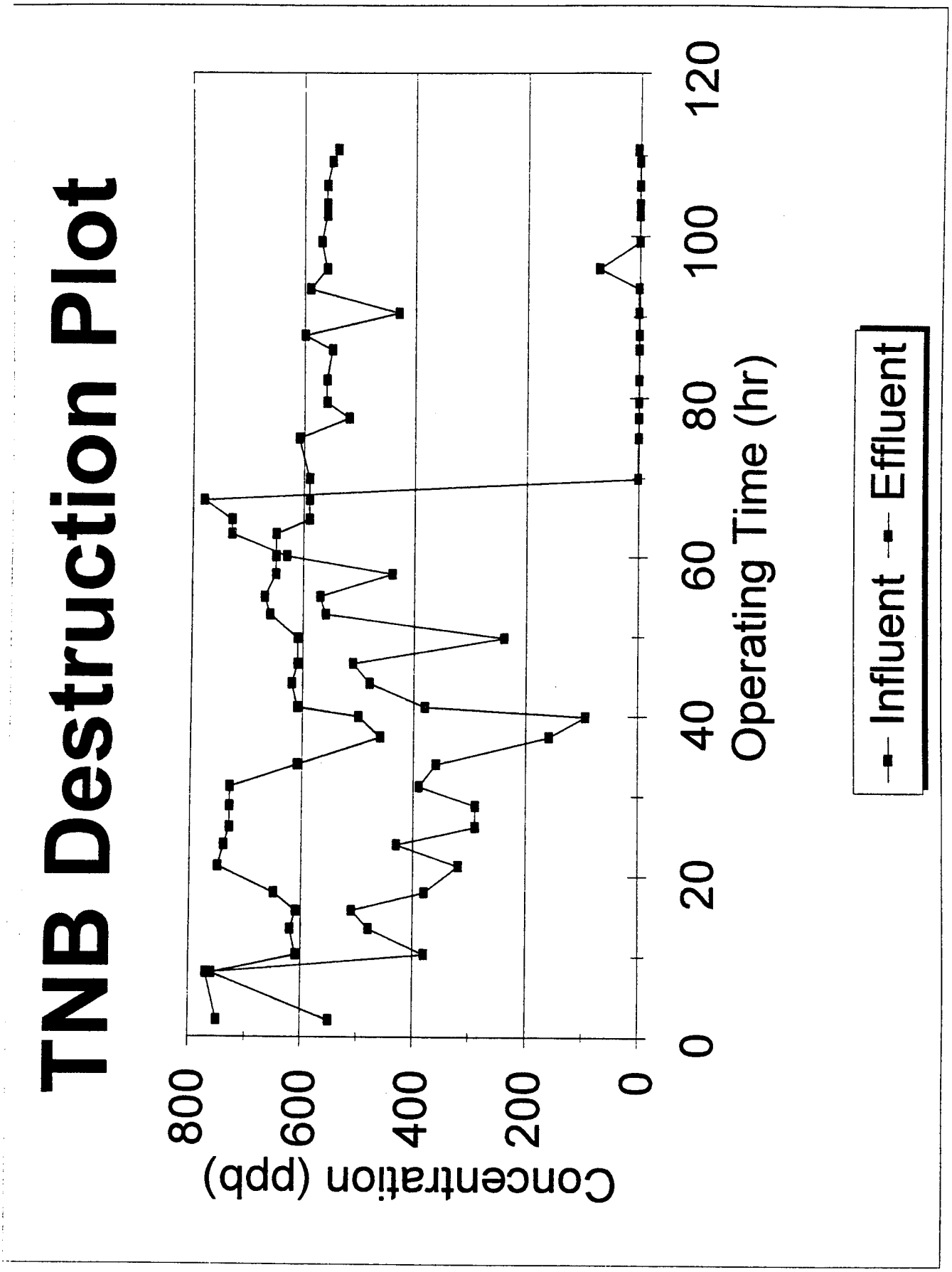
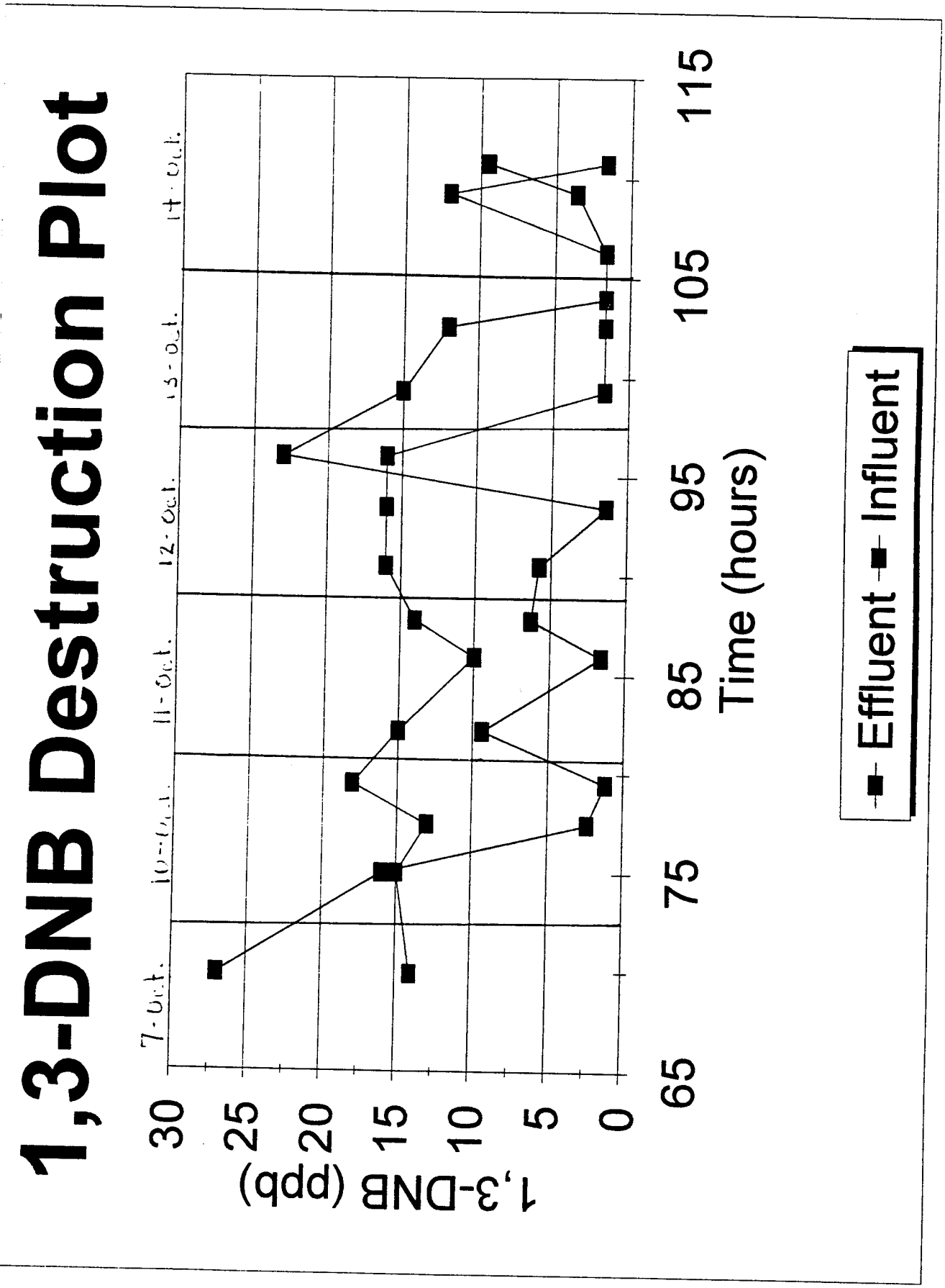


Figure 4: 1,3-DNB Destruction Plot



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6.0 Projected Full-Scale System Costs

Utilizing treatment scheme Mode B, as demonstrated on October 10, 1994, the projected full-scale treatment costs are as follows:

Table 2: Full-Scale O&M Treatment Costs

Operating	Cost Per kgal	Maintenance	Cost Per kgal
Power	$2.12	Lamps	$1.52
H_2SO_4	$0.237	Lamp labor	$0.032
NaOH	$0.073	Annual Maintenance	$0.002
Additive	$0.187	General Maintenance	$0.091
TiO_2	$0.008		
Total Operating	**$2.62**	**Total Maintenance**	**$1.64**

See Appendix 1 for equipment sizing and cost calculations/ assumptions. The projected capital cost is $687,500 US.

It should be noted that additional pretreament options such as percipitation would significantly reduce the equipment and operating cost described above. This type of pretreatment was not investigated by Purifics in this demonstration program.

7.0 Full-Scale Process Description

Referring to Figure 1, groundwater is pumped through the filtration equipment to remove the inorganic suspended solids. Downstream of the filtration is the pH adjustment which will remove the alkalinity (pH 3-4). Slurry catalyst is recycled back into the influent line, and is rapidly mixed with the influent ground water prior to treatment. The proprietary additive is added to the treatment process by a metering pump. In order to obtain a flow rate of 50 gpm, 49 DL racks are plumbed in parallel. Each rack has a volumetric flow rate of 1.025 gpm. Each DL rack contains the same capacity as the 2 D rack system utilized in the pilot study. After treatment, the decontaminated ground water is sent to the continuous flow separation system where the slurry is removed from the treated groundwater, and recycled back to the inlet. Downstream of the separation system, the purified groundwater is then neutralized by NaOH addition before discharge.

The PFD is the same as shown in Figure 1. See Figures 5 and 6 for commercial systems that are 1/10 and 1/5, respectable, the size of the full scale system. Figure 6 is a fully automated system which operates autonomously in the field treating groundwater. Figure 7 is a computer modified photo of what a full scale system will look like. Note, this design has the racks located below the cabinets in order to reduce the foot print and to meet containment specifications.

Major Component List
1) Power distribution cabinet
2) Photocatalytic racks
3) TiO_2 Separation System

Spare Parts Inventory
1) Lamps
2) pH probes

Figure 5: Typical Commercial System

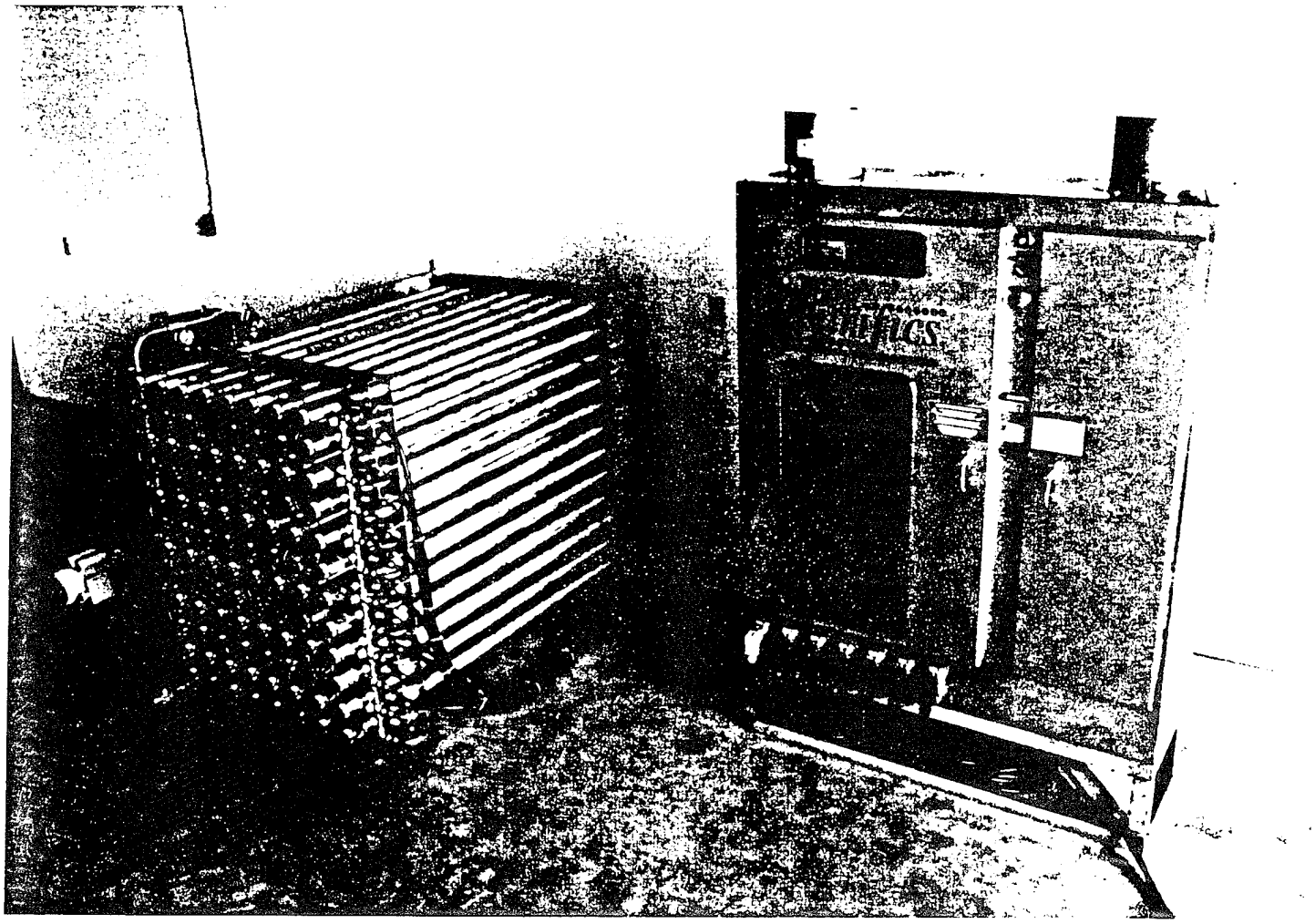
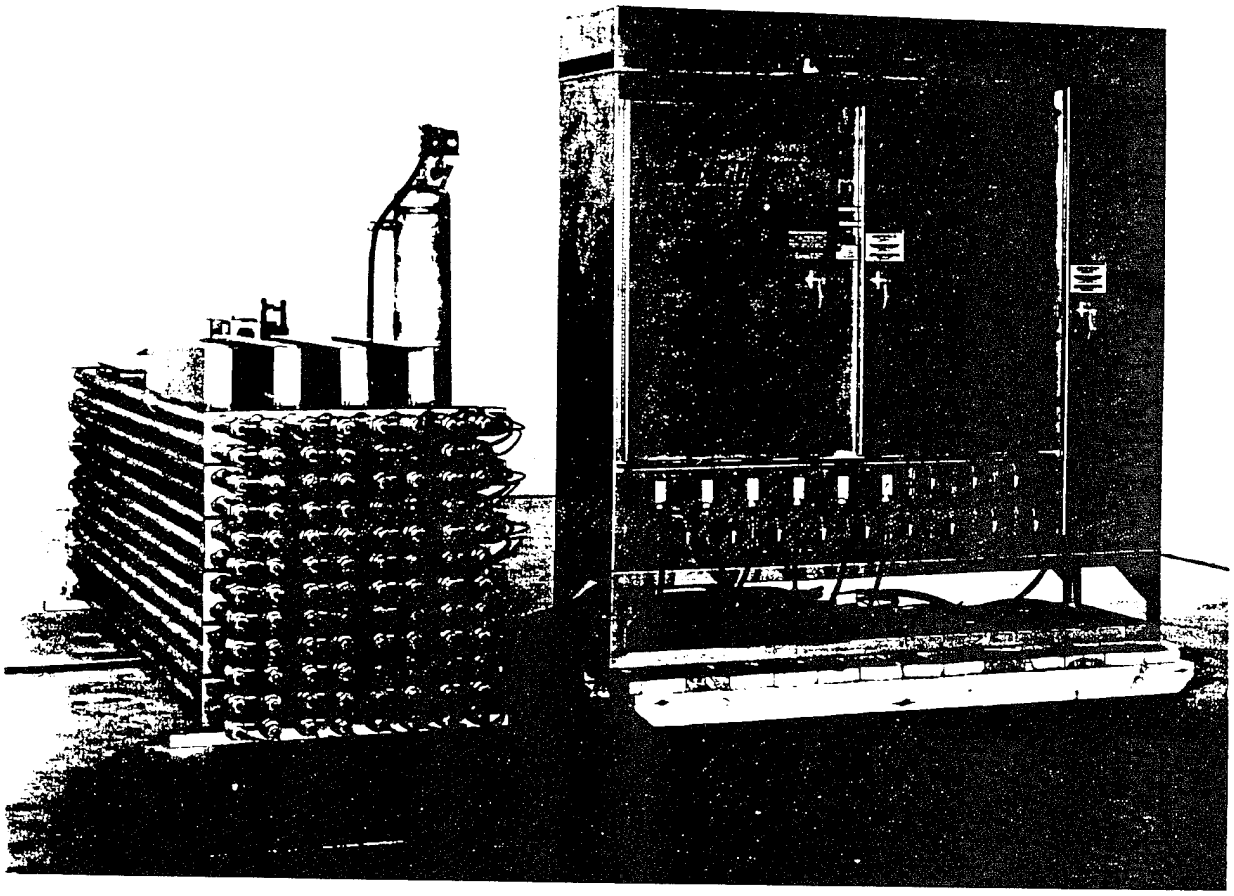


Figure 6: Purifics Automated Photocatalytic Treatment System



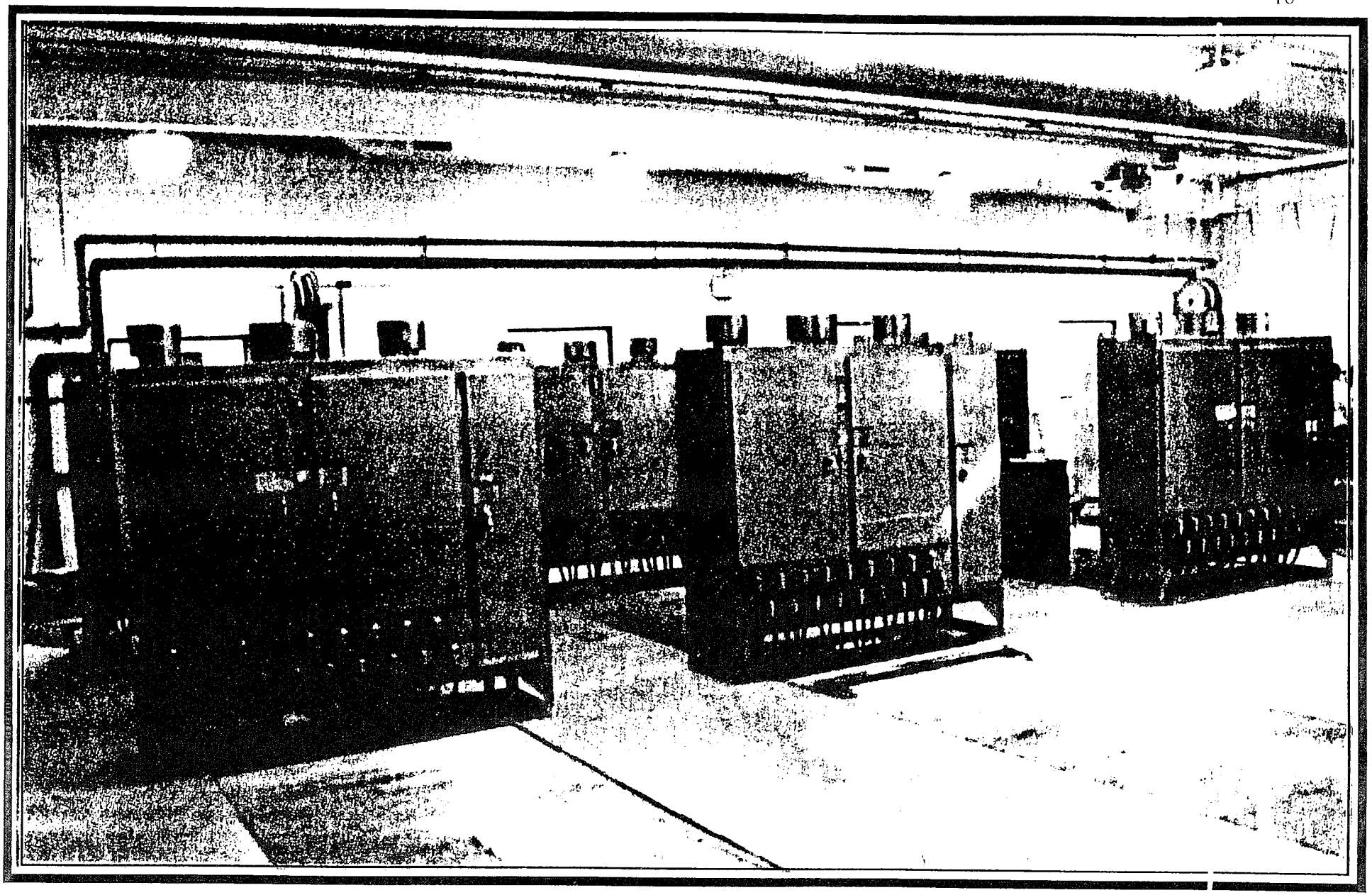


Figure 7: Purifics 50gpm Full Scale Groundwater Treatment System for Explosives
(Computer Generated Representation)

8.0 O&M Checklist

On-site maintenance consists of the following:

- checking acid/caustic and additive reservoir levels
- general visual inspections of the equipment.
- lamp replacement after 12,000 hours of operation
  - A totalizer located in power distribution cabinet records lamp usage.
  - Lamps can be changed while the system is operating as no water seals are affected.

The entire process is controlled by a PLC and can be linked to a data highway. Remote diagnostics can be performed by a modem. All operating parameters are monitiored and controlled by a PLC and are displayed on a visual diagnostic card. This visual diagnostic card can be seen in Figure 6 through the window of the cabinet door.

APPENDIX 1

CALCULATIONS / DATA

Full - Scale System Calculations and Assumptions

Equipment Sizing

- Average flow rate on Oct. 10, 1994 of the pilot study was 1.025 gpm. Treatment specification was maintained on this day, consequently, equipment size and cost information will be based on the conditions of this day.
- Equipment size used in the pilot test was a 2D rack system, which is equivanlent to one (1) DL type rack. Purifics full-scale systems are comprised of DL type racks.

Thus, the full-scale system (50 gpm) requires (50 / 1.025 * 1) C type racks.

The flow configuration will simply be 49 C type racks in parallel. The total power of the full-scale system is 106.6 kW. The cost of power for the system is $2.12 per kgal.

Sulfuric Acid Costs

Purifics used 5.5L of 98% sulfuric acid to pretreat 6910 gallons of water.
Projected full-scale costs are:
5.5L * 1.84 kg/L * (98% / 93%) * 2.2 lb/kg * $0.07/lb = $1.64 for 6910 gallons
Thus, Cost per kgal = $1.64 / 6.91kgal
= $0.237 / kgal

Sodium Hydroxide Costs

Purifics used 1.5L of 50% sodium hydroxide to post-treat 6910 gallons of water.
Projected full-scale costs are:
1.5L * 1.53 kg/L * 2.2 lb/kg * $0.10 / lb = $0.505 for 6910 gallons
Thus, Cost per kgal = $0.505 / 6.91kgal
= $0.073 / kgal

Additive Costs

The dosage rate of the Additive on October 10, 1994 was 42.9 mg/L. The price for the Additive is $1.15 per kg ($0.52 / lb).
Projected full-scale costs are:
Cost per kgal = 42.9 mg/L * 1000 gal * 3.785 L/gal * $1.15 / kg * (1 kg/ $1X10^6$ mg)
= $0.187 / kgal

Maintenance Summary:

1) Scheduled lamp changeout is performed every 12,000 hours, which correlates to $1.52 per kgal treated.

2) It will require approximately 78.4 hours of labor to change lamps with the system on-line. At general labor rates, the cost is:
Total cost = 14.88 *78.4 = $1166.60 per 12,000 hours
= $0.032 / kgal

3) Other maintenance (performed during lamp change-out), which includes catalyst change-out and general equipment cleaning, requires 3 man days.
Total cost = 24 * 14.88 = $44.64
= $0.002 / kgal

4) Purifics recommends an average of 2 hours per week of routine maintenance, etc.. One hour will be for a regular laborer and one hour for a supervisor.
Total cost = 1000 gal / 50 gpm * [1 / (7*24*60)] week/min * (14.88+31) $/week
= $0.091 / kgal

Purifics' Thrice Daily TNT, TNB, & 1,3-DNB Data

Sample D.	TNB influent	TNB Effluent	TNT Influent	TNT Effluent	1,3-DNB Influent	1,3-DNB Effluent
Sept. 27	550	750	750	12	25	11
	--	780	--	12	--	11
	760	770	970	4.5	25	13
Sept. 28	610	380	940	4.7	10	12
	620	480	1500	6.9	16	9.9
	610	510	830	6.5	24	8
Sept. 29	650	380	840	14	25	77
	750	320	920	3.1	6.6	43
	740	430	910	4	18	66
Sept. 30	730	290	890	9.1	17	12
	730	290	900	3.2	8.8	13
	730	390	870	4	8.9	55
Oct. 3	610	360	750	3.1	40	48
	460	160	560	1.3	9.4	5.6
	500	95	600	0.74	18	2.8
Oct. 4	610	380	750	13	9.3	14
	620	480	770	6.4	14	17
	610	510	760	9.7	19	89
Oct. 5	610	240	740	6	11	7.5
	660	560	820	34	16	14
	670	570	810	21	18	14
Oct. 6	650	440	800	4.1	17	93
	650	630	790	7.3	19	15
	650	730	790	4.3	21	18
Oct. 7	590	730	690	12	12	17
	590	780	700	6.6	4.6	20
	590	1.7	680	1.7	14	27
Oct. 10	610	1.6	720	1.6	15	16
	520	1.6	690	1.6	13	2.4
	560	1.6	700	1.6	18	1.2
Oct. 11	560	1.6	690	1.6	15	9.4
	550	1.6	670	1.6	10	1.6
	600	1.6	700	1.6	14	6.3
Oct. 12	430	1.7	530	1.7	16	5.8
	590	2.4	690	2.4	16	1.4
	560	74	670	1.1	16	23
Oct. 13	570	1.6	680	1.6	1.6	15
	560	1.6	690	1.6	1.6	12
	560	1.6	670	1.6	1.6	1.6
Oct. 14	560	1.6	670	1.6	1.6	1.6
	550	1.6	680	1.6	12	3.6
	540	4.5	660	1.6	1.6	9.5

APPENDIX 2

PRODUCT PROFILE

PROCESS DESCRIPTION

Purifics' Photocatalytic equipment is a continuous flow process used to purify and detoxify water contaminated with organic chemicals and/or complexed metals. This automated, ambient temperature process can treat water down to levels that exceed drinking water standards. It is essentially a solid state device that is very efficient and can operate without concern. The modular design accommodates ever changing environmental standards or treatment requirements.

Purifics photocatalytic systems are based on a closed loop photocatalyst slurry design as shown in Figure 1. The turn key modular technology is comprised of sets of photocatalytic racks, each containing a number of individual cells. Depending on the concentration of the contaminants and the throughput required, the racks are linked together in a serial and/or parallel mode. For sustained single pass treatment, the TiO_2 slurry is contained inside a slurry loop and is continually recycled to the inlet stream. The TiO_2 is constantly in motion and is thus continually mixed. Figure 2 depicts a typical commercial system.

A key element of the Purifics technology is the <u>continuous</u> TiO_2 separation process (patented), which allows the catalyst to be separated out of the purified water and reintroduced into the inlet stream. Consequently, this process is not restricted to or inhibited by any particular type of TiO_2, pH level, turbidity, pressure, temperature or type of contaminants or other elements of water chemistry. Purifics' systems are designed to operate on water containing iron and alkalinity.

Purifics technology has been driven by, and developed for the water treatment / performance requirements of industry. Consequently, high levels of reliability, robustness and minimal operator and maintenance requirements have been engineered into these commercial systems.

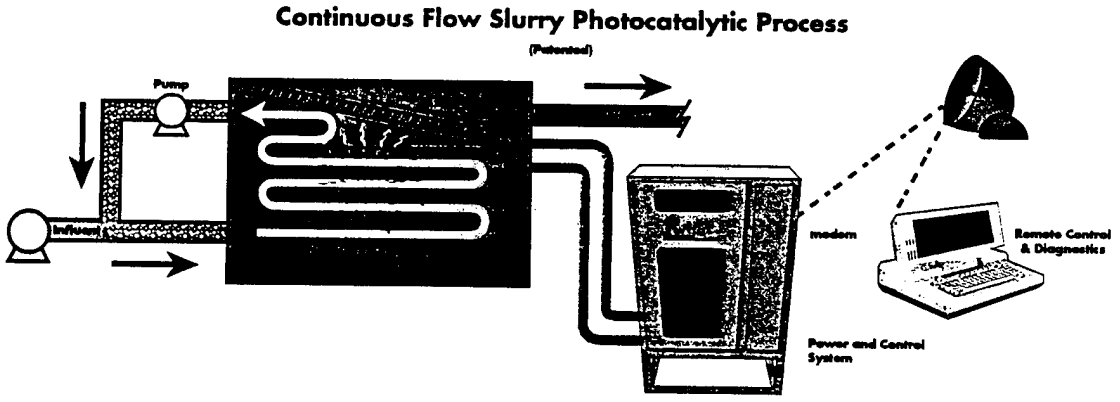


FIGURE 1

APPENDIX 2

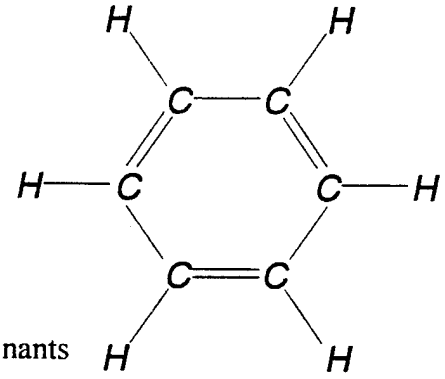
APPLICATIONS

Purifics' Photocatalytic process for water is used to:

- purify and/or
- detoxify and/or
- break apart complexed metals and/or
- remove metals and/or
- disinfect or sterilize (as a by-product)

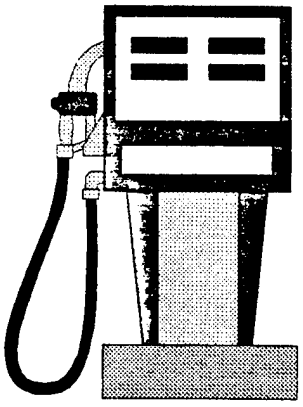
The source of the water can be:

- groundwater
- surface water
- plant process water
- potable well water
- high purity water



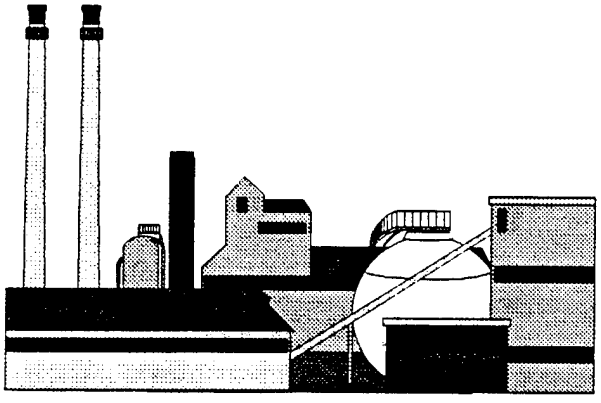
Purifics' systems can handle water containing the following:

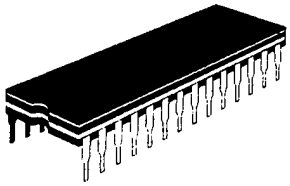
- high levels of turbidity
- high levels of suspended and\or dissolved solids
- iron, calcium carbonate and other natural occurring contaminants
- pH levels in the range of 3-10
- any level of dissolved oxygen
- second phase constituents



To achieve the desired reductions in:

- BOD: Biochemical Oxygen Demand
- COD: Chemical Oxygen Demand
- TOC: Total Organic Carbon
- or targeted contaminant reductions in the ppm, ppb or ppt levels.





PURIFICATION AND DETOXIFICATION CAPABILITY

Conventional Organics Destruction

Chlorinated Alkanes	Ketones
Alkanes	Aldehydes
Alkenes	Ethers
Alkynes	Pesticides / Herbicides
Aromatics	TOC, COD, BOD, AOX
Nitro-Aromatics	Dioxins
Alcohols	

Complexed Metals Destruction / Removal

Arsenic	Iron
Selenium	Others TBD

Metals Removal

Copper	Mercury
Nickel	Platinum
Chromium	Iron
Cadmium	Manganese
Zinc	Aluminum
Silver	

Disinfection and Sterilization

As a by product of the above processes disinfection and in-certain application sterilization will occur.

SYSTEM BENEFITS

Purifics' photocatalytic treatment systems offer many benefits to the conscientious operator/user who wishes to purify, detoxify, and/or remove metals in water. The benefits are:

- DESTRUCTION of organic pollutants at the source location which eliminates handling, shipping, and the need for long term disposal and its associated liability.
- HIGH RELIABILITY because Photocatalytic systems are constructed from highly developed components with an established low service field history. This translates into minimal maintenance requirements, readily available replacement parts and low life cycle costs.
- COMMUNITY ACCEPTANCE because these systems have a low aesthetic profile, and generate negligible heat, noise, or waste. Photocatalytic systems use readily available electrical power supplies which minimizes site preparation requirements and servicing in the community.
- HIGHLY AUTOMATED systems eliminate or significantly reduce operator requirements and training.
- ABLE TO TREAT fluids at a broad range of temperatures, pressures, pH ranges and contamination levels (ppm to ppt). Turbid water and dyes are also easily treated with this process.
- CONSISTENT transitional products as large molecules are sequentially reduced to smaller molecules.
- MODULAR design allows for ease of installation and portability. The modular design also allows for incremental adjustments to system capacity in order to meet changing flow requirements or new stringent environmental regulations.
- SAFE because the process is intrinsically safe by design. There are no thermal hazards: and a high level of seal integrity and durability. GFI and other automatic shut off safety features plus separation of the external equipment from the wet environment ensures a high degree of electrical safety.
- SYSTEM SIMPLICITY because Purifics systems eliminate the need for extensive pretreatment to remove turbidity or high levels of dissolved solids. Consequently, pretreatment technologies such as flocculation and ultrafiltration are eliminated.

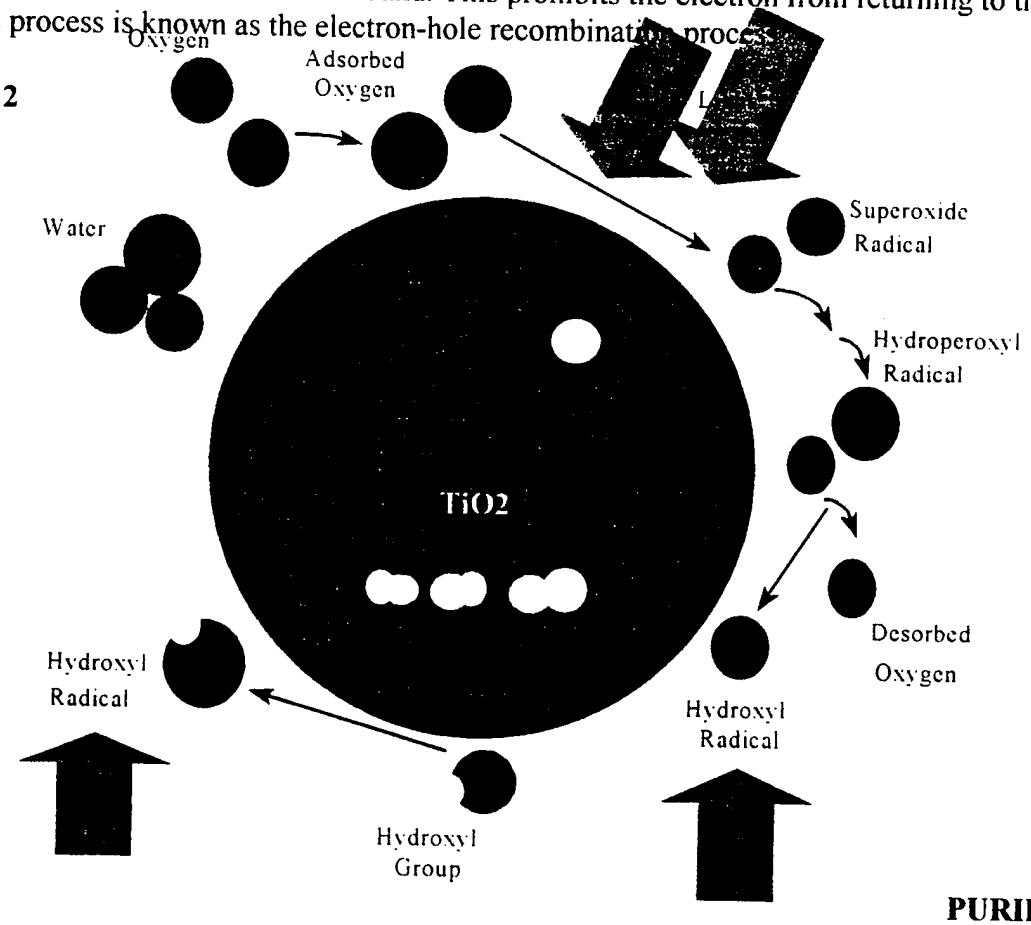
CHEMICAL PROCESS

Purifics technology uses an illuminated or light activated titanium dioxide (TiO_2) catalyst for this treatment process. The treatment process functions in a manner similar to other catalyst processes such as the catalytic convertor on automobiles. The major difference in TiO_2 photocatalytic oxidation is that the TiO_2 catalyst uses light energy for activation, rather than heat energy as is the case with conventional catalyst technologies. Essentially, the only input to the technology is electric power which is required to produce light.

The lamp emits low intensity ultraviolet light which photo-generates electrons into the conduction band of the catalyst (see Figure 2) and positive "holes" at the surface of the TiO_2. A reduction reaction then occurs with the electron, and an oxidation reaction at the hole. Typically oxygen is reduced to form the superoxide ion, which further disproportions to form a hydroxyl radical ($^{\circ}OH$). At the hole either adsorbed hydroxyl ions or water molecules are oxidized to form hydroxyl radicals, or organic contaminants can be oxidized directly. The generated hydroxyl radicals, which are very strong oxidizing agents, break down and mineralize the organic molecules into CO_2, water, and halide ions (if they exist).

In certain cases the efficiency of the process can be increased by the addition of irreversible electron acceptors. The electron acceptors will react with the electron from the TiO_2 catalyst when the electron is in the conduction band. This prohibits the electron from returning to the hole. This process is known as the electron-hole recombination process.

FIGURE 2



SYSTEM SPECIFICATIONS

Purifics' Photocatalytic systems are available in number of configurations and designs and can include auxiliary equipment to meet your requirements. Systems are available to the following specifications:

Certifications

- UL/CSA
- ISO 9000
- ASME B&PV Code
- NEMA 4X or 12
- Explosion proof (pending)

Materials of construction

- 316 Stainless Steel
- Plastic

Process

- Batch
- Continuous Flow
- Portable or stationary

Controls

- Solid state electronics and PLC
- Remote control and diagnostics via Modem
- Control Cabinet <--> Reactor separation by up to 32 m (100 ft)

Power

- Ground Fault Interrupts on all circuits
- 110/220/380/480/600 volt
- 50 or 60 Hz
- Single or three phase(with PCR).

Capacity

- 4 to 2000 L/min
- treatment time 0.5 to 20 min

Delivery

- 60 to 90 days

Training, warranties and performance guarantees can also be specified

SOLARCHEM

PILOT-SCALE REPORT

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Solarchem

Report on the

Rayox® Field Test to Treat Groundwater at the

Savanna Army Depot Activity (SADA), Savanna, Illinois

Prepared for

Roy F. Weston Inc.

by

Solarchem Environmental Systems

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APPENDIX

1. SUMMARY

This report outlines the results for the on-site pilot phase of **Rayox®** treatability testing of groundwater at the Savanna Army Depot Activity (SADA) in Savanna, Illinois. The objectives of the pilot testing were:

- to confirm the effectiveness of the **Rayox®** processes for destruction of TNT, TNB and other contaminants in order to meet the specified discharge criteria, and
- to confirm that the results obtained in the previous bench scale test are reproducible in the pilot scale phase.

The pilot scale test work completed has confirmed that:

- the results from the optimization part of the pilot scale test matched those obtained in the bench test,
- during the optimization phase, a new treatment configuration of treating at pH=12 was tested, which was not tested in the bench scale test,
- the treatment at pH=12 was found to be more cost effective than the treatment at pH=9 during the optimization phase, so it was used for the three week demonstration period.
- the pilot scale unit was not configured to treat at low flow rate (1-2 gpm) so some inefficiency resulted, at the optimum low UV/Ozone ratio. To obtain best results in future pilot systems, the pilot system should be designed/built after bench testing is completed.

Based on the results of the pilot test, the most cost effective configuration of **Rayox®** equipment is the use of 4 x 30 kW UV reactors together with 237lbs/day of ozone, treating at pH of 12. The selling price of the **Rayox®** system is $460,000. Operating costs are estimated at $ 9.13/1000 gallons or $230,000/year treating 50 gpm.

2. INTRODUCTION

As part of a comprehensive study on application of UV/Oxidation processes to the treatment of contaminated groundwaters at army depots, Solarchem Environmental Systems was contracted by Roy F. Weston Inc. on behalf of the U.S. Army Environmental Center to conduct both bench and pilot testing.

In the first phase of the study, bench scale tests were conducted at the Solarchem facilities using groundwater from the Savanna Army Depot Activity (SADA) in Savanna, Illinois. Through this work, the application of ultraviolet (UV) light in combination with ozone was identified as the most suitable process for effective destruction of ordnance compounds in the groundwater sample. Based on this preliminary work, operating and capital costs of $7.56/1000 gallon and $600,000 were estimated for a full scale system having a 50 gpm capacity. Details of this work are presented in the "Draft Report on the **Rayox®** Design Test to Treat Groundwater at the Savanna Army Depot Activity (SADA), Savanna, Illinois" dated September 23, 1994.

The second phase of the study involved on-site pilot scale testing. This report outlines the results of the field tests on the **Rayox®** treatment of groundwater from the Savanna Army Depot Activity in Savanna, Illinois. This work was conducted in parallel with three other UV/Oxidation vendors to provide comparative data on system treatment performance and energy efficiency.

The objectives of the field test were:

- confirm bench scale results and identify optimum operating conditions for full scale treatment.
- operate the pilot unit under optimized conditions in order to demonstrate treatment performance, energy efficiency and reliability of the **Rayox®** system
- determine the operating cost and capital investment required to meet discharge limits for a full scale flowrate of 50 gpm.

3. THEORY

3.1. Advanced Oxidation Processes (AOP)

In advanced oxidation processes, the degradation of pollutants in water can be associated with a number of mechanisms. The primary mechanism involves the reaction of UV light with hydrogen peroxide or ozone to generate highly reactive hydroxyl radicals (OH) as shown below:

$$H_2O_2 + \text{UV light} \longrightarrow 2 \bullet OH \quad [1]$$

$$O_3 + H_2O + \text{UV light} \longrightarrow 2 \bullet OH + O_2 \quad [2]$$

The OH radical then initiates a rapid cascade of oxidation reactions which, if allowed to proceed to completion, result in carbon dioxide and water as end products.

In some cases, other mechanistic pathways can also be identified such as direct photolysis of the contaminants by UV light or direct reaction of ozone or oxygen radicals with the target contaminants or their intermediate byproducts.

3.1.1. UV Light

The formation of hydroxyl radicals relies on the absorbance of UV light in the range of 200 to 240 nm. In the Rayox system, this light is provided by high intensity medium pressure mercury vapor lamps. The lamps are housed in quartz tubes and a patented device is used to prevent fouling of the quartz tubes. Solarchem's medium pressure UV lamps have been designed to give out significantly more UV light in the 200 to 240 nm range than any other UV light source. While UV light is needed for the formation of hydroxyl radicals from hydrogen peroxide and ozone, it may also serve to break or weaken the chemical bonds of many organic compounds by direct photolysis. This is important for compounds that react slowly with hydroxyl radicals.

3.1.2. Hydrogen Peroxide

Hydrogen peroxide is a commonly used chemical oxidant in advanced oxidation processes. It is normally supplied in concentrations of 35 or 50 % in water and is metered into the flow line upstream of the UV lamps.

3.1.3. Ozone

Ozone is a strongly oxidizing gas that may react directly with organic compounds. Ozone also reacts to form hydroxyl radicals through direct photolysis, reaction with hydrogen peroxide or reaction under high pH conditions (shown below).

$$O_3 + H_2O + OH^- \longrightarrow \quad \bullet OH + O_2 + HO_2 \qquad [3]$$

Ozone is normally created on site by an ozone generator which requires either clean dry air or oxygen as its feed source. Ozone is typically produced at a concentration of 2% from air feed and 4 to 7% from oxygen feed. The amount of ozone that is consumed in the treatment process will vary with system geometry, ozone dispersion, UV power, UV/Ozone ratio and sample pH. In previous Solarchem bench and pilot studies using 2% ozone, only 10 to 40% of added ozone reacted during the treatment process. Ozone uptake is dramatically improved at full scale by using a two or more reactors in series to maximize water/ozone contact. The highest ozone uptake values are normally observed when ozone is applied in combination with UV light.

3.2. AOP Treatment of TNT

In the past, process water from the manufacture of TNT has been tested by Solarchem to determine the most promising AOP for the destruction of high levels of TNT. As UV/peroxide is well known as an efficient treatment method for other aromatic compounds such as substituted benzenes and phenols, this treatment regimen was the first AOP tested for the treatment of TNT process water.

The UV/peroxide based **Rayox®** treatment of high concentration TNT process water was successful at removing the TNT but toxicity testing (96 hour LC50 rainbow trout) demonstrated that although the TNT was removed, the water was still not detoxified. A refractory byproduct from the hydroxyl radical decomposition of TNT , identified as trinitrobenzene (TNB), was detected in the treated water. Hydroxyl radical reaction with TNT is postulated to proceed through a series of reaction steps beginning with UV activation of the TNT molecule and resulting in the production of TNB as an intermediate byproduct.

Testing was also done on TNT groundwater and results confirmed an increase in TNB concentration during the UV/peroxide treatment run. The TNB is destroyed very slowly by UV/peroxide treatment, requiring prohibitively high UV doses for complete detoxification of the TNT contaminated water.

The next AOP to be considered was the UV/Ozone based **Rayox®-O** process. Although the removal of organic compounds by UV/Ozone systems is conventionally believed to proceed through formation and photolysis of hydrogen peroxide generating hydroxyl radicals, additional mechanistic pathways for destruction of TNT and its byproducts (esp. TNB) might allow for more cost effective treatment. These additional pathways may include the reaction of ozone or oxygen radicals with TNT or with an intermediate compounds, or the direct photolysis of TNT by UV light.

Testing of both groundwater and process water, with **Rayox®-O**, demonstrated that efficient TNT removal could be achieved without the buildup of TNB. This indicates that hydroxyl radical attack is not the sole reaction mechanism present in the UV/Ozone TNT treatment system.

The application of ozone under high pH conditions and without UV light, was also found effective, especially for removal of high concentrations (> 10 ppm) of TNT. At the lower concentrations, normally seen in groundwaters, a UV/Ozone polishing step was required to economically remove the final trace contaminants. UV/Ozone was also found more effective for removal of overall TOC and therefore was the preferred process both for treatment of TNT and for removal of potentially undesirable byproducts. A full scale **Rayox®** system using the UV/Ozone process for TNT destruction is currently in place.

Bench scale testing of groundwater from the Savanna Army Depot Activity confirmed that direct UV photolysis and UV/peroxide treatment were not effective for destruction of TNB. The most promising treatment option involved a combination of UV light and ozone with a low UV to ozone ratio. High pH conditions were also found to enhance degradation of ordnance compounds in the groundwater.

3.3. Design Parameters

3.3.1. UV Dose

Solarchem's design parameter for the scale-up of UV oxidation systems is the "UV Dose" which is defined as the amount of UV lamp power (in kWh) applied to 1000 gallons of water. This design parameter is calculated as follows:

$$\text{UV Dose (kWh/1000gal)} = \frac{\text{Lamp Size (kW) x 1000 (gal/ 1000gal)}}{\text{Flow Rate (gpm) x 60 (min/h)}}$$

The UV Dose is used to determine the number of lamps required for a full scale system. For full scale systems using 30 kW lamps, the calculation used the 27.5 kW nominal running power instead of the 30 kW maximum power.

3.3.2. Electrical Energy per Order (EE/O)

The destruction of a contaminant by a UV/Oxidation process involves a complex series of chemical reactions. However, experience has shown that this destruction generally follows a first order relationship with the amount of energy input into a unit volume of water. A simple design parameter, which incorporates the energy input to the system and the number of orders of contaminant destruction, can be used to compare and scale-up processes. This design parameter is known as the Electrical Energy per Order or the EE/O and its units are in kWh/1000gal/order.

For example, if it takes 10 kWh of electrical energy to reduce the concentration of a target compound from 10 ppm to 1 ppm (1 order of magnitude or 90% destruction) in 1000 gallons of water, then the EE/O is 10 kWh/1000gal/order for this compound.

The EE/O values obtained in a pilot system can be applied to a full scale flowthrough system. The equation for the EE/O which applies to both batch and flow through situations is:

$$EE/O = \frac{\text{UV Dose (kWh/1000gal)}}{\log (C_i/C_f),}$$

where C_i is the initial concentration and C_f is the final concentration.

In scaling up from bench or pilot scale results to a full scale system the EE/O value is calculated. In systems with more than one compound of interest the EE/O for each compound must be determined in the batch testing. The compound that treats the slowest will have the largest EE/O value and will determine the minimum requirements for a full scale system. This compound is termed the Rate Limiting Compound. Once the system requirements are determined based on the limiting compound, the effluent concentration for each compound can then be calculated for the full scale design.

Note that for this report, Overall EE/O refers to the total Electrical Energy for both UV Lamps and Ozone Generation.

3.3.3. UV/Ozone Ratio

UV/Ozone ratio may be expressed in terms of kWh of electrical energy used to power the UV lamps per pound of ozone fed to the system. However, because ozone uptake varies between pilot and full scale systems, a key design parameter for UV/Ozone systems is the ratio of UV dose to the ozone **consumed** in the reaction. For the purpose of estimating operating costs, it is assumed that 10 kWh are required to generate 1 pound of ozone.

4. EXPERIMENTAL TESTING

4.1. Equipment

The pilot test work was conducted using the UV/Ozone pilot system shown schematically in Figure 1.

4.1.1. Overview

The flow rate into the pilot system is controlled by a globe valve at the system inlet. The raw groundwater is fed into the 27 gallon stainless steel UV/Ozone reactor tower where it is contacted with ozone and UV light. Treated effluent from the tower is directed to the 300 gallon plastic effluent tank. The level in the effluent tank tower is controlled by a discharge pump which automatically pumps the treated water out of the pilot system. The unit is rated for 10 GPM. The pilot scale system was operated in concurrent flow mode during pilot scale testing.

4.1.2. UV/Ozone Reactor

The UV/Ozone reactor tower is the heart of the treatment system. The reactor contains three 1 kW UV lamps, each housed in a quartz sleeve which is mounted horizontally across the tower. Each quartz sleeve is provided with a transmittance controller which automatically wipes the surface of the tube to ensure that the transmittance of UV light is not reduced by any foulants or scale collected on the quartz. Ozone is introduced into the reactor through a sparger at the bottom of the vessel. Offgas containing any unreacted ozone is collected at the top of the reactor, directed through a moisture trap and a length of heated pipe, and then passed through an ozone destruction catalyst. The groundwater may be introduced into the bottom of the reactor (concurrent to the ozone flow) and drawn off at the top; or introduced at the top and drawn off the bottom (counter current mode).

4.1.3. Ozone

Ozone is generated from air using a PCI Model G-21 ozone generator. Although rated for 21 lb/day and operated at full amperage (210 kWh/day), the ozone generator did not operate at maximum capacity during the pilot testing and produced only 16 lb/day of ozone at a concentration of approx. 2.5 % in air. This ozone production rate was confirmed on a weekly basis by a PCI ozone monitor. The ozone monitor was also used on a regular basis to monitor the concentration of ozone in the offgas from the UV/Ozone reactor. This provided hard data on the amount of ozone consumed in the treatment process (ozone uptake).

4.1.4. Chemical Addition

The pilot unit is provided with diaphragm metering pumps to deliver controlled doses of reagents. Calibration cylinders are used to determine the pump rate. Chemical injection ports are provided downstream of the flow control valve and downstream of the discharge pump and in-line static mixers are used to disperse the chemical in the groundwater stream. An additional injection port is located at the inlet side of the effluent tank. In this case, the process flow into the tank provides the mixing. During this study, sodium hydroxide (50%) was metered into the groundwater to raise the pH before the reactor. Sulphuric acid (95%) was then used to reduce the pH of the treated groundwater prior to discharge.

4.2. Procedures

4.2.1. Pilot Plant Operations During Optimization Testing

Throughout the study the ozone generator was operated at its maximum output. During optimization testing, the applied ozone dose was varied by adjusting the groundwater flow rate. The dose of ultraviolet light applied to the groundwater was varied both by adjusting the flow rate and by turning on different numbers of lamps, as shown in Table 1.

Table 1: Variation of ozone and UV dose with operating conditions.

Flow gpm	Ozone feed rate lb/kgal	UV Dose (kWh/1000gal)			
		3 lamps	2 lamps	1 lamp	No lamps
0.5	22.2	100	67	33	0
1.0	11.1	50	33	17	0
1.5	7.4	33	22	11	0
2.0	5.6	25	17	8	0
2.5	4.9	23	14	7	0
4.0	2.8	13	8	4	0
8.0	1.4	6	4	2	0

4.2.2. Sample Analysis

A number of analytical regimes were employed over the course of the study both to facilitate process optimization and to confirm treatment performance.

Field test kits based on an immunoassay technique (Dtech TNT Explosives Test Kit) were provided by Weston to assist in process optimization and monitoring. These provided quick semiquantitative data on TNT explosives content in the pilot plant effluent in the range of 5 to 60 ppb. Due to

uncertainty regarding the accuracy of the Dtech Test method, these results are not presented here. The discussion of UV/oxidation performance relies instead on analytical results obtained using standard laboratory techniques.

Selected feed and effluent samples were analyzed by Solarchem for 2,4,6-trinitrotoluene (TNT) and 1,3,5-trinitrobenzene (TNB) using a Water's HPLC equipped with a 30 cm x 0.46 cm C-18 column with detection using UV spectrometry at 225 nm. Sample analysis focused on TNT and TNB because these contaminants are present in the highest concentration in the wastewater. However, in order to confirm that other ordnance compounds were being successfully treated, some samples were submitted to an MRD-certified laboratory, PACE Inc., for analysis using USATHAMA methods.

Sample collection during the optimization study was performed by Solarchem. However, during the demonstration program, Roy F. Weston Inc. conducted a comprehensive analytical sampling regime to monitor pilot plant performance. Samples of the influent groundwater and the treated effluent from the UV/Oxidation system were collected by Weston three times a day at random times over the eight hour test period. Samples were analyzed for the full range of ordnance compounds according to Method SW8330 and the results were provided to Solarchem for incorporation into this report. In addition, one of the daily influent samples was analyzed for hardness, alkalinity, iron and manganese.

4.3. Optimization Testing

4.3.1. Scope of Optimization Tests

Optimization tests were conducted to investigate the effect of the following process parameters on TNT and TNB destruction efficiency:

1) UV/Ozone ratio
2) flow configuration
3) groundwater pH

The starting point for the test work was the most promising conditions identified through the in-house bench scale testing: namely, high pH conditions and low UV/ozone ratios.

4.3.2. Results of Optimization Tests

Details of the test runs conducted and results obtained are tabulated in the Appendix and summarized below.

UV/Ozone Ratio

A series of test runs (Tests 1 - 4) were conducted at pH 9 and in concurrent flow mode to examine the effect of UV/Ozone ratio on treatment efficiency.

When UV light and ozone were applied in combination, the TNT was found to treat at a somewhat faster rate than the TNB. The treatment system requirements are therefore controlled by the TNB. When ozone was applied alone, the rate of treatment was found to be limited by TNT.

In Figure 2, the destruction of TNB at UV/Ozone ratios of 17, 12 and 8 kWh/lb are compared as a function of the total energy consumed (UV dose and ozone consumed). Data from testing with ozone only (no UV light applied) is also presented in Figure 2. Treatment was found to be most effective at the lower UV to ozone ratios with ozone alone providing the most effective TNB destruction. However, Figure 3 illustrates that ozone alone at pH 9 was not any better than UV/Ozone for the treatment of TNT. In addition the ozone uptake for ozone alone is much lower making full scale design impractical. This agrees with the bench scale test results and with previous Solarchem studies indicating that ozone uptake and TOC destruction are improved when UV light is applied in combination with ozone.

Flow Configuration

While ozone must be introduced through a sparger at the bottom of the UV reactor tower, the groundwater may be introduced at either the top or the bottom of the tower. To investigate the effect of flow configuration, testing was conducted in countercurrent flow mode at pH 9 and with a UV/Ozone ratio of 17 kWh/lb (Test 5). Results from this work were then compared to results from a similar run (Test 1) previously conducted in concurrent mode. From the test results, illustrated in Figure 4, the two flow modes were shown to provide similar treatment with a slight improvement in the TNB and TNT destruction rates in the concurrent flow mode. Subsequent optimization tests as well as the demonstration program were therefore conducted with the UV reactor configured for concurrent flow.

Sample pH

To examine the effect of pH, tests were conducted with groundwater pretreated to pH 9, 11 and 12 by addition of sodium hydroxide (Tests 6-8). The effect of sample pH on TNB destruction is shown graphically in Figure 5. Treatment was found to improve with increasing pH conditions. In addition, ozone uptake or consumption was also found to improve with sample pH with values of 10 to 20% uptake at pH 9 increasing to > 45 % uptake at pH 11 and pH 12.

4.3.3. Extrapolation of Optimization Test Results

Table 2 presents the scale up data obtained from the optimization tests and the calculated UV lamp and ozone requirements for a full scale 50 GPM UV/Ozone system. These scale up calculations are based on treatment of TNT and TNB from 1500 ppb to 2 ppb.

By comparing EE/O values for each test run, one can see a trend towards reduction in electrical power with decreasing UV/Ozone ratio and increasing sample pH. The most effective treatment was obtained in Test 8 with a UV/Ozone ratio of 10 kWh/lb and a pH of 12. Based on this test, a full scale system would require four (4) 30 kW UV lamps and 225 lb/day of ozone.

It was therefore determined to conduct the pilot plant demonstration testing at pH 12. While Test 8 had been conducted with all three 1 kW lamps on, it was expected that improved treatment would be obtained if less UV light was applied (providing a lower UV/ozone ratio) during the pilot demonstration program.

4.3.4. Correlation to Bench Scale Results

In the optimization test program, low UV/ozone ratios and high pH conditions were identified as most effective for destruction of TNT and TNB. Similar results were obtained through in-house bench scale testing although pH levels greater than 9 were not investigated at bench scale.

It should be noted however that there was a strong correlation between bench scale and pilot scale results obtained at pH 9. The proposed preliminary design from the bench scale testing consisted of a 5 x 30 kW reactor system with a 350 lb/day ozone generator. The most effective pilot scale test conducted at pH 9 was Test 3 and a full scale system based on these results would require 5 lamps and 358 lb/day ozone.

4.4. Demonstration Test Program

4.4.1. Test Procedure

The demonstration phase of the test program was conducted over the three week period from Sept. 27 to Oct. 14. The pilot plant was operated for 8 hours per day for a total of 14 days. A total of 9668 gallons of groundwater was processed over this period.

Throughout the demonstration testing, the groundwater was pretreated to pH 12 by addition of 50% sodium hydroxide upstream of the UV/Ozone reactor. Other process conditions were varied slightly in the first and second week of the demonstration program based on results of analysis of selected samples

Table 2: Process Descriptions and Scale Up Data from Optimization Test Program

Test	Conditions						Scale Up Data		Requirements for Full Scale 50 GPM System				
	pH	Flow rates tested (gpm)	Flow pattern	No. of lamps on	Ozone Uptake (% of fed ozone)	UV/O3 ratio (kWh/lb)	Limiting compound	Overall EE/O	Total Energy (kWh/ kgal)	UV Dose (kWh/k gal)	Ozone (lb/kgal)	No. of 30 kW lamps	Ozone (lb/day)
1	9	2,4,8	CO	3	26	16.8	TNB	115.1	330.9	208.3	12.3	23	883
2	9	4,8	CO	2	25	11.8	TNB	49.5	142.3	77.6	6.5	9	466
3	9	4,8	CO	1	18	8.2	TNB	31.1	89.4	39.7	5.0	5	358
4	9	4,8	CO	0	12	na	TNT	39.4	113.3	0	11.3	0	816
5	9	2,4,8	CC	3	26	17.1	TNB	122.1	351.3	221.2	13.0	24	937
6	9	2	CO	3	20	22.3	TNB	101.0	290.4	199.7	9.1	22	654
7	11	2	CO	3	43	10.4	TNB	32.8	94.3	47.2	4.7	6	340
8	12	2	CO	3	45	10.0	TNB	21.7	62.4	31.2	3.1	4	225

by Solarchem. The objective of these minor process variations was to minimize the energy consumption while still maintaining the minimum treatment requirements. However, the sample turnaround time and real time variations in feed characteristics made this type of fine tuning difficult. In the final week of the demonstration, process conditions were maintained constant. Table 3 summarizes the operating conditions employed during the demonstration program.

Table 3: Process Conditions during Demonstration Program

	Flow (gpm)	No. of lamps on	pH	UV Dose kWh/kgal	Ozone Consumed lb/kgal	UV/O3 Ratio kWh/lb
Week 1	1 - 2.5	1 - 2	12	7 - 33	2.9 - 5	2.4 - 6.6
Week 2	1.2 - 2	1 - 2	12	7 - 15	2.4 - 5.0	2.9 - 4.2
Week 3	1.5	1	12	11	3.2 - 3.7	3.3
AVERAGE	1.6	---	12	13.3	3.14	4.2

4.4.2. Treatment of TNT and TNB

The performance of the pilot plant in terms of TNT and TNB destruction is presented in the Appendix and summarized in Table 4. Other ordnance compounds were reduced to below discharge limits in all the effluent samples.

Table 4: Destruction removal efficiency for TNB and TNT during the pilot plant demonstration (Weston Analytical Data)

		Range	Average
TNB	Influent, ppb	430 - 1100	626
	Effluent, ppb	ND - 150	9.7
	% Removal	80.3 - 99.9	98.5
TNT	Influent, ppb	530-1500	774
	Effluent, ppb	ND-110	17.5
	% Removal	85.3 - 99.9	97.6

The analytical results indicate that the operating conditions selected for the demonstration program were not suitable to ensure adequate treatment of the TNB and TNT throughout the demonstration program. This result was not anticipated in the optimization tests and merits further discussion.

A review of the daily analytical results can provide additional insight into the pilot plant performance. There is some noticeable trend towards improved treatment of both TNT and TNB over the course of the day, even in those cases when the contaminant levels in the influent water increased. One

explanation for this would be that untreated or partially treated water may be discharged to the effluent tank at system start-up. If so, more consistent and improved treatment performance could be expected from a UV oxidation system in continuos operation.

The effect of operating the pilot plant at a low flowrate and with a low UV dose also should be considered. At the rated flow rate of 10 gpm, the pilot plant is designed to operate as a plug flow reactor with the levels of TNT and TNB decreasing up the length of the tower. At low flowrates, the system may operate instead as a stirred tank where the inlet water would mix rapidly with the treated water. In this scenario, the groundwater would be at a constant and somewhat diluted concentration throughout the 27 gallon reactor.

During the pilot demonstration program, the top two UV lamps were normally shut off so that only the water in the bottom third on the reactor was treated by UV light as well as ozone. If the reactor operated as a stirred tank, much of the inlet water would effectively bypass the UV light and be treated by ozone alone. The fact that TNT rather than TNB was found to be the limiting compound during most of the pilot plant demonstration, tends to confirm the theory that much of the treatment was by ozone alone.

One objective of the pilot plant demonstration was to determine if treatment performance can be maintained over long term operation. To examine this effect, the destruction removal efficiency for TNT and TNB is plotted against run time in Figure 6. In general, removal efficiency of both TNT and TNB remained above 95% throughout the testing. Several incidents of poor treatment were observed which did not correlate strongly to either influent concentration levels or operating conditions (in terms of total power consumption). These may represent natural variations in treatment performance or reflect the non-steady state operation of the pilot plant over the demonstration performance. The fact that performance fluctuations were most commonly observed early in the day and on the first day of the test week supports the latter assumption.

4.4.3. Effluent pH levels

The effluent pH level varied widely during the demonstration study due to pilot plant limitations. In the first week of the study, the pH of the treated water was reduced by manually adding measured doses of acid to the effluent tank. Muriatic acid (35% HCl) was used for the first two days of the study then replaced with 98% sulphuric acid. In daily titration tests, dosage rates of approx. 10 mL muriatic acid or 3.3 mL sulphuric acid per gallon of water were found to be effective for reducing the pH in the treated groundwater from 12 to 7. However, when the acid was batch dosed into the effluent tank, poor mixing resulted in discharge pH values varying widely with time (pH 2 to 12)

In the second week of the study, a metering pump was obtained and acid was continuously dosed at the inlet side of the discharge tank. Despite this modification, pH excursions still occurred in the last two weeks of the demonstration. These were associated with poor mixing (due to low process flow rates) and with lack of pH process control (metering pump was manually adjusted based on periodic measurement of discharge pH).

4.4.4. Energy Efficiency

Table 5 shows the calculated energy efficiency for each day of the demonstration study. These values are based on totalized flow and metered power over the eight hour test period. The power consumed for ozone generation represented roughly 75% of the total power consumed. It is therefore important to note several inefficiencies associated with ozone production and uptake in this pilot plant study.

Table 5 : Measured Pilot Plant Energy Efficiency

Run Day	Volume Treated (gal)	Total Metered Power (kWh)	Efficiency (gal/kWh)
1	377	90	4.2
2	953	104	9.2
3	979	101	9.7
4	1033	93	11.1
5	849	94	9.0
6	824	96	8.6
7	776	96	8.1
8	700	100	7.0
9	465	96	4.8
10	493	80	6.2
11	522	90	5.8
12	440	74	5.9
13	650	94	6.9
14	607	96	6.3
AVE.	691	93	7.4

First, when operated at 100 % output, the PCI G21 ozone generator is designed to use 210 kWh /day and to produce 21 lb/day of ozone. During the pilot plant demonstration study, the ozone generator was operated between 96 and 100% output and therefore consumed 204 kWh/day or approx. 68 kWh of power over the course of an eight hour run. However, the average ozone output from the unit was only 16 lb/day rather than 21. This operational inefficiency was associated with a low flow rate due to back pressure on the ozone line caused by fouling of the ozone sparger. The sparger employed a fine stainless steel mesh which may have been fouled by in-house testing prior to shipment of the pilot plant or by residual water left in the unit during

shipment. This problem is remedied in the full scale Solarchem UV/Ozone unit by the use of a stainless steel sparger with larger ports that are highly resistant to plugging or fouling.

Ozone consumption in the UV/Ozone reactor is also an important element in the overall energy efficiency of the system. The average ozone uptake during the pilot plant demonstration was approx. 45%. However, full scale system designs allow for 95% ozone uptake.

Because of the inefficiencies described above, the energy requirements for a full scale system will be calculated from the ozone consumption data rather than scaled up from measured pilot plant energy efficiency.

4.4.5. Maintenance Requirements

The Solarchem UV/Ozone pilot plant was operational throughout the pilot plant demonstration program and required minimal operator attention over most of the study. Cleaning of the quartz tubes was not required over the three week test period because the transmittance controllers operated automatically to remove scale from the tubes.

Problems noted upon commissioning the unit at the field site included reduced air flow through the ozone generator and a leaking seal on the discharge pump.

Plugging and fouling of the ozone sparger was apparent immediately upon start up and resulted in reduced air flow (approx. 220 cfh versus maximum of 600 cfh) through the ozone generator with reduced electrical efficiency. A slight decline in air flow down to 170 cfh was also observed during the course of the demonstration program so that on the eighth day of the demonstration, an acid cleaning of the sparger was conducted to restore the initial air flow rate. This involved draining the reactor, adding 10 litres of water adjusted to pH 2 and blowing air through the sparger for 10 to 15 minutes. A second acid wash was performed on Day 13 of the study in order to maintain adequate air flow through the ozone generator. This procedure would not be cited as a regular maintenance requirement in the full scale system because of the use of a different sparger design. However, some requirement for cleaning of the sparger may be encountered over long term full scale operations.

Because of the leak at the discharge pump, the pump was operated manually and a bucket was used to contain any spills. After the first week of the demonstration study, this problem was solved by installing new seals in the pump.

4.4.6. Chemical Addition

The required dosage of 50% sodium hydroxide to adjust the groundwater to pH 12 was approx. 1.5 ml/L or 13 ml/gallon. Concentrated sulphuric acid was dosed at 0.8 ml/L (3.5 ml/gallon) to reduce the pH of the treated groundwater to approx. 7.

Addition of caustic to the influent groundwater via a metering pump was complicated in the last week of the study by cold ambient temperatures. Ice formation in the reagent lines and metering pump fittings as well as increased viscosity of the sodium hydroxide interfered with successful caustic metering at system start-up. These problems were resolved by recirculating water through the pump overnight to keep the lines and fittings clear. The requirement to add acid to meet discharge requirements for groundwater pH also introduced some operating difficulties. These were, for the most part, associated with limitations of the pilot plant design, and have been discussed previously. Reagent dosing and pH control are standard feature of Solarchem's installations and have not been problematic in full scale operation.

4.4.7. Scale up of Test Program Results

In scaling up from pilot scale results to a full-scale design, the EE/O value is calculated. Contaminant EE/O values from the pilot plant demonstration study were calculated based on Weston analytical data and are listed in Table 6, along with lamp and ozone requirements for a 50 gpm full scale system. These calculations are based on the treatment of both TNT and TNB from 1500 ppb to 2 ppb.

Based on the pilot scale data averaged over the 14 day study, a system using three 30 kW lamps and 436 lb/day of ozone would be required for a 50 GPM application.

4.4.8. Correlation to Optimization Test Results

From the optimization test program, the energy requirement for a full scale system was calculated to be 62 kWh/kgal. At a UV/Ozone ratio of 10, this corresponded to a requirement for 4 UV lamps and 225 lb/day of ozone.

The performance of the pilot plant during the demonstration program was less efficient than expected based on the optimization tests. Based on the demonstration program, the total power required for a full scale system would be 86 kWh/kgal corresponding to 3 UV lamps and 436 lb/day of ozone. Low flow of the pilot plant as well as non-continuous operation have been discussed as possible causes for relatively poor treatment and high ozone

Table 6: Process Descriptions and Scale Up Data from Demonstration Test Program

Day	Average Daily Process Conditions							Scale Up Data		Requirements for Full Scale 50 GPM System				
	pH	Flow rate (gpm)	Flow pattern	No. of lamps on	Ozone Uptake (% of fed ozone)	UV/O3 ratio (kWh/lb)	Total Power Used (kWh/ kgal)	Limiting Compound	Overall EE/O	Total Power Req'd (kWh/ kgal)	UV Dose (kWh/ kgal)	Ozone (lb/kgal)	No. of 30 kW lamps required	Ozone required (lb/day)
1	12	1	CO	2	45	6.6	83.3	TNB	82.2	236.3	94.0	14.2	11	1025
2	12	2-2.5	CO	1-3	44	6.7	40	TNT	22.2	63.8	25.6	3.8	3	275
3	12	2.5	CO	1-2	59	3.6	39.5	TNB	18.3	52.6	13.9	3.9	2	279
4	12	2-2.5	CO	1	59	2.4	36	TNT	27	77.6	15	6.3	2	451
5	12	2	CO	1	43	3.3	32	TNB	26.1	75.0	18.6	5.6	2	406
6	12	2	CO	1	43	3.3	32	TNT	24	66.8	16.6	5.0	2	361
7	12	2	CO	1-2	45	5	37.5	TNT	24.8	71.3	23.8	4.8	3	342
8	12	1.5-2	CO	1-2	38	7.8	44.5	TNT	25.5	73.3	32.1	4.1	4	297
9	12	1.2	CO	1-2	38	4.2	51	TNT	22.2	63.8	18.9	4.5	2	323
10	12	1.5	CO	1	45	3.3	44	TNT	36.3	104.4	25.9	7.9	3	565
11	12	1.5	CO	1	43	3.4	43	TNT	29.3	84.2	21.4	6.3	3	452
12	12	1.5	CO	1	50	3.0	48	TNT	26.9	77.3	17.8	6.0	2	428
13	12	1.5	CO	1	43	3.4	43	TNT	25.2	72.5	18.4	5.4	2	389
14	12	1.5	CO	1	45	3.3	44	TNT	28.3	81.4	20.2	6.1	3	441
AVE	12	1.6	CO	---	46	4.2	44.1	---	29.9	85.9	25.4	6.0	3	436

system, the treatment efficiency would correspond to or exceed the best case from the optimization program. The use of four (4) 30 kW UV lamps in combination with 225 lb/day of ozone is therefore recommended for a full scale system to treat TNT and TNB contaminated groundwater at the Savanna site.

5. FULL SCALE DESIGN

The full scale design is based on treatment of 50 gpm groundwater to reduce levels of both TNT and TNB from 1500 ppb to 2 ppb.

The full scale UV/Ozone system would comprise of two UV/Ozone reactor towers each containing two 30 kW UV lamps. A total of 225 lb/day ozone would be required for treatment. Assuming 95% ozone uptake in the reactor towers, a total of 237 lb/day ozone would be fed into the system.

5.1. Rayox® System

A process flow diagram of the UV/Ozone Oxidation system is illustrated in Drawing 432-OZ-500022

The system is designed to reduce TNT and TNB from levels of 1500 ppb to 2 ppb at a flowrate of 50 gpm.

The groundwater pH is adjusted to 12 by addition of caustic soda upstream of the UV/Ozone reactor tower. The pretreated groundwater is fed at a rate of 50 GPM into the first UV/Ozone reactor tower. Partially treated water from the first reactor is then fed into the second reactor. Ozone is injected into the second reactor through a sparger at a rate of 237 lb/day (3.3 lb/kgal). Offgas containing unreacted ozone is then compressed by a liquid ring compressor and fed into the first reactor.

The ordnance compounds are destroyed by the combination of UV light and ozone and the treated water is discharged from the second reactor. Sulphuric acid is injected and mixed into the effluent line to reduce the pH to discharge levels.

Each UV/Ozone reactor tower contains two (2) 30 kW UV lamps, each enclosed in a quartz tube. The quartz tubes are automatically cleaned by air actuated wipers (transmittance controllers).

Air for ozone generation and wiper operation is compressed by a rotary air compressor and dried by a dessicant air dryer. The clean dry air is fed to the ozone generator at a rate of 110 scfm. The PCI HT-230 ozone generator is rated for 230 lb/day of 2% ozone in air. A 40 ton chiller provides cooling water for the ozone generator and air compressor.

Offgas from the first reactor, containing residual unreacted ozone, is directed through a moisture trap and then to a bed of ozone destruction catalyst. The

catalyst reduces the level of ozone in the offgas to <0.1 ppm prior to discharge to the atmosphere.

Detailed system specifications are presented in the APPENDIX.

5.2. Economic Analysis

5.2.1. Capital Cost

The capital cost for the full scale system is $ 480,000.

5.2.2. Operating Cost

A breakdown of the operating costs for a flow rate of 50 gpm is shown in Table 7.

*Table 7: Operating Cost Breakdown for **Rayox®-O***

Component	Operating Costs ($/1000 gal)	Annual Costs ($/yr)
Lamp Power (at 0.06$/kWh)	$2.39	$60,228
Ozone Power (at 0.06$/kWh)	1.97	49,745
Chiller Power (at 0.06$/kWh)	0.60	15,120
Replacement UV Lamps	1.11	27,972
Acid (at $0.07/lb, 93%)	0.86	21,672
Base (at $0.10/lb, 50%)	1.90	47,880
O&M Labor (at $14.88/hr)*	0.30	7,619
Total	**$9.13**	**$230,236**

* O&M Labor is based on 4 days per month operating labor and four days per quarter maintenance and lamp replacement for a total of 64 days per year or 512 hours.

6. SYSTEM DESCRIPTION

6.1. Equipment Specification

Rayox® *UV Oxidation Towers*

Solarchem Lamps	:	Four (4) 30 kW Solarchem UV lamps
	:	Fully shielded for protection from UV light
	:	Air cooling fans on lamp ends
Transmittance Controllers	:	Automatic action for cleaning UV lamp quartz sleeve
	:	Adjustable cycle frequency via PLC
	:	Pneumatic drive
	:	Proximity switches to detect operation

Hydraulic System

Treatment Capacity	:	50 gallons per minute
Pipe Diameter	:	2" 316L stainless steel, schedule 10
Hydraulic Capacity	:	75 gallons per minute
Minimum Flowrate	:	10 gallons per minute
Materials of Construction	:	316 or 316L stainless steel, quartz, Teflon (wetted) and Viton
Sample Points	:	Before and after UV Oxidation Towers
Maximum System Pressure	:	10 psig
Pressure Loss @ 50 gpm	:	4 psi
Flow Measurement	:	One (1) Magnetic flowmeter on effluent
Skid By-Pass Valving	:	All valves and piping for hydraulic isolation of individual UV Oxidation Towers to allow partial system operation during servicing
	:	Bypass valve status indicator lights on control panel

Electrical System

Electrical Supply Required	:	480 VAC, 60 Hz, 3 Phase
	:	Running current full load 295 Amps
High Voltage System	:	Housed in a NEMA 1 ventilated and drip-proof enclosure
	:	480 VAC
	:	Four (4) x 30 kW Lamp Power Supplies

	:	480/120 VAC Transformer
	:	Transformers in the high voltage enclosure are capable of rugged long term performance Power factor better than 0.9 at full power
	:	Lamp Current and Voltage displays
Low Voltage System	:	120 VAC for cooling fans, air solenoids, and PLC
	:	24 VDC for interlock and input devices

Physical Specifications

The physical specifications for each UV Oxidation Tower are as follows:

Approximate Dimensions	:	3.6' DIA x 12.5' H UV Oxidation Tower
Required Side Clearance	:	5'
Material	:	316L Stainless Steel
Rayox® Tower Weight (Dry)	:	2500 lbs empty (each tower)
	:	10000 lbs full (each tower)

Air Preparation System

All air preparation system components are mounted on individual frames suitable for floor installation. Specifications for the air preparation system components are as follows:

System Components	:	Atlas Copco Air Compressor Model GA30-125
	:	140 CFM @ 125 psig
	:	40 hp motor capacity, Air cooled
	:	Water-cooled after cooler
	:	Anderson Industrial Model MPS-100C Air Drier
	:	Air Storage Tank Capacity 120 Gallons
Approximate Dimensions	:	3'W x 6'L x 4'H for air compressor
	:	3'W x 2L x 6'H for air drier
	:	2'DIA. x 6'H for air storage tank

Ozone Delivery System

The ozone generator is mounted on a frame suitable for floor installation. Specifications for the ozone delivery system components are as follows:

Approximate Dimensions	:	7.6'W x 11.3'L x 8.3'H for ozone generator
Ozone Generator	:	PCI Model HT230
	:	Capacity 230 lb/day of ozone (2% in air)
	:	Flowsheet ozone output 172 lb/day (2% in air)
	:	Maximum current requirement 105 amps
	:	Remote ON/OFF
	:	Rotameter
	:	Safety Interlocks
Ozone Recycle System	:	Liquid Ring Compressor
	:	Two Solenoid-actuated Shut-off Valves
	:	316L Stainless steel
Chiller	:	40 ton chiller provides cooling water requirement 80 gpm at 70 ° F

Catalytic Ozone Destruction Unit

The catalytic ozone destruction unit consists of a Demister Heater and Catalyst Chamber above the UV Oxidation Towers. Specifications for the catalytic ozone destruction unit components are as follows:

Demister	:	Removes fine water droplets
	:	Stainless steel wool demister pad
Heater	:	Electric heater element
	:	Raises temperature above dew point
	:	Includes variable potentiometer for manual control
Approximate Dimensions	:	20"W x 30"L x 40"H
Catalytic Ozone Destruction unit	:	Capacity 110 SCFM Air (2% Ozone)
	:	316 SS Construction
	:	Removable lid for maintenance

Regulatory Compliance

- Certified by CSA, an OSHA accredited Nationally Recognized Testing Laboratory (NRTL)
- Conforms to NFPA National Electric Code (NEC)

6.2. Process Control Specification

The ultraviolet oxidation treatment system operates under the control of a local PLC. The main functions of the PLC software are to control the process, monitor the system status and alert the operator to any fault conditions. The system is failsafe for operator and equipment safety. Alarm and status messages are displayed on the alphanumeric message annunciator on the control panel. A modem will be incorporated to enable remote diagnostics and reprogramming of the PLC as required. Control system specifications are as follows:

Control System

Control Panel	:	NEMA 12 Enclosure
	:	Local System Start/Stop buttons
	:	Lamp selector switches
	:	Digital display flow, temperature, and level indicators
	:	Alphanumeric fault and system status display
Programmable Logic Controller	:	Siemens (TI) Model TI-545
	:	Battery back-up in the event of power failure
	:	Programmed to ensure safe, controlled shutdown
Dial-up Modem	:	Allows remote monitoring, diagnosis

Fail-safe Operation

Flow	:	Alarm and/or automatic system shutdown on effluent flowrate out of range
	:	Alarm and shutdown on leak detection
Ozone Generator	:	Alarm on high dew point

	:	Alarm on panel door open
	:	Alarm on low cooling water flow
	:	Alarm on high ozone temperature leaving generator
	:	Alarm on low air flow
	:	Alarm on air pressure
	:	Alarm on inverter failure
UV Oxidation Towers	:	Alarm and shutdown on lamp failure (each lamp)
	:	Alarm on high water level
	:	Alarm and shutdown on extra high water level
	:	Alarm and shutdown on lamp cooling fan failure
	:	Power interlock on HV cabinet doors
	:	Alarm and shutdown on UV access covers
Air Preparation System	:	Alarm and shutdown on low air pressure
	:	alarm and shutdown on high air dew point
Ozone Distribution System	:	Alarm and shutdown on high pressure
	:	Rupture disks provide overpressure relief on each tower
	:	Alarm on high or low temperature to catalyst bed
	:	Alarm on high temperature from catalyst bed
	:	Alarm and shutdown on high ozone discharge concentration
Transmittance Controller	:	Alarm on failure to operate Alarm on low air pressure

6.3. Equipment Layout

The floor area required for the entire system approximately 24' x 24'. The layout is made considerably more compact through the use of two, vertical UV Oxidation towers, which minimizes the total cross-sectional area needed to house the **Rayox®** system.

7. KEY FEATURES OF RAYOX® SYSTEM

Solarchem **Rayox®** UV/Oxidation systems represent second generation technology which is unique in the market. The key state of the art improvements inherent in second generation systems include:

- Higher Power UV Lamps

Each Solarchem UV lamp has a power of 30 kW. This is in contrast to a first generation system using **thousands** of low power, low pressure mercury arc lamps. The labor requirements to change thousands of lamps would be significantly higher, resulting in a much higher overall cost if Net Present Value included labor cost.

Another advantage of Solarchem lamps is the spectrum of UV output. Destruction of TNT and RDX with UV/oxidation occurs by both photolysis and hydroxyl radical attack. Therefore, it is critical for the UV lamp to have maximum energy output in the wavelengths where the explosive compounds strongly absorb light, below 240 nm. Solarchem UV lamps have far greater output below this wavelength than any other commercially available UV lamp, and exhibit an energy efficiency in excess of 30% between 200 nm and 300 nm. This means that photolysis occurs more efficiently, so a lower lamp power is required, lowering operating costs.

- Automatic Quartz Cleaning

Each **Rayox®** reactor has a mechanical cleaner for each quartz sleeve surrounding the UV lamp. This is not available or possible in systems with thousands of low power lamps. This cleaning is important to prevent fouling due to dissolved metals such as ferrous ions. In addition, small amounts of scale are produced due to the oxidation of organic chemicals to carbonate. The wiper is driven by an air-actuated piston with the automatic operation controlled and monitored by the PLC. This continual cleaning ensures that treatment system is at peak performance (no UV blockage from fouling) and is therefore meeting the treatment specification. It makes shutdown for manual cleaning of quartz unnecessary, resulting in reduced maintenance labor and cost. Automatic quartz cleaners have been included in every system Solarchem has built.

- Efficient Power Supplies

Solarchem power supplies (ballasts) have a 92% conversion efficiency. This means that a lamp power of 26,500 watts actually uses 28,800 watts of electricity.

This is important because actual power draw determines the real cost for electricity. This 92% efficiency is much higher than the 75% which is typical of low pressure mercury arcs. This is to say a 65 W low pressure lamp may actually use 87 W of electricity. The improved efficiency of the Solarchem power supply means actual operating costs for electricity are reduced.

Another advantage of the power supply is Power Factor Correction to a PF> 0.92, so no penalties from the utility are incurred. Also, the PLC has direct control over voltage and current to ensure constant lamp power and therefore UV output.

- Compact, Simple Design

A system with high power UV lamps will be significantly less complex, with less components than one with thousands of lamps. This will result in better Availability, Reliability, and Maintainability (ARM). Also, the building size for the **Rayox®** system will be much smaller than for a system with thousands of lamps. A smaller building will mean lower overall project costs.

- Programmable Logic Controller

Solarchem has used PLC control on every system we have installed. Approximately one half of Solarchem's installed PLC's interface directly with plant controllers, and we are confident that the DCS interface proposed for this project will be implemented without difficulty. Solarchem's PLC will allow easy operator interface, with error messages displayed on an alphanumeric display panel.

These features demonstrate why the **Rayox®** system proposed represents the state-of-the-art in UV/Oxidation destruction of water-borne contaminants.

APPENDIX

Effect of UV/Ozone Ratio on TNT and TNB Destruction

Run 1: UV/Ozone Ratio of 17 kWh/lb at pH 9 with cocurrent flow

UV Dose kWh/kgal	Ozone Dose kWh/kgal	Ozone consumed kWh/kgal	Total Power Consumed kWh/kgal	TNT ppb	TNB ppb
0	0	0	0	700	1000
6	14	3.7	9.7	438	747
12.5	28	7.4	19.8	220	530
25	56	14.9	39.6	140	453

Run 2: UV/Ozone Ratio of 12 kWh/lb at pH 9 with cocurrent flow

UV Dose kWh/kgal	Ozone Dose kWh/kgal	Ozone consumed kWh/kgal	Total Power Consumed kWh/kgal	TNT ppb	TNB ppb
0	0	0	0	700	1000
4	14	3.4	7.4	500	709
8	28	6.9	14.9	-	-

Run 3: UV/Ozone Ratio of 8 kWh/lb at pH 9 with cocurrent flow

UV Dose kWh/kgal	Ozone Dose kWh/kgal	Ozone consumed kWh/kgal	Total Power Consumed kWh/kgal	TNT ppb	TNB ppb
0	0	0	0	700	1000
2	14	2.5	4.5	590	732
4	28	4.9	8.9	278	517

Run 4: Ozone only at pH 9 with cocurrent flow

UV Dose kWh/kgal	Ozone Dose kWh/kgal	Ozone consumed kWh/kgal	Total Power Consumed kWh/kgal	TNT ppb	TNB ppb
0	0	0	0	700	1000
0	14	1.7	1.7	682	738
0	28	3.4	3.4	574	513

Effect of Flow Configuration on TNT and TNB Destruction

Run 1: Cocurrent flow test at UV/Ozone ratio of 17 kWh/lb and pH 9

UV Dose kWh/kgal	Ozone Dose kWh/kgal	Ozone consumed kWh/kgal	Total Power Consumed kWh/kgal	TNT ppb	TNB ppb
0	0	0	0	700	1000
6	14	3.7	9.7	438	747
12.5	28	7.4	19.8	220	530
25	56	14.9	39.6	140	453

Run 5: Counter current flow test at UV/Ozone ratio of 17 kWh/lb and pH 9

UV Dose kWh/kgal	Ozone Dose kWh/kgal	Ozone consumed kWh/kgal	Total Power Consumed kWh/kgal	TNT ppb	TNB ppb
0	0	0	0	700	1000
6	14	3.6	9.6	444	775
12.5	28	7.3	19.8	285	668
25	56	14.6	39.6	204	474

Effect of pH on TNT and TNB Destruction

Run 6: pH 9 test at UV/Ozone ratio of 22 kWH/lb and cocurrent flow

UV Dose kWh/kgal	Ozone Dose kWh/kgal	Ozone consumed kWh/kgal	Total Power Consumed kWh/kgal	TNT ppb	TNB ppb
0	0	0	0	700	1000
25	56	11.2	36	146	440

Run 7: pH 11 test at UV/Ozone ratio of 10 kWh/lb and cocurrent flow

UV Dose kWh/kgal	Ozone Dose kWh/kgal	Ozone consumed kWh/kgal	Total Power Consumed kWh/kgal	TNT ppb	TNB ppb
0	0	0	0	700	1000
25	56	24	49	< 5	32

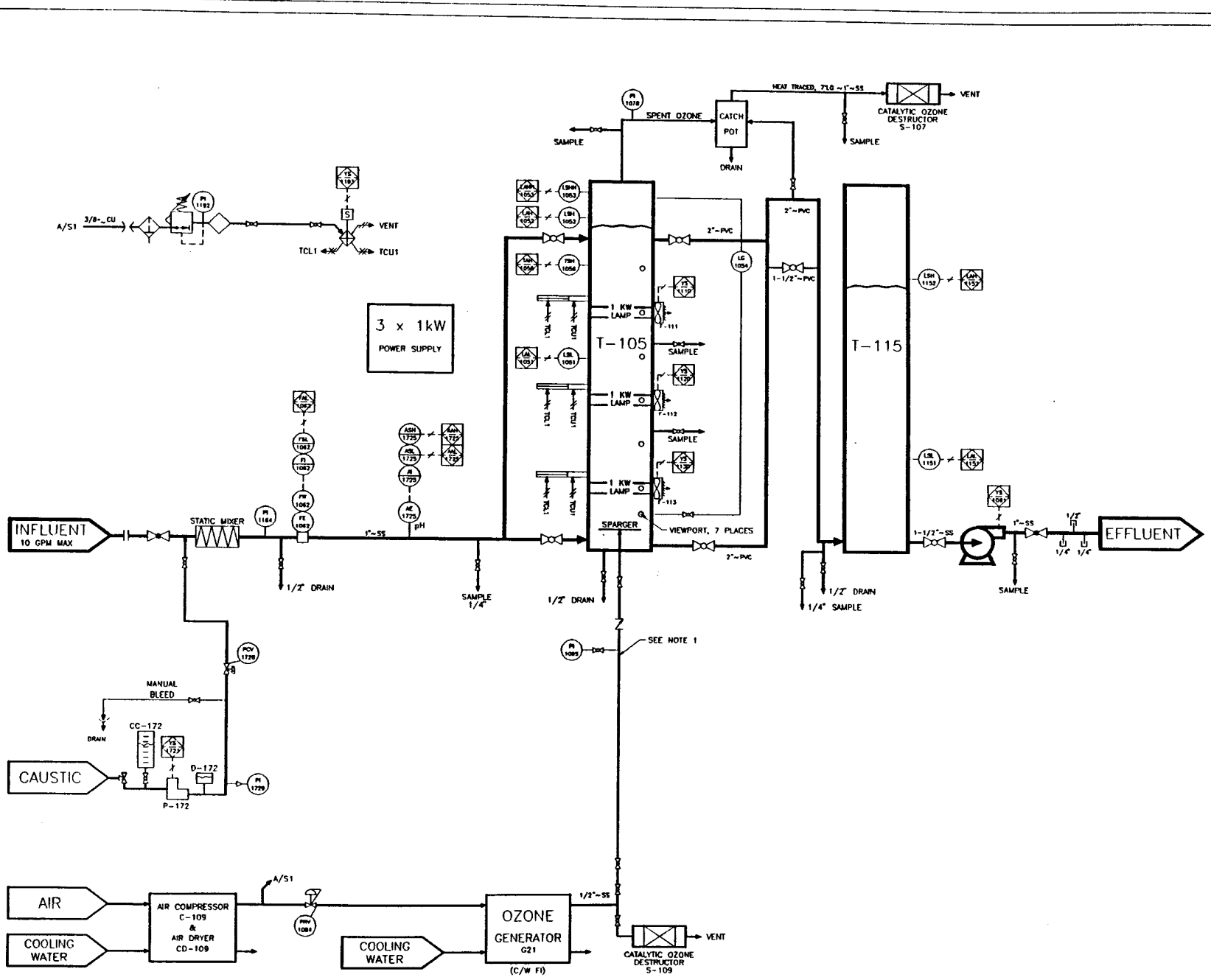
Run 8: pH 12 test at UV/Ozone ratio of 10 kWh/lb and cocurrent flow

UV Dose kWh/kgal	Ozone Dose kWh/kgal	Ozone consumed kWh/kgal	Total Power Consumed kWh/kgal	TNT ppb	TNB ppb
0	0	0	0	700	1000
25	56	25	50	< 5	< 5

Destruction Removal Efficiency for TNB and TNT from Pilot Plant Demonstration

Day#	Date	Time	TNB, ppb			TNT, ppb		
			Inf.	Eff.	% removal	Inf.	Eff.	% removal
1	Sept. 27	1210	550	34	93.8	750	ND(<0.76)	99.9
		na	na	6.5	na	na	ND (<0.98)	na
		1803	760	150	80.3	970	1.4	99.9
2	Sept. 28	1016	730	17	97.7	940	23	97.6
		1330	1100	7.8	99.3	1500	2.2	99.9
		1545	640	4.6	99.3	830	26	96.9
3	Sept. 29	1000	650	11	98.3	840	ND (<0.76)	99.9
		1317	750	2.3	99.7	920	5.4	99.4
		1620	740	1.7	99.8	910	ND (<0.66)	99.9
4	Sept. 30	1010	730	9.9	98.6	990	0.6	99.9
		1249	730	ND (<0.88)	99.9	900	ND (<0.88)	99.9
		1515	730	1.4	99.8	870	ND (<0.88)	99.9
5	Oct. 3	959	610	91	85.1	750	110	85.3
		1325	460	0.9	99.8	560	0.71	99.9
		1610	500	1.7	99.7	600	ND (<0.44)	99.9
6	Oct. 4	910	610	21	96.6	750	48	93.6
		1210	620	ND (<0.91)	99.9	770	32	95.8
		1440	620	ND (<0.84)	99.9	760	26	96.6
7	Oct. 5	953	610	4.8	99.2	740	32	95.7
		1250	660	1	99.8	820	23	97.2
		1505	670	ND (<0.78)	99.9	810	18	97.8
8	Oct. 6	955	650	2.9	99.6	800	18	97.8
		1210	650	ND (<0.78)	99.9	790	15	98.1
		1500	650	ND (<0.78)	99.9	790	9.6	98.8
9	Oct. 7	845	590	9.3	98.4	690	8.9	98.7
		1130	590	ND (<0.78)	99.9	700	ND (<0.78)	99.9
		1355	590	ND (<0.78)	99.9	680	ND (<0.78)	99.9
10	Oct. 10	1100	610	2.5	99.6	720	90	87.5
		1330	520	1.4	99.7	690	19	97.2
		1530	560	3.2	99.4	700	21	97.0
11	Oct. 11	1010	560	2.2	99.6	690	29	95.8
		1355	550	ND (<0.78)	99.9	670	22	96.7
		1545	600	ND (<0.78)	99.9	700	19	97.3
12	Oct. 12	1050	430	3.5	99.2	530	21	96.0
		1345	590	1.2	99.8	690	ND (<0.78)	99.9
		1600	590	ND (<0.78)	99.9	670	9.5	98.6
13	Oct. 13	1120	570	0.97	99.8	680	12	98.2
		1435	560	ND (<0.78)	99.9	690	17	97.5
		1435	560	ND (<0.78)	99.9	670	11	98.4
14	Oct. 14	1030	560	ND (<0.78)	99.9	670	24	96.4
		1315	550	ND (<0.78)	99.9	680	19	97.2
		1445	540	ND (<0.78)	99.9	660	13	98.0
AVE.			622.2	9.7	98.5	769.3	17.5	97.6

FIGURE 1 -- PILOT SCALE SYSTEM SCHEMATIC PROCESS FLOW DIAGRAM



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REVISIONS

REV	DESCRIPTION	DATE	APPVD
A			
B			
C			
D			
E			

NOTES

1. OZONE SUPPLY LINE MUST BE RUN ABOVE TOP OF TOWER.

FINISH

MATERIAL

DIMENSIONS IN INCHES (unless otherwise specified)

TOLERANCES (unless otherwise specified)

ANGULAR	±0°30'	DECIMAL 2 PLACES	± .010
FRACTIONAL	± 1/32	DECIMAL 3 PLACES	± .005
DECIMAL 1 PLACE	± .015	DECIMAL 4 PLACES	± .0005

Solarchem
7320 SMOKE RANCH RD
LAS VEGAS, NEVADA
U.S.A. 89128
130 ROYAL CREST CT
MARKHAM, ONTARIO
CANADA L3R 0A1

	NAME	SIGN.	DATE
DRAFT.	T. D. R.		24 Aug/94
DESIGN			
CHECK	S. P.		
APPR.			

TITLE: P. & I. D.

SHEET No.: SHEET 1 OF 1 — SCALE: NONE

DWG. No.: 446-OZ-500014 — REV

Figure 2
Effect of UV/O3 Ratio on TNB Destruction (at pH 9)

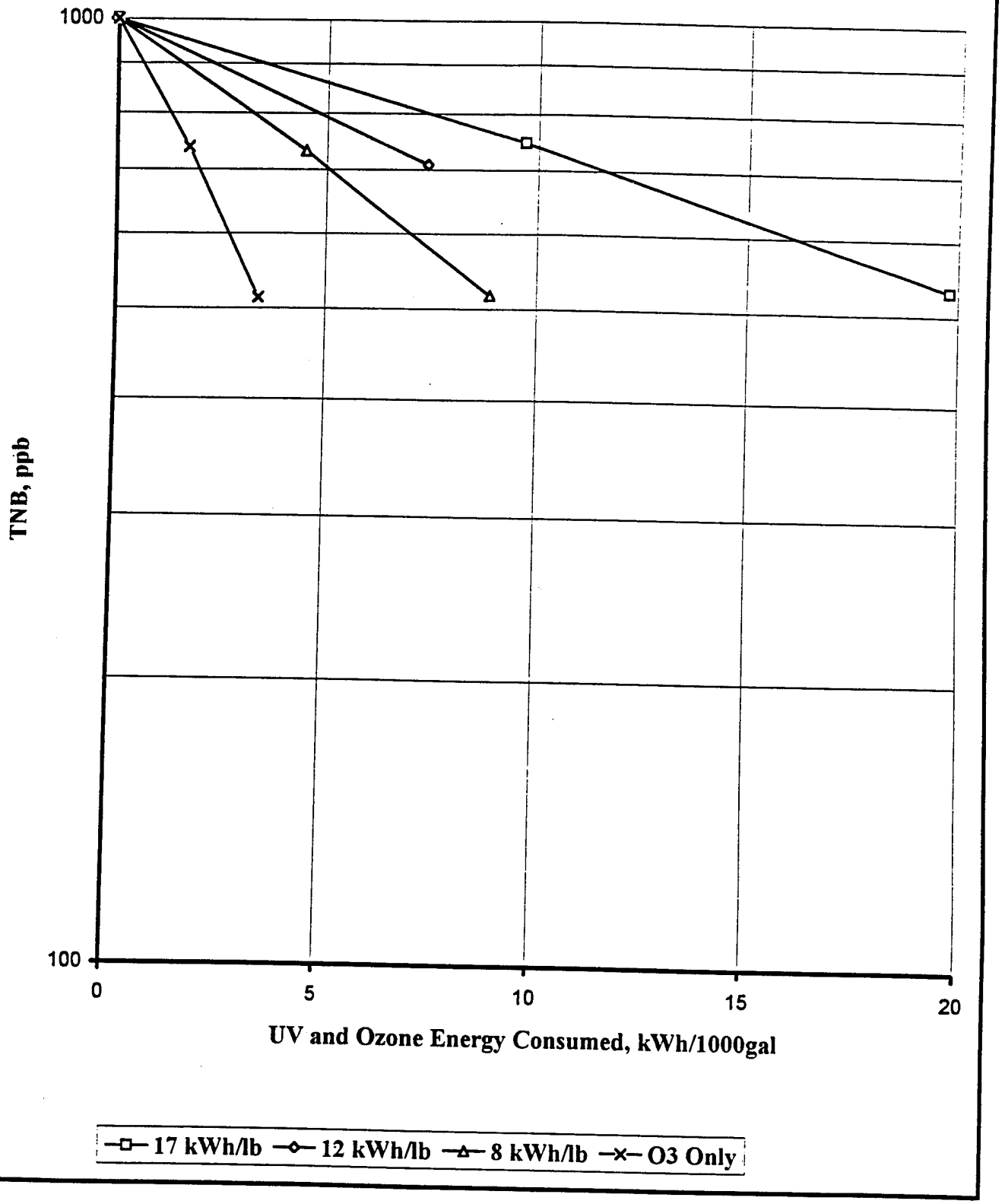


Figure 3
Effect of UV/O3 Ratio on TNT Destruction (at pH 9)

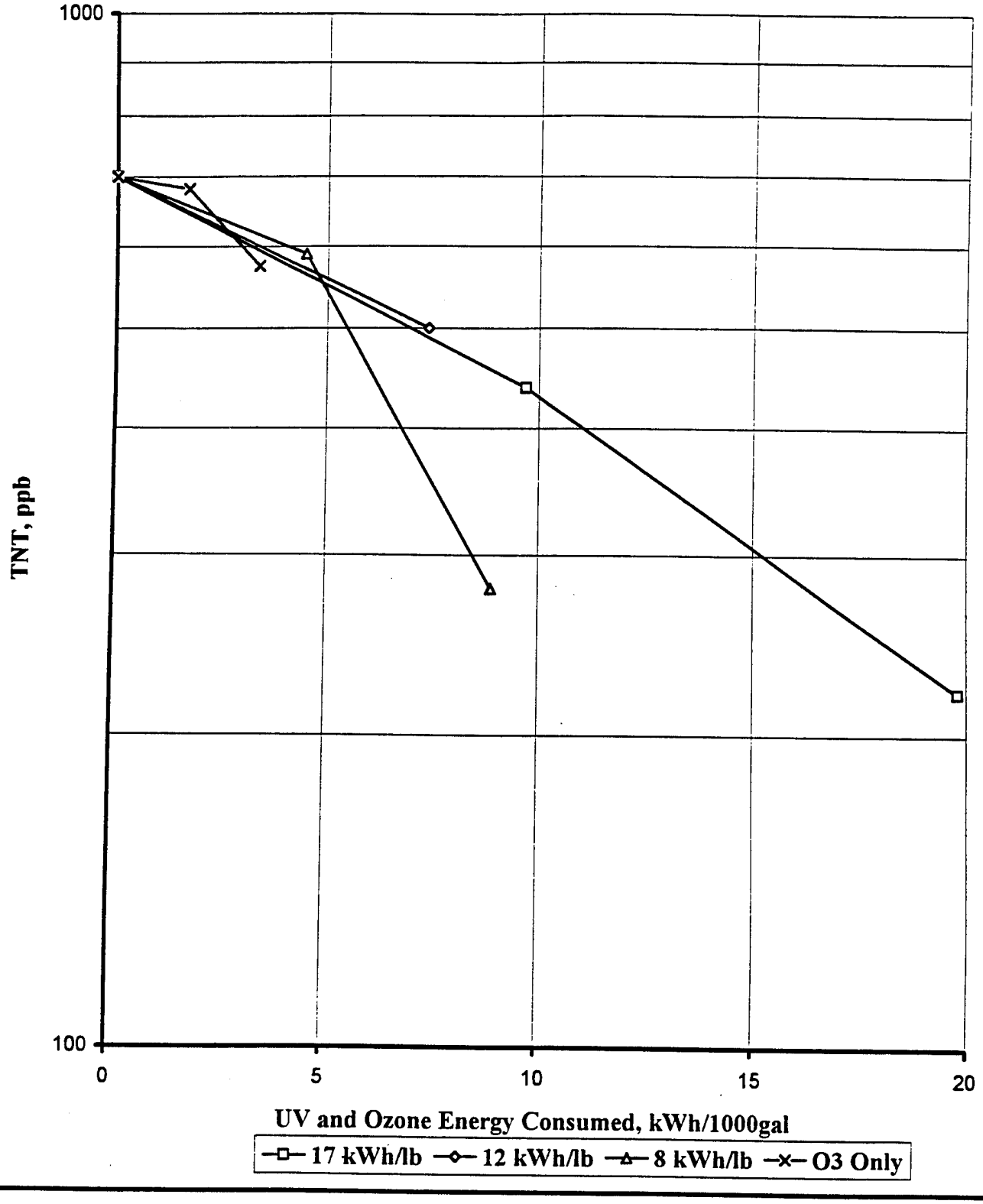


Figure 4
Effect of Flow Configuration on Treatment of TNB and TNT
(at pH 9 and UV:O3 ratio of 17 kWh/lb)

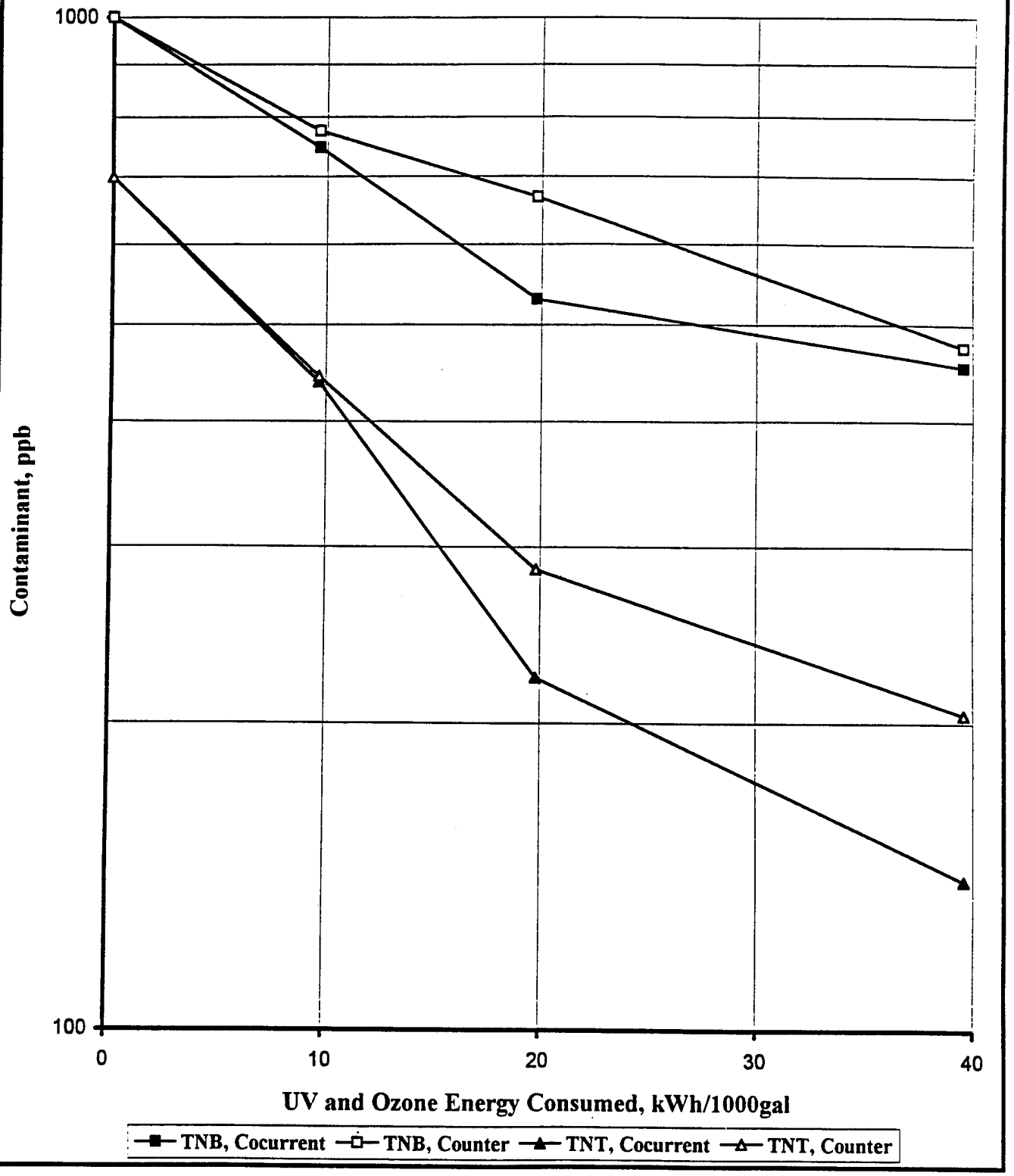


Figure 5
Effect of pH on TNB Destruction

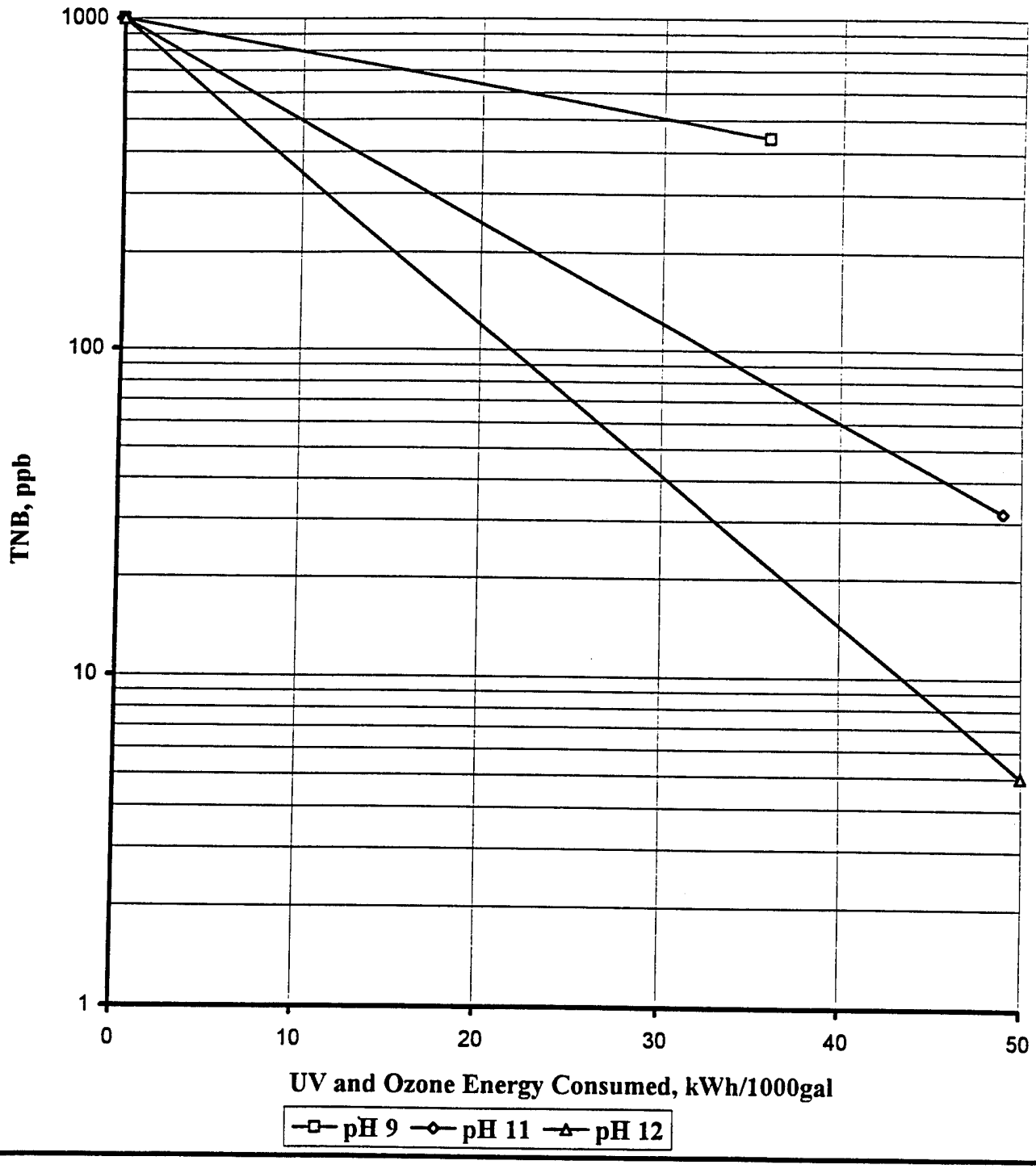


Figure 6 Destruction Removal Efficiency for TNB and TNT

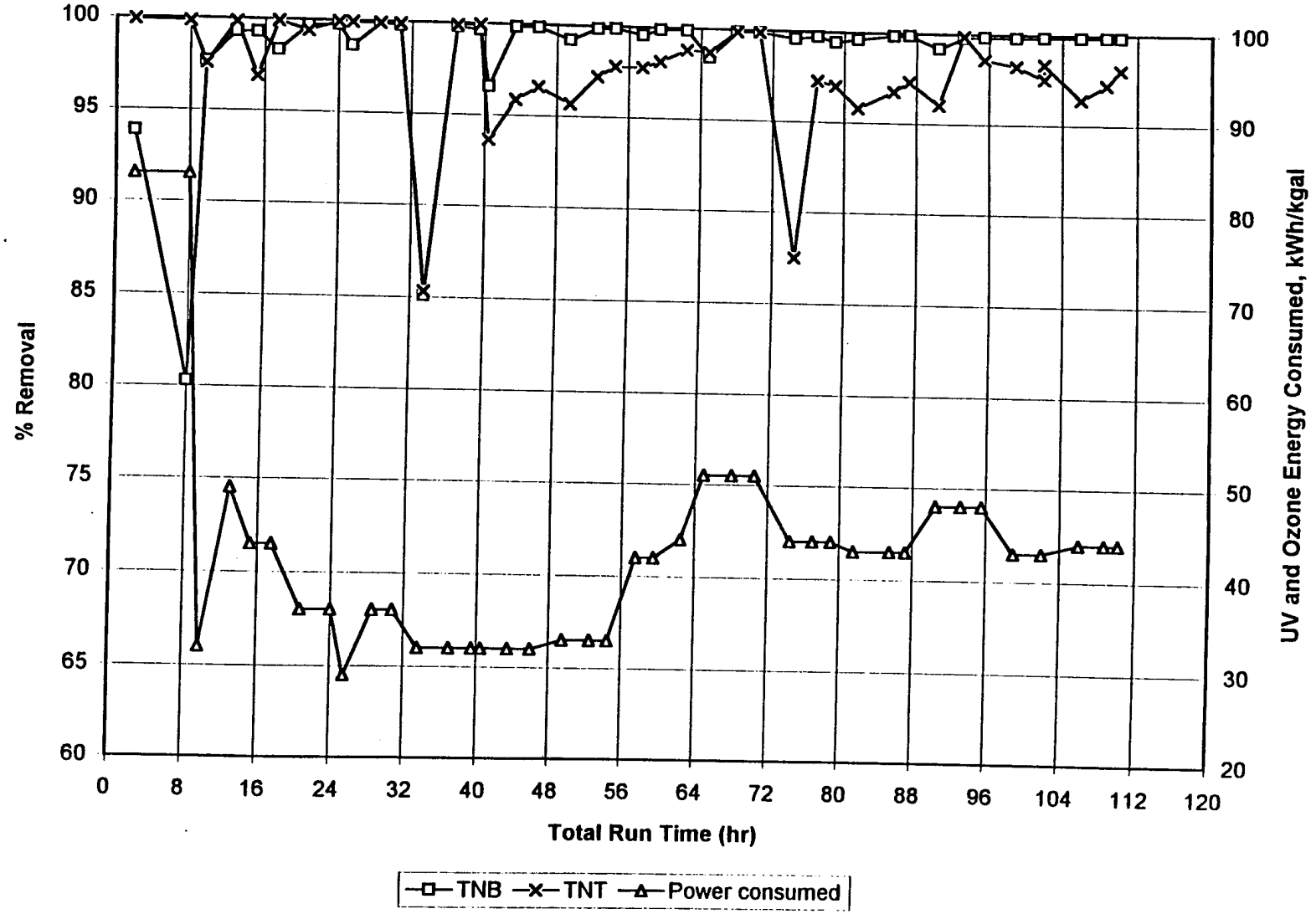
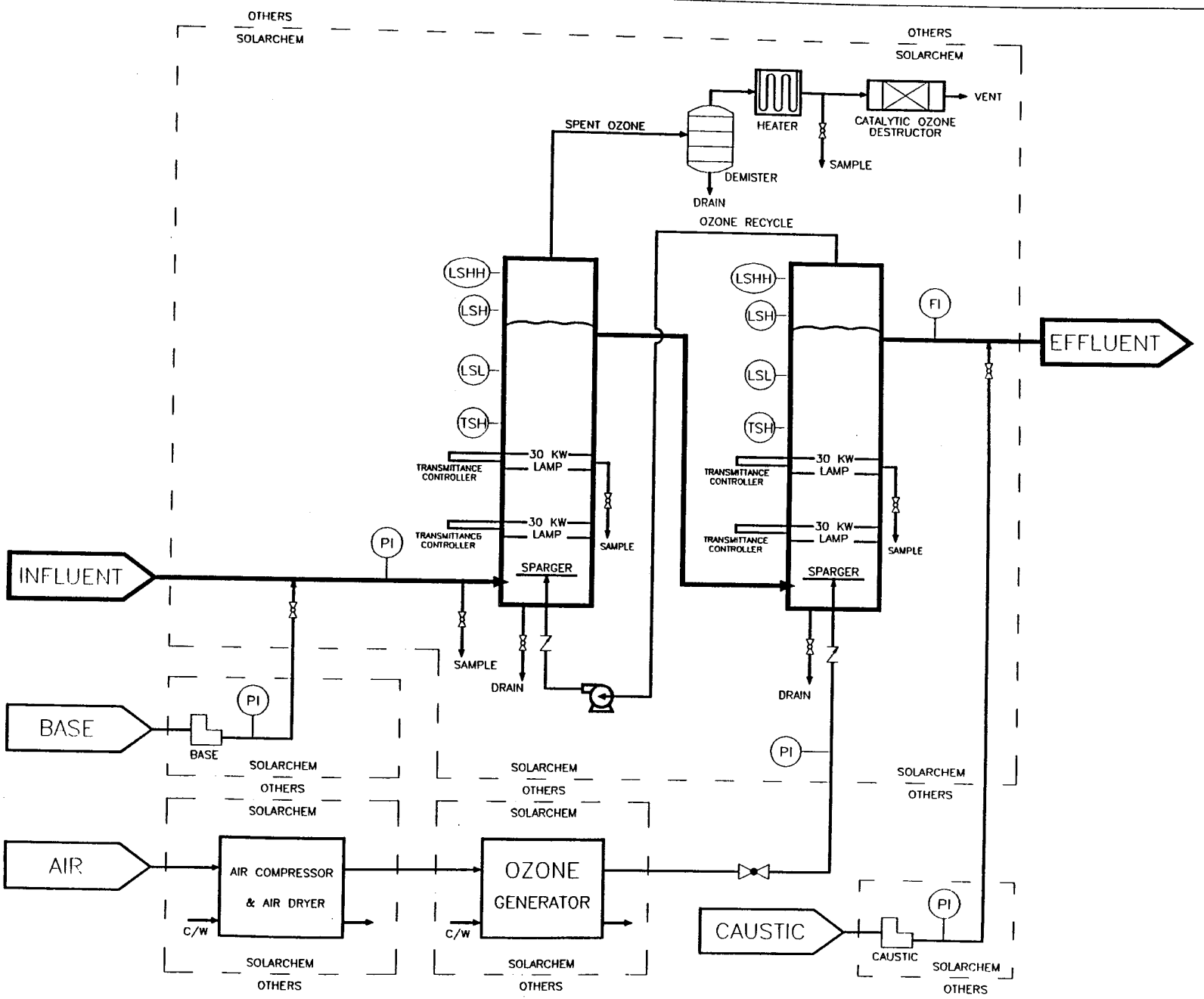


FIGURE 7 – FULL SCALE SYSTEM SCHEMATIC PROCESS FLOW DIAGRAM



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REVISIONS

REV	DESCRIPTION	DATE	APPVD
A	K. G. B.	13 Apr/94	
B			
C			
D			
E			

NOTES

FINISH

MATERIAL

DIMENSIONS IN INCHES (unless otherwise specified)

TOLERANCES (unless otherwise specified)

ANGULAR	±0°30'	DECIMAL 2 PLACES	± 010
FRACTIONAL	±1/32	DECIMAL 3 PLACES	± 005
DECIMAL 1 PLACE	± 015	DECIMAL 4 PLACES	± 0005

Solarchem
7320 SMOKE RANCH RD. LAS VEGAS, NEVADA U.S.A. 89128
130 ROYAL CREST CT. MARKHAM, ONTARIO CANADA L3R 0A1

	NAME	SIGN.	DATE
DRAFT.	T. B. R.		12 Jan/95
DESIGN			
CHECK	K. G. B.		
APPR.			

TITLE: PROCESS FLOW SCHEMATIC

SHEET No.: SHEET 1 OF 1 — SCALE: NONE

DWG. No.: 432-OZ-500022 — RFV: A1

432-OZ-500022

432-OZ-800004
SPARE PARTS FOR ONE YEAR OPERATION
OF RAYOX UV/OZONE GROUND WATER TREATMENT SYSTEM

	QTY	PART NUMBER	DESCRIPTION
UV OXIDATION CHAMBERS	2	D300195	Lamp 30Kw - short leads
	2	D300050	Quartz 30Kw
	6	350123	Seal viton O-ring reactor 30Kw
	15	350018	O-ring quartz seal 30Kw
	2	D300198	Fan cooling motor assembly with cage - 30Kw
	3	350031	Switch air flow 250 top 30 Kw
	1	350084	Cylinder, air 30Kw
	2	150025	Switch proximity transmittance controller
	1	350080	Solenoid valve (no base) 82 series
	10	D300144	Insulator quartz seal 30 Kw
	1	pkg	fuse kit for control panel TBD
	4	Z3000005	Lampholder, top
	10	D300231	Cylinder rod bushing
	10	350085	Polypak seal for cylinder
	10	350083	U-cup seal for cylinder
	1	350043	Fan, cooling for power supplies
	4	150535	Fuse 80A lamp power supply
	4	150393	Fuse 4A lamp power supply
	2	150396	Fuse 7A lamp power supply
	5	150536	Fuse 1/4A lamp power supply
	2	150394	Fuse 5A lamp power supply
	2	150561	Fuse 15A lamp power supply
FOR OZONE GENERATOR	20	X33941	Dielectric spacer
	3	HT glass	HV electrode
	6	B3000-75	HV connector
	10	A4500-2224-2	Electrode connecting link
	5	A1590-4500-5	HV fuse for HT series
	5	FG 1875	Fuse gasket
	1	C447PB	SCR
	1	A397PB	Diode
	1	SKKD 81/12	Diode bridge
	1	2100-2	Trigger board
	1	2198	Control board
	1	2227	4 SCR pulse board
	1	2224-1	Varistor board
	3	A70P150	150 amp 700 volt fuse
	2	ATQ-2	2 amp 500 vac fuse
	3	TRM-5	5 amp 250 vac fuse
R COMPRESSOR	2	2901 0046 00	Filter kit
	1	1631 6105 00	Oil filter
FOR PUMPS	4	Type 6	Mechanical Seal, John Crane
	4	TBA	Sealing Gasket

RAYOX
INSPECTION CHECKLIST

Operating Conditions

_____ Ambient temperature between 4 and 32 degrees C (41 and 90 degrees F)
_____ Relative humidity less than 95%

Air System

_____ Air pressure regulator
_____ Air / water separator and oil mister
_____ Air compressor
Air dryer dew point

Control Panel

_____ Flow reading
_____ Operating status
_____ Indicator lights
_____ Selector switch positions
_____ pH pretreatment and discharge
_____ System - discharge / recirculate

Rayox Contact Tower

_____ UV lamp installed and all connections made
_____ Cover panels / access lids fastened
_____ Air blowers ON
_____ Transmittance controller cycling
_____ Drain valve closed
_____ Sample valve closed
_____ No water leaks

Rayox Power Supply

_____ Power ON
_____ Meter readings
_____ Status indicators
_____ Fans operating

Ozone Generator

_____ Power level OK
_____ Flow rate
_____ Air pressure
_____ Dew point

Cooling Water System

_____ Chiller operation
_____ Circulating pump operation
_____ Flow rate
_____ Piping and connections secure
_____ Postioning of manual valves

Dwg. 432-RX-800009B

RAYOX
MAINTENANCE CHECKLIST

MONTHLY MAINTENANCE: Date of last session _____
Date of this session _____

A PERFORMANCE REVIEW

Power Supply/Lamps

Reactor Number	_____	_____	_____
Lamp (On / Off)	_____	_____	_____
Volts	_____	_____	_____
Amps	_____	_____	_____
kW (Calculated)	_____	_____	_____
Elapsed Hours	_____	_____	_____

Operating Parameters

Water Flow Rate		_____		
Water Temperature		_____		
Influent pH		_____		
Effluent pH		_____		
System Discharging, Recirculating, Batch		_____		
		Stroke/min	% Stroke	mL/min
Reagent Flow	Acid	_____	_____	_____
	Caustic	_____	_____	_____
Reagent Tank Level	Acid	_____		
	Caustic	_____		
Ambient Temperature		_____		
Relative Humidity		_____		

B AIR SUPPLY SYSTEM

Air Pressure	_____
Air Quality	_____
Air Compressor	_____
Oil Lubricator Level	_____
Air Dew Point	_____
Air Flow rate	_____

RAYOX
MAINTENANCE CHECKLIST

C TRANSMITTANCE CONTROLLERS

Solenoid firing at normal intervals	_____ Frequency? _____
Transmittance Controller traverses the entire Quartz Tube	_____
No unusual noise or vibration	Yes/No
Fast Cycle Mode performed	Yes/No
Test Cycle Mode performed	Yes/No

D STOP EVENTS

Stop Button

a) SYSTEM STOP Button Pushed	_____
- UV lamp OFF	_____
- Discharge valve goes to RECIRCULATE	_____
- Main pump stops	_____
- Transmittance controller stops	_____
- Reagent pumps stop	_____
- Air blowers stop after 3 minutes	_____

Emergency Stop Button

a) Push EMERGENCY STOP Button	_____
- System goes to EMERGENCY STOP, buzzer sounds, alarm message displayed	_____
- All pumps stop immediately	_____
- Lamps OFF immediately	_____
- Blowers stop immediately	_____
- All automatic valves go to "fail safe" position	_____
b) Emergency Stop Acknowledged	_____
c) EMERGENCY STOP Button Pulled Out	_____

E RAYOX CONTACT TOWER

a) Rayox Power Supply LOCKED OUT	_____
b) Remove Cover Panel(s)	_____
c) Water Leaks?	Yes/No
d) Moisture Sensor Inspected/Tested	Yes/No
e) Fan Dust Filters Cleaned (if applicable)	Yes/No
f) Quartz Tube Inspected	Yes/No
g) Quartz Seals Inspected	Yes/No
h) Ceramic Insulators Inspected	Yes/No
i) Pressure test system #psi	_____

RAYOX
MAINTENANCE CHECKLIST

F RAYOX POWER SUPPLY

Rayox Power Supply LOCKED OUT _____
Visual Inspection for dirt/dust _____

G REPAIRS _____ To Be Noted

H START-UP EVENTS

a) Re-install Cover Panel(s) _____
b) Turn ON Rayox Power Supply _____
c) SYSTEM READY Displayed at Control Panel _____
d) All Selector Switches in Auto Position _____
e) SYSTEM START Button Pushed _____
- Main pump starts _____
- Flow display shows water flow _____
- Reagent pumps start _____
- Transmittance controller starts _____
- UV lamp starts _____
- Air blowers start (indicate voltage level) _____
- Discharge valve to DISCHARGE _____

I OTHER

a) pH probes, inspect per OEM data _____
b) Ozone generator, inspect per OEM data _____
c) _____ _____
d) _____ _____
e) _____ _____
f) _____ _____

RAYOX
MAINTENANCE CHECKLIST

3,000 HOUR MAINTENANCE:

Date of last session _____
Date of this session _____

a)	System Shutdown	_____
b)	Mains Disconnect OFF and Locked OUT	_____
c)	Cover Panel(s) Removed	_____
d)	Reactor Drained	_____
e)	UV Lamp Removed	_____
f)	Quartz Tube Removed	_____
g)	Quartz Tube OK	_____
h)	Quartz Tube Re-installed	_____
i)	Upper Quartz Seal Replaced	_____
j)	Ceramic Insulator Replaced	_____
k)	Lower Quartz Seal Replaced	_____
l)	Main Pump Running, Reactor Filled	_____
m)	Leak test system for 5 minutes	_____
n)	Inspection for leaks	_____
o)	UV Lamp Installed	_____
p)	Power Leads to UV Lamp Re-connected	_____
q)	Cover Panel(s) Re-installed	_____
r)	Lamp Hours Reset (if applicable)	_____
s)	Lamp Restarted	_____
t)	Service Completed	_____
u)	Other: _____	_____
	_____	_____
	_____	_____
	_____	_____

NOTES:

ULTROX

PILOT-SCALE REPORT

ULTROX

A Division of Zimpro Environmental, Inc.

2435 South Anne Street
Santa Ana, CA 92704-5308
Phone: 714 545-5557
Fax: 714 557-5396

ULTROX DIVISION OF ZIMPRO ENVIRONMENTAL, INCORPORATED

UV/OXIDATION FIELD PILOT STUDY REPORT

FOR THE

UV/OXIDATION SYSTEM PILOT SCALE DEMONSTRATION PROGRAM SAVANNA ARMY DEPOT ACTIVITY SAVANNA, ILLINOIS

DACA31-91-D-0079/006
WORK ORDER NO. 02281-012-006

Submitted by:
Bill Himebaugh
ULTROX division of Zimpro Environmental, Inc.

January 20, 1995

Revision 1
April 7, 1995

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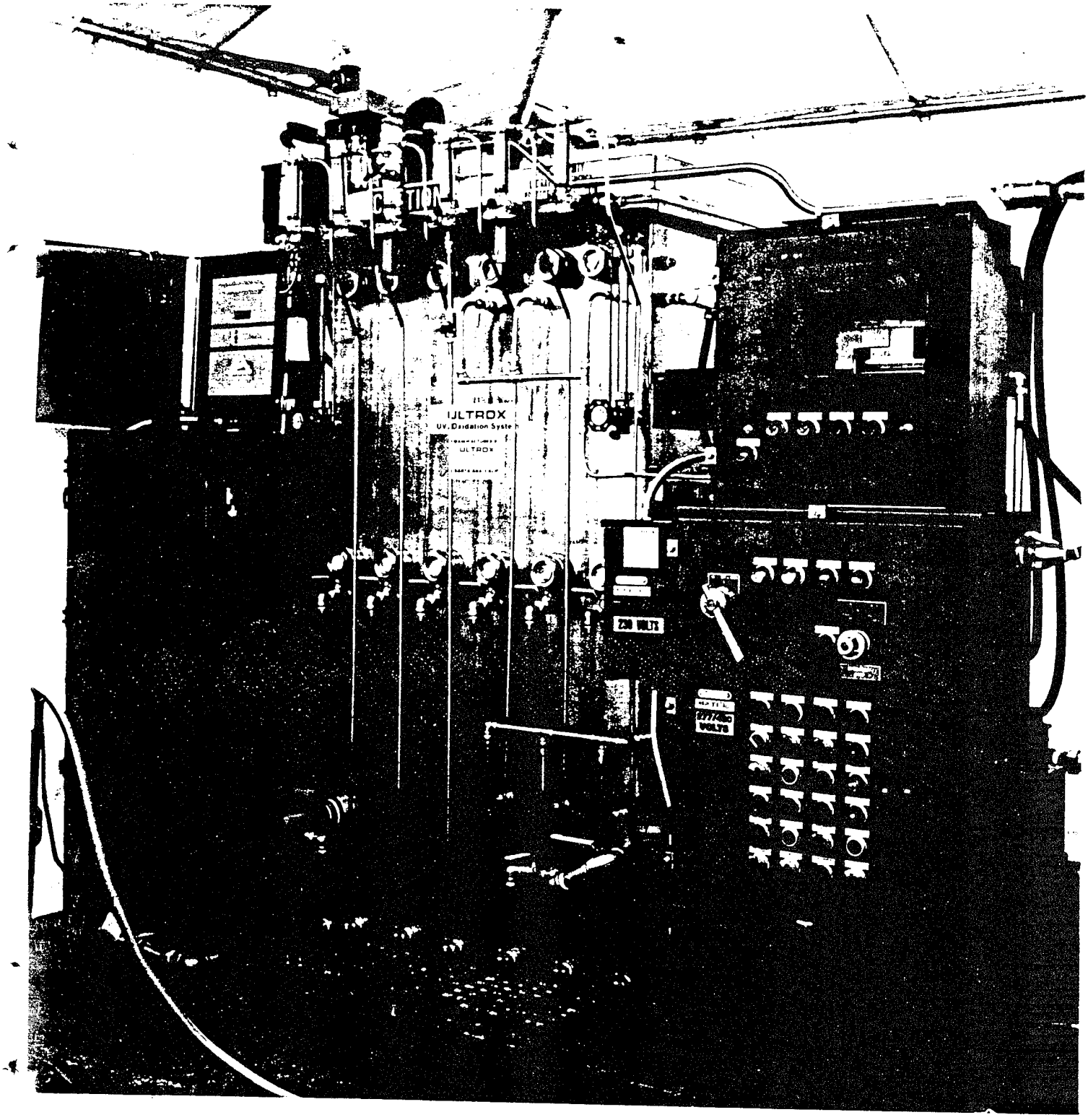


ULTROX® UV/OXIDATION WATER TREATMENT SYSTEM

1.0 EXECUTIVE SUMMARY

Ultrox division of Zimpro Environmental, Inc. (Ultrox) was contracted by Roy F. Weston, Inc. (Weston) to conduct a field pilot study to evaluate the effectiveness of the Ultrox® advanced oxidation process (AOP) on the treatment of explosives in groundwater from the Savanna Army Depot Activity (SADA) in Savanna, Illinois.

Prior to performing the field pilot test, Ultrox conducted a bench scale test on a groundwater sample from the site. A total of nine (9) bench-scale oxidation tests were performed on this sample. Results of the bench-scale testing indicated that the Ultrox® UV/Oxidation system could reduce all explosives in the groundwater to below their respective treatment objective concentrations with between 90 and 156 minutes of UV exposure and between 90 mg/l and 120 mg/l of ozone after reducing the pH to 4 by addition of sulfuric acid. The pH reduction was prescribed to reduce the high carbonate/bicarbonate concentration that competes with ozone and hydroxyl radicals in the treatment process. Prior to pH reduction, the pH was elevated to 11 by addition of sodium hydroxide to precipitate manganese in the groundwater. Precipitation was required to remove the manganese which had precipitated on the ozone diffuser and lamp sheaths in the bench-scale reactor. Pretreatment was prescribed to avoid this potential problem during the field pilot demonstration.

The Ultrox field technicians arrived at SADA on September 12, 1994 and the Ultrox® UV/Oxidation system arrived on September 14, 1994. Ultrox field technicians coordinated installation of the Ultrox® AOP system with Weston personnel. The system consisted of two 30 gallon pH adjustment tanks equipped with Wingnet mixers, Masterflux pumps, pH controllers, an Ultrox® P-325 UV treatment tank, 14 lb/day ozone generator, a residual ozone destruction unit and an effluent pH controlled sump tank.

The on-site optimization testing began on September 20, 1994. Based upon the combined results of the bench-scale testing and the field optimization tests, Ultrox determined that all explosive compounds could be destroyed to below treatment objectives with 90 minutes of exposure to Ultrox® UV lamps and 120 mg/l of ozone (2% concentration).

These conditions were based upon the water being pretreated for removal of dark precipitate (possibly manganese as detected in the bench-scale tests) by elevation of pH to 11 by addition of sodium hydroxide, followed by filtration of the precipitate. Reduction of pH to 4 by addition of sulfuric acid reduced the carbonates and bicarbonates which compete for oxidant with the explosives . These conditions were utilized to treat the groundwater during the three week demonstration period.

Analytical results of the treated groundwater during the three week demonstration program indicate that the treatment objectives for all explosive compounds were achieved with the prescribed conditions for all samples collected.

2.0 TECHNOLOGY DESCRIPTION

2.1 The Ultrox® Technology

The Ultrox® technology is an enhanced or advanced oxidation process (AOP) utilizing various combinations of UV light, H_2O_2, and/or O_3. H_2O_2 and O_3 vary in their effectiveness depending on the compounds targeted. Ultraviolet light, when combined with H_2O_2 and/or O_3, produces a highly oxidative environment significantly more destructive than that typically created with O_3 or H_2O_2 by themselves or in combination.

The application of UV light significantly enhances ozone or H_2O_2 reactivity by:

i) Transformation of O_3 and H_2O_2 to highly reactive hydroxyl (OH) radicals;

ii) Excitation of the target organic solute to a higher energy level; and

iii) Cleavage of chemical bonds to destroy the target contaminants.

The type of UV lamp employed is crucial to the creation of the highly oxidative environment. When Ultrox pioneered it's UV/Oxidation technology in the early 1980's, the lamp design was developed specifically for use with ozone to create that oxidative environment in water. Ultrox® UV lamps create this oxidative environment in water with significantly lower electrical consumption than other conventional advanced oxidation processes that employ UV light with hydrogen peroxide alone or ozone with lamps designed for use with hydrogen peroxide.

Table 1 illustrates the relative oxidant strength of hydroxyl radical $(OH)^{\circ}$, O_3, H_2O_2 and $C1_2$. Hydroxyl radicals can be formed from UV with O_3, UV with H_2O_2, UV with O_3 and H_2O_2 or O_3 with H_2O_2.

Ultrox® UV/Oxidation treatment systems typically consist of a UV or Oxidation treatment tank, an ozone generator, an air preparation system, a hydrogen peroxide feed system and an off gas treatment system. The UV treatment tank is a gravity vessel constructed of 316L stainless steel and is baffled to provide a

serpentine and sinusoidal pathway for the wastewater as it flows through the treatment tank. This flow provides optimized exposure to the UV and oxidants while preventing backflow. Ozone is produced on site from compressed, filtered and dried air. The ozone flows from the ozone generator into a manifold on the UV treatment tank which distributes the ozone into the groundwater through Ultrox® spargers or diffusers which are located in the bottom of the treatment tank. These spargers are designed for optimum mass transfer of ozone and long life. Any residual ozone is destroyed by an Ultrox® Decompozon™ destruction unit. The Decompozon™ employs a proprietary, nickel based catalyst which reduces the residual ozone to below the OSHA limit of 0.1 parts per million (by wt.). This unit has been tested by the Environmental Protection Agency (EPA), which concluded that no VOCs or ozone were detected to be emitting from the DECOMPOZON™ unit (EPA SITE Report No.EPA/540/589/012).

TABLE 1

Relative Oxidation Potential (C12 = 1.0)	Species	Oxidation Potential (Volts)
2.23	fluorine	3.03
2.06	hydroxyl radical	2.80
1.78	atomic oxygen (single)	2.42
1.52	ozone	2.07
1.31	hydrogen peroxide	1.78
1.25	perhydroxyl radical	1.70
1.24	permanganate	1.68
1.15	chlorine dioxide	1.57
1.07	hypoiodous acid	1.45
1.00	chlorine	1.36
0.80	bromine	1.09
0.39	iodine	0.54

2.2 UV/Oxidation of Explosives

Explosives compounds typically treated in the United States include derivatives of benzene and heterocyclic compounds. The most common heterocyclic compounds include HMX and RDX which are characterized by having nitrogen atoms in the ring and are more readily oxidized than the toluene and benzene derivative explosives. The most persistent of the benzene derivatives is 1,3,5-trinitrobenzene (1,3,5-TNB). This is especially true when 2,4,6-trinitrotoluene (2,4,6-TNT) is present. The oxidation of 2,4,6-TNT can directly affect the oxidation rate of 1,3,5-TNB because during the oxidation of 2,4,6-TNT, the methyl group is cleaved resulting in 1,3,5-TNB. Therefore, the 1,3,5-TNB levels can increase as 2,4,6-TNT is oxidized resulting in 1,3,5-TNB being the oxidation rate controlling compound. According to hypotheses, the cleavage of the methyl group is initiated by UV photolysis when a proton is abstracted from the methyl group resulting in an anion which is much more susceptible to a reaction with hydroxyl radicals or ozone.

The nitro groups can be cleaved off either before or after the ring is broken. According to generally accepted hypothesis, destruction of the benzene or toluene ring occurs when two adjacent OH groups are substituted in the ring. Ozone or OH radicals react with a hydrogen atom or nitro group substituent. The addition of oxygen to the nitro group results in the formation of nitrates detected after the oxidation of these compounds. Once the ring breaks, possible byproducts include a mixture of catechol, resorcinol and hydroxyquinones, which are then broken down into organic acids such as oxalic and formic acids. Further oxidation results in carbon dioxide and water.

3.0 PROGRAM OBJECTIVES

3.1 The objectives of the field pilot demonstration were as follows:

3.1.1 To demonstrate the effectiveness of Ultrox® UV/Oxidation in the destruction of explosives in the SADA groundwater;

3.1.2 To identify and demonstrate the appropriate dosages of oxidant and UV exposure time or retention time required to achieve the objective concentrations for explosives in the SADA groundwater; (Table 2)

3.1.3 To identify any pretreatment required for optimal performance of the Ultrox® UV/Oxidation system in the treatment of the SADA groundwater;

3.1.4 To develop capital, operating and maintenance costs of a full scale system capable of achieving the treatment objectives (see Table 2) at a flow rate of 50 gpm.

TABLE 2 - Treatment Objective Concentrations

Parameter	Treatment Objective Concentration (mg/L)
2,4,6-Trinitrotoluene	0.007
2,4-Dinitrotoluene	0.006
2,6-Dinitrotoluene	0.009
1,3,5-Trinitrobenzene	0.007
Tetryl	0.044
HMX	0.013
1,3-Dinitrobenzene	0.004
2-Amino-4,6-Dinitrotoluene	0.036
Nitrobenzene	0.010
RDX	0.014
pH	6-9

4.0 EQUIPMENT AND MATERIALS

The pilot plant project included the following equipment and materials:

- Ultrox® P-325 UV Treatment Tank
- Air Preparation System consisting of:
  - Compressor
  - Air Filter
  - Air Dryer
- 14 lb/day Ozone Generator
- Decompozon™ Offgas Treatment Unit
- Hydrogen Peroxide Feed Assembly
- Pretreatment System
  - pH 11 Adjustment Tank
  - In-line filter
  - pH 4 Adjustment Tank
- Effluent sump and sump pump (pH controlled)

4.1 Pretreatment System

The pretreatment system included two 30 gallon pH adjustment tanks and an in-line filter unit. Each pH tank was equipped with an electric mixer and a pH meter which controlled the caustic or acid metering pump. The first pH adjustment tank pH meter was set to maintain a pH of 11. A caustic solution was prepared in a reservoir which fed the pH controller actuated metering pump. Flow to the pH 11 adjustment tank was controlled by a level controller in the adjustment tank which actuated a valve on the effluent of the client's equalization tank. The precipitate formed by the elevation of pH was removed by a 25 micron (μ) in-line filter. The groundwater was pumped from the pH 11 adjustment tank through the in-line filter to the pH 4 adjustment tank by a sump pump located in the pH 11 tank and actuated by a float controller in the pH 4 adjustment tank. A pH of 4 was maintained in the adjustment tank by a pH meter controlled metering pump. A sulfuric acid solution was prepared in a reservoir which fed the metering pump.

4.2 Ultrox® P-325 UV Treatment Tank

The pretreated groundwater was pumped from the pH 4 adjustment tank to the P-325 UV treatment tank with a variable speed centrifugal pump. The Ultrox® P-325 UV Treatment Tank is constructed of 316L stainless steel and has a working capacity of 325 gallons. The P-325 is a gravity tank designed with six internal baffles which divide the inside of the tank and provide a serpentine and sinusoidal flow of water through the tank. The P-325 contains 36 Ultrox® UV lamps (6 lamps per baffled area), Ultrox® ozone diffusers and seven sample ports, with one located in the UV treatment tank influent line, one in each of cells 2-6, and one in the effluent line. The report cover provides a photograph of an Ultrox® UV/oxidation pilot system.

4.3 Air Preparation

The Air Preparation System employed consists of a rotary vane type air compressor, air filter unit (to remove compressor oils and particulates), and a regenerative desiccant dryer (reduces dewpoint in the air to less than -70°F).

4.4 Ozone Generator

The ozone generator employed during the field pilot test was a 14 lb/day, fixed voltage, variable frequency inverter generator. This system produces ozone from the air treated in the Air Preparation System. The resulting ozone concentration of approximately 2% in air flows to the P-325 UV treatment tank ozone manifold for distribution throughout the UV treatment tank.

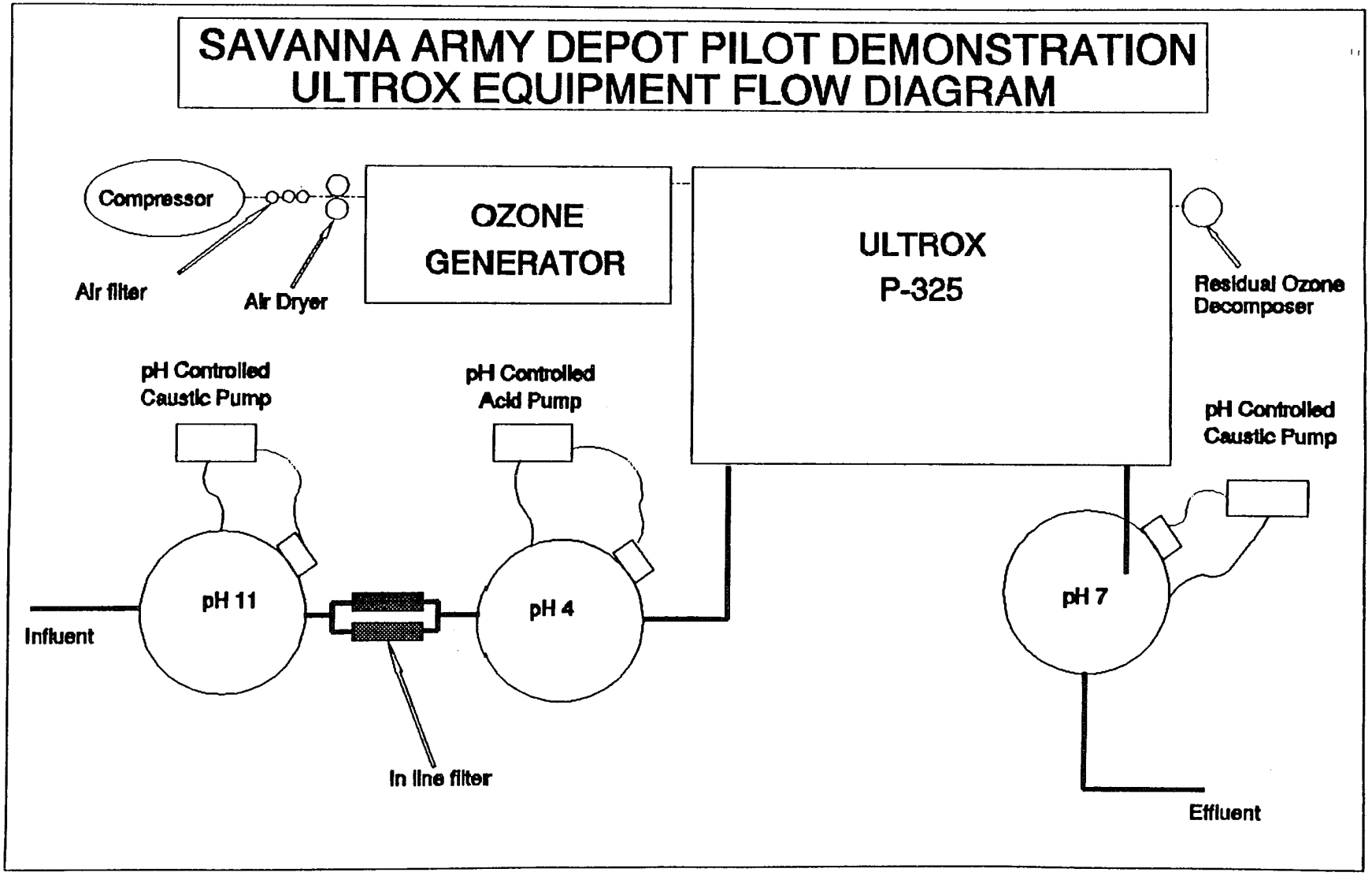
4.5 Decompozon™ Offgas Treatment Unit

The Decompozon™ unit is a catalytic ozone destruction unit which reduces the residual ozone from the P-325 UV treatment tank to below 0.1 ppm by weight.

4.6 Effluent Sump

A polyethylene tank was provided to collect the treated groundwater from the P-325 UV Treatment Tank. A pH meter in the effluent sump controlled a metering pump which maintained a pH of 7 in the sump by injecting a caustic

solution. The treated groundwater was pumped from the sump by a float actuated sump pump located in the bottom of the sump.


SAVANNA ARMY DEPOT PILOT DEMONSTRATION
ULTROX EQUIPMENT FLOW DIAGRAM
Compressor
Air filter
Air Dryer
OZONE GENERATOR
ULTROX P-325
Residual Ozone Decomposer
pH Controlled Caustic Pump
pH Controlled Acid Pump
pH Controlled Caustic Pump
pH 11
pH 4
pH 7
Influent
In line filter
Effluent

5.0 PROGRAM PROCEDURES

5.1 Field Pilot Test Preparation

The Ultrox field technicians arrived on site on September 12, 1994. On September 15, 1994 the equipment arrived and was off loaded by forklift and placed in the test area. Equipment was inspected and repairs were made on damages caused by transport. Since the ozone generator was damaged in transit, it was replaced by Ultrox. Site personnel provided electrical power and piping connections to the Ultrox® system. Start up procedures were implemented by the Ultrox field technician and calibration of the equipment was performed. All equipment was operating at the start of the optimization testing on September 20, 1994.

5.2 Field Pilot Optimization Testing

The Ultrox field technician tested the settling rate of the precipitates formed in the pH 11 adjustment tank and concluded that significant precipitation occurred after 6 minutes of retention time. To accommodate the required flow rate for the UV/Oxidation system, the in line filter was used to remove the precipitate. However, this settling test indicated that a gravity separator could be used in full scale system design as opposed to an in-line filter.

The Ultrox field technician performed three oxidation tests on September 20 and 21 (see conditions below). He collected influent and effluent samples and shipped them by overnight courier to Ultrox's laboratory in Santa Ana, California for analysis of explosives (EPA 8330).

TABLE 3			
Optimization Test No.	Retention Time (minutes)	Ozone Dosage (mg/l)	pH
1	120	120	4
2	150	120	4
3	90	150	4

5.3 Three Week Demonstration Program

The three week demonstration program began on September 27, 1994. The prescribed conditions for the demonstration included pretreatment of the groundwater by adding a 15% solution of sodium hydroxide (NaOH) to elevate the pH to 11. The precipitate was filtered through a 25 μ filter and the pH was lowered to 4 by addition of 14% solution of sulfuric acid (H_2SO_4) prior to entering the P-325 UV/Oxidation treatment tank. The 15% NaOH solution was prepared by adding 300 milliliters (ml) of 50% NaOH solution per liter of water. The 14% H_2SO_4 solution was prepared by adding 150 ml of 93% H_2SO_4 per liter of tap water.

The pretreated water was pumped into the P-325 UV treatment tank at a flow rate of approximately 3.6 gpm. At this flow rate, the retention time within the UV treatment tank is approximately 90 minutes.

The prescribed ozone dosage for the demonstration program was 120 mg/l. The ozone concentration was approximately 2% throughout the program. Ozone concentration was measured by a PCI high concentration ozone monitor. For the first three days, the actual ozone dosage averaged 124.5 mg/l. Actual ozone dosage was calculated as follows:

- Desired O_3 Dosage (mg/l) x groundwater flow rate (gpm) x 3.785 (liters/gal) x 1440 (min/day) ÷ 453,592 mg/lb = Desired O_3 Dosage (lbs/day)

- Required Air Flow (CFM) = Desired O_3 Dosage (lbs/day) x 0.926 ÷ O_3 Concentration (% as measured by ozone monitor)
- Since the air meter on the ozone generator registers standard cubic feet per hour (SCFH), the required air (SCFH corrected for 15 PSI) = required air (CFM) x (60 minutes/hr) ÷ 1.42.

Once the required air is calculated, the air flow is adjusted by a valve on the influent of the ozone generator.

The average ozone dosage for the remaining oxidation tests was 134 mg/l. The increased ozone dosage can be attributed to increased air output by the compressor and improved ozone concentration due to lower ambient and/or cooling water temperatures. These changes resulted in no measured increase in electrical consumption. At no time did the ozone dosage fall below the prescribed 120 mg/l. Electrical consumption rates were consistent throughout the demonstration.

The treated groundwater from the UV treatment tank required elevation of pH to neutral (7). A solution of 2% NaOH was prepared by adding 40 ml of 50% NaOH solution per liter of water. This solution was metered into the effluent sump tank at rates controlled by the pH meter in the sump. A float controlled sump pump pumped the neutral pH treated groundwater to the client's holding tank.

5.4 Sample Analyses.

All samples collected during the optimization testing (September 20 - September 21) were analyzed for explosive compounds by Ultrox's contract laboratory (Pyramid Laboratories, Inc., Costa Mesa, CA) using EPA 8330. All samples collected during the pilot test period (September 27 - October 14) were analyzed by Weston's Lionville Analytical Laboratory.

6.0 RESULTS AND CONCLUSIONS

6.1 Optimization Test Results

The results of the untreated sample analyzed by Ultrox's contract laboratory during the optimization period indicated that explosives concentrations were within the range of explosives concentrations detected by Weston's designated laboratory. Results of all treated samples analyzed by Ultrox's contract laboratory indicate levels below detection limits for all explosives.

Pretreatment of the groundwater was prescribed due to results obtained during the laboratory treatability study. During the bench-scale testing, dark particulates (indicative of oxidized manganese) precipitated. It was determined that the dark precipitate could be removed by elevating the pH of the groundwater to 11 by addition of NaOH. Remaining carbonates and bicarbonates which compete for oxidants (ozone) and hydroxyl radicals could then be reduced by reducing the pH to 4 by adding sulfuric acid. By performing this pretreatment, no precipitates were observed in the UV treatment tank and no labor was required to operate the Ultrox® UV/Oxidation system. The only labor associated with the maintenance of the Ultrox® UV/oxidation system was approximately 5 minutes allocated to tighten pipe fittings.

6.2 Demonstration Program Results

Analytical results from Weston's Lionville Analytical Laboratory indicate that the untreated groundwater concentrations of analyzed explosive compounds fluctuated. The Table below lists the ranges and averages of the concentrations detected. An additional column is provided which lists the bench-scale results of the untreated sample for comparison.

TABLE 4				
Compound	Low Range (μg/l)	High Range (μg/l)	Average (μg/l)	Untreated Bench Scale Sample (μg/l)
HMX	*6.0	*6.9	*	*
RDX	*3.4	6.4	*	*
1,3,5-TNB	430	1,100	622.0	590
1,3-DNB	*1.6	40	14.1	33
Nitrobenzene	*0.71	*6.5	*	*
Tetryl	*2.0	*23	*	*
Amino DNT	8.9	82	46.5	*
2,4,6-TNT	530	1,500	766.8	1,515
2,6-DNT	*1.6	9.0	5.6	*
2,4-DNT	0.67	120	17.6	140
Hardness (mg/l)	304	353	336.1	569
Alkalinity (mg/l)	*2.0	226	176.6	182
Iron	124	665	319	890
Manganese	1,630	1,930	1741.4	3,360

* Below detection limit

The fluctuations of influent sample concentrations had no measurable affect on the reduction levels achieved by the Ultrox® UV/Oxidation process. The analytical results of the treated samples indicate that all treated samples contained concentrations below detection limits. Because the effluent explosive concentrations were below detection limits and detection limits are not completely consistent, a destruction removal efficiency (DRE) can not be calculated with complete accuracy.

- DRE = (Influent Concentration - Effluent Concentration) ÷ Influent Concentration x 100

The pretreatment system employed during the demonstration program was designed to remove dark precipitates (believed to be manganese) observed in the bench scale test and to reduce the hardness in the groundwater. This system is not considered optimized for full scale implementation. A comparison of the bench-scale results with the field demonstration results indicates a higher hardness and manganese concentration present in the untreated bench-scale samples than those detected in the untreated samples collected during the field demonstration program (3,280 μg/l of manganese vs 1,741 μg/l of manganese). This indicates that perhaps the pH adjustment to 11 would not be required since the average manganese concentration detected in the field demonstration program is below the concentration typically pretreated by Ultrox (greater than 3 mg/l). The lower hardness concentration detected in the field demonstration untreated samples (336 mg/l vs. 634 mg/l in the bench scale sample) indicates that acidification to pH 4 should be evaluated to determine if additional ozone may be more economical than pH reduction before UV/Oxidation followed by pH neutralization after UV/Oxidation.

Assuming the lower manganese concentration (< 2 mg/l), pretreatment and therefore usage rates of sodium hydroxide and filters would not apply. If hardness reduction proves cost effective to the oxidation process, sodium hydroxide would still be required to neutralize the treated water. Further, if manganese removal

is required, a filter would not be recommended for full scale since a clarifier with 6 minutes of retention time could provide separation of the manganese precipitate. However, observations of the filtrate in the field indicate a peanut butter color as opposed to the black precipitate associated with manganese as detected in the untreated bench-scale sample.

A comparison of the results of the field pilot test, treated sample, analytical results and the bench-scale treated sample results indicates a correlation exists. By comparing Test 6 of the bench-scale test data, all treatment objectives were achieved with 90 minutes of UV exposure and 120 mg/l of ozone except 2,4,6-TNT. The results of the 2,4,6-TNT analysis in test 6 of the bench-scale test are considered to be an anomaly since no 1,3,5-TNB was detected and 2,4,6-TNT oxidizes to form 1,3,5-TNB by cleavage of the methyl group. Therefore, it is highly unlikely that 2,4,6-TNT could be detected without detecting 1,3,5-TNB. Assuming this to be true, Test 6 of the bench-scale test correlates well with the results of the field pilot test. The ozone dosage of 117.6 - 144.1 mg/l in the field demonstration was likely caused by increased efficiency of the air preparation system and/or cooling of the ozone generator. The electrical consumption remained virtually unchanged, despite these increased efficiencies. Clearly, no 2,4,6-TNT was detected in the treated effluent during the field demonstration.

6.3 Full Scale UV/Oxidation System

The full scale system designed to achieve the treatment objectives as described in Table 2 at a flow rate of 50 gpm is provided below. The full scale system specifications and a process flow diagram are provided in the Appendix.

Pre/Post Treatment

Because no dark deposits characteristic of manganese were observed on the filter during the field pilot demonstration, Ultrox does not recommend pretreatment for manganese removal in the full scale system. Manganese levels greater than 3 mg/l are typically removed due to propensity to foul ozone diffusers and the quartz sheaths which house the UV lamps. As previously discussed, the analytical

results of the influent samples collected during the field demonstration indicate that manganese concentrations were lower than those detected in the laboratory (which was the basis for manganese pretreatment during the field pilot demonstration). However, Ultrox does recommend pretreatment for hardness by acidification. The relatively high hardness of the groundwater indicates the presence of sufficient concentrations of carbonates/bicarbonates to compete for the oxidating species (ozone and hydroxyl radicals). Acidification of the groundwater to a pH of 4 reduces the hardness resulting in improved efficiencies in the oxidation of the explosives. Therefore, the full scale system design includes a sulfuric acid supply tank, an acid metering pump, and in-line static mixer, and an electronic pH probe capable of controlling the acid metering pump. Because the pH of the influent groundwater is reduced to 4, the pH must be neutralized after treatment and prior to discharge. Therefore, a caustic feed system is included in the full scale system design. This includes a sodium hydroxide supply tank, caustic metering pump, and in-line static mixer, and an electronic pH probe capable of controlling the caustic metering pump. Sulfuric acid solution is injected into the influent line of the UV/Oxidation treatment tank upstream of the in-line static mixer. As the acidified water flows through the in-line static mixer, the pH adjustment is accelerated. Downstream of the in-line static mixer, a pH monitor detects the pH of the groundwater and sends a signal to the acid metering pump to increase the flow of acid solution in the event of a pH greater than 4 and to reduce the flow of acid solution if the pH is less than 4. Downstream of the UV treatment tank effluent, the caustic soda solution is metered into the effluent line by the caustic soda metering pump. The pH adjustment is accelerated by an in-line static mixer downstream of the caustic soda injection point. A pH monitor downstream of the in-line static mixer detects the pH of the treated groundwater. If the pH is less than 6.5, the pH monitor signals the caustic soda metering pump to increase the flow of caustic soda solution. If the pH is greater than 7.5, the pH monitor signals the caustic soda metering pump to reduce flow of caustic soda.

Should the client require a manganese pretreatment system, we recommend a design different from that used in the field demonstration. The full scale manganese removal system consists of a caustic supply tank (also used to supply the caustic for neutralization of effluent pH), a caustic metering pump, a floc tank and the LME separator. The untreated groundwater flows to a 1,000 gallon floc tank. Air from the compressor is diffused into the floc tank to promote flocculation and precipitation. Water from the floc tank flows to an LME separator which separates the precipitated manganese from the groundwater. This equipment would be upstream and in addition to the acidification pretreatment. The optional manganese removal system is shown contained within a dotted square on the process flow diagram located in the Appendix.

Full Scale Advanced Oxidation System

The full scale advanced oxidation system consists of an Ultrox® 4,500 gallon UV treatment tank, a 75 lb/day ozone generator, an air compressor, air dryer, air filter, residual ozone destruction system and a master control panel. The 4,500 gallon UV treatment tank capacity is based upon the retention time scale up from the demonstration retention time. The retention time from the demonstration was 90 minutes. Therefore, to treat 50 gpm, the working volume of the full scale UV treatment tank is 4,500 gallons. The ozone dosage applied during the demonstration was 120 mg/l. Based on a flow rate of 50 gpm, the full scale ozone dosage is 72 lbs/day. By designing for a 75 lb/day ozone generator, an additional 5 mg/l of ozone capacity is available. After pretreatment, the groundwater flows into the UV treatment tank. The UV treatment tank is a gravity vessel with a minimum of six compartments. Should a sump be required, a seventh compartment without UV lamps would serve as a sump and control the level within the tank via an internal weir between the sixth and seventh compartment. A level controller located in the seventh compartment (sump) actuates a sump pump to discharge the water from the seventh compartment through the in-line static mixer to the discharge point. Ozone is created from air in the full scale system. Compressed air flows from the compressor through a series of air filters which remove compressor oils and particulates from the air.

From the air filters, the air flows through a reciprocating air dryer which lowers the dewpoint to below -70°F. From the air dryer, the air flows to the ozone distribution manifold on the UV treatment tank. Via rotometers, the ozone distribution is controlled to the diffusers located in the bottom of each of the six compartments of the UV treatment tank. Any residual ozone which breaks out into the vapor region above the surface of the groundwater within the UV treatment tank is vacuumed through the Decompozon™ residual ozone destruction system. The resulting air is vented to the atmosphere. An ambient ozone monitor may be provided which shuts down the system in the event of ozone detections in the atmosphere. The ozone generator requires 20 gpm of cooling water which may utilize the treated water as a medium of heat exchange as opposed to the more costly use of potable water. With this design, treated water from the seventh compartment of the UV treatment tank (identified as sump on the process flow diagram) is pumped through one side of the heat exchanger and back to the seventh compartment. A closed loop of potable water is pumped from the ozone generator to the other side of the heat exchanger and back into the ozone generator. Since an 8°F temperature rise in cooling water results from the ozone generator, pump design and flow rates are based upon an 8°F temperature reduction in cooling water circulating from the ozone generator through the heat exchanger.

7.0 ECONOMICS

This section provides price estimates in U.S. dollars for the supply of Ultrox® equipment and services as described below and in the Full Scale System Specification Section of this report. Freight costs are not included. Prices do not include federal, state, provincial, regional or municipal taxes. Duties, permits, costs of obtaining permits, bonds and interest or penalties are not included.

7.1 Assumptions

Capital equipment price estimates and costs are based upon the following assumptions:

Flow Rate	50 gpm
Electrical Cost	$0.06/kWh
UV Lamp Cost	$50/lamp
UV Lamp Life	1 year
Caustic Soda (based on 50% solution)	$0.10/lb
Sulfuric Acid (based on 93% solution)	$0.07/lb
Supervisor labor hours	$31.00/hr
Laborer labor hours	$14.88/hr
Sludge Disposal costs	$1.00/lb

7.2 Pretreatment/Posttreatment Equipment Costs

The full scale pretreatment system designed to reduce the carbonates and bicarbonates in the groundwater prior to oxidation is estimated to be $18,000. This system includes the following equipment:

- Sulfuric Acid Supply Tank
- Caustic Soda Supply Tank
- Sulfuric Acid Chemical Metering Pump
- Caustic Soda Chemical Metering Pump
- Influent pH Monitor Probe
- Effluent pH Monitor Probe
- Influent and Effluent In-Line Static Mixers

Should it be determined that the manganese removal pretreatment is required, installation is recommended upstream and in addition to acidification pretreatment equipment described above. The manganese removal system will utilize the above provided caustic soda supply tank and includes the following additional equipment:

- Caustic Soda Metering Pump
- Floc Tank
- LME Separator
- LME Separator pH Monitor Probe
- Filter Press

The estimated price for the addition of the manganese removal system is $55,000.

7.3 Ultrox® UV/Oxidation Equipment Prices

The full scale Ultrox® UV/Oxidation system designed to reduce the explosives in the SADA groundwater to below detection limits is estimated to be $375,000. This system includes the following equipment:

- Ultrox® F-4500 UV Treatment Tank
- 75 lb/day Ozone Generator
- Rotary Vane Air Compressor
- Air Filter Assembly
- Air Dryer Assembly
- Effluent Sump Compartment
- Effluent Sump Pump
- Decompozon™ Residual Ozone Destruction System

7.4 Operating and Maintenance Costs

Operating and maintenance costs associated with the field pilot system and the full scale treatment system are provided under Consumables in the Appendix of this report. These figures differ because pretreatment methods used during the field pilot test can be more efficiently applied by using the capital equipment described in Section 7.2 of this report. The most significant savings the full scale

treatment system offers over the field demonstration equipment is the elimination of filters and the labor associated with filter replacement. Further, because the demonstration period was performed for three weeks, no lamp replacement was required. Every 1-1.2 years, the UV lamps of the full scale system will need to be replaced. The labor associated with lamp replacement includes removal of the lamp shield (or section if treatment continues during lamp replacement), unplugging the quick disconnect wires to each lamp, sliding each lamp up from the quartz sheath, and replacing it with the new lamp, then reconnecting the quick disconnect wire. This process is expected to take approximately 2 minutes per man per lamp. Additional minor maintenance items include replacement of the air filters, and changing the compressor oil and filter. The labor associated with these tasks is included in the estimated operating labor costs.

The consumables usage rate indicates high efficiency of explosives oxidation after reduction of hardness. Two tables have been provided in the Consumables section of this report: One for the actual consumables realized during the field pilot test; and the other for the full scale system.

During the pilot demonstration, a 25 μ filter was used to capture the manganese. While filtration at elevated pH provided the desired manganese reductions in the field demonstration, filtration is not recommended for full scale treatment if manganese pretreatment is selected. By using a floc tank followed by a LME separator, the filter replacement costs realized during the field pilot demonstration would not apply and have been deleted from the full scale system table. The sludge resulting from the separation of manganese (and suspended solids) will be filter pressed, resulting in approximately three pounds of filter cake per day. Evaluation of other manganese removal processes, such as green sand filtration, is suggested. This evaluation should examine labor costs associated with filter press operation, given that manganese green sand filtrate is typically greater than the sludge resulting from an LME separator. Labor and disposal costs should be considered in the evaluation.

The primary sources of electrical consumption include the UV lamps and the ozone generator. By removing the manganese removal process from the full scale system design, a chemical metering pump, transfer sump pump and electric mixers are deleted. This results in some minor reductions in electrical consumption. We were not able to quantify the reductions in electrical consumption associated with the manganese reduction, so the electrical consumption rate of the full scale system remains unchanged.

During the three week pilot demonstration, the Ultrox field technician logged the amount of time allocated to each phase of treatment (i.e., pretreatment or UV/Oxidation). During the test period, approximately 5 minutes of attention to the UV/Oxidation system was required to tighten a loose fitting. No other adjustments or maintenance was required or performed on the UV/Oxidation system. The system was never shut down during the operating day, and operation of the equipment was performed without incidence during the entire demonstration program. During full scale operation, UV/Oxidation labor requirements are minimal. Once per year UV lamps are replaced and periodic inspection of the equipment calibration is all that is required. This is due to the simplicity of the system design and ease of system control via the Master Control Panel (MCP). All other labor hours were allocated to the pretreatment of the groundwater and the pH neutralization of the treated groundwater.

The labor associated with the pretreatment involved preparation of a 15% NaOH solution, preparation of a 14% sulfuric acid solution and replacement of the in-line filters. The full scale treatment design would not require as many batch preparations of the acid and caustic solutions. Further, the labor associated with changing the water filters during the field demonstration would also not apply to the full scale system operations.

Maintenance requirements not performed during the field demonstration which may be required for the full scale system include replacement of air filters, and changing the compressor oil and filter. These are minor tasks which are included

under UV/Ox Labor in the Full Scale System Operating and Maintenance Costs in the Appendix.

7.5 Full Scale System Cost Summary

We are providing two cost considerations. One involves a treatment system without manganese reduction and the other involves treatment with manganese reduction. Both systems provide hardness reduction by acidification and neutralization of pH after treatment.

7.5.1 Costs of Full Scale System Without Manganese Reduction

Total Capital Costs $393,000

Total Annual O&M Costs $96,822

7.5.2 Costs of Full Scale System With Manganese Reduction

Total Capital Costs $423,000

Total Annual O&M Costs $113,819

7.6 Delivery Time of Full Scale System

Delivery time required between receipt of order and delivery on site is 18 weeks. Expedited arrangements may be negotiated.

7.7 Terms and Conditions

Unless otherwise negotiated, the Zimpro Terms and Conditions found in the appendix apply.

APPENDIX

Analytical Data

Consumables

Full Scale System Specification

Process Flow Diagram

Spare Parts List

Zimpro Terms & Conditions

Analytical Data

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX
DATE:		27-Sep-94			28-Sep-94			29-Sep-94	
SAMPLE NAME:	U09271	U09272	U09273	ULT09281	ULT09282	ULT09283	ULT09291	ULT09292	ULTR09293
SAMPLE TIME:	12:10	15:30	17:50	10:20	13:22	15:54	10:05	13:19	16:25
HMX	6.9 U	7.0 U	4.6 U	6.1 U	8.8 U	5.5 U	6.1 U	5.6 U	4.7 U
RDX	3.4 U	3.4 U	2.2 U	3.0 U	4.3 U	2.7 U	3.0 U	2.7 U	2.3 U
1,3,5-Trinitrobenzene	0.78 U	0.79 U	0.52 U	0.69 U	1.0 U	0.62 U	0.69 U	0.64 U	0.53 U
1,3-Dinitrobenzene	0.78 U	0.79 U	0.52 U	0.69 U	1.0 U	0.62 U	0.69 U	0.64 U	0.53 U
Nitrobenzene	0.81 U	0.82 U	0.54 U	0.72 U	1.0 U	0.65 U	0.72 U	0.66 U	0.55 U
Tetryl	2.3 U	2.4 U	1.6 U	2.1 U	3.0 U	1.9 U	2.1 U	1.9 U	1.6 U
Amino DNTs	1.6 U	1.6 U	1.0 U	1.4 U	2.0 U	1.2 U	1.4 U	1.3 U	1.1 U
2,4,6-Trinitrotoluene	0.78 U	0.79 U	0.52 U	0.69 U	1.0 U	0.62 U	0.69 U	0.64 U	0.53 U
2,6-Dinitrotoluene	0.81 U	0.82 U	0.54 U	0.72 U	1.0 U	0.65 U	0.72 U	0.66 U	0.55 U
2,4-Dinitrotoluene	0.78 U	0.79 U	0.52 U	0.69 U	1.0 U	0.62 U	0.69 U	0.64 U	0.53 U
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

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J = Analyte present below the lower detection limit.

USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX
DATE:		30-Sep-94			3-Oct-94			4-Oct-94	
SAMPLE NAME:	ULT09301	ULT09302	ULT09303	ULT10031	ULT10032	ULT10033	ULT10041	ULT10042	ULT10043
SAMPLE TIME:	10:12	13:01		10:03	13:30	16:15	9:15	12:15	14:45
HMX	7.1 U	4.7 U	BROKEN	6.5 U	3.2 U	3.2 U	4.0 U	6.9 U	6.9 U
RDX	3.5 U	2.3 U	DURING	3.2 U	1.6 U	1.6 U	2.0 U	3.4 U	3.4 U
1,3,5-Trinitrobenzene	0.80 U	0.53 U	SHIPMENT	0.74 U	0.36 U	0.36 U	0.46 U	0.78 U	0.78 U
1,3-Dinitrobenzene	0.80 U	0.53 U	-	0.74 U	0.36 U	0.36 U	0.46 U	0.78 U	0.78 U
Nitrobenzene	0.84 U	0.55 U	-	0.77 U	0.38 U	0.38 U	0.47 U	0.81 U	0.81 U
Tetryl	2.4 U	1.6 U	-	2.2 U	1.1 U	1.1 U	1.4 U	2.3 U	2.3 U
Amino DNTs	1.6 U	1.1 U	-	1.5 U	0.73 U	0.73 U	0.91 U	1.6 U	1.6 U
2,4,6-Trinitrotoluene	0.80 U	0.53 U	-	0.74 U	0.36 U	0.36 U	0.46 U	0.78 U	0.78 U
2,6-Dinitrotoluene	0.84 U	0.55 U	-	0.77 U	0.38 U	0.38 U	0.47 U	0.81 U	0.81 U
2,4-Dinitrotoluene	0.80 U	0.53 U	-	0.74 U	0.36 U	0.36 U	0.46 U	0.78 U	0.78 U
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

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USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX
DATE:		5-Oct-94			6-Oct-94			7-Oct-94	
SAMPLE NAME:	ULT10051	ULT10052	ULT10053	ULT10061	ULT10062	ULT10063	ULT10071	ULT10072	ULT10073
SAMPLE TIME:	9:54	12:40	14:55	9:45	12:00	14:45	8:45	11:20	13:45
HMX	6.9 U	6.9 U	6.9 U	7.5 U	6.9 U	6.9 U	7.4 U	6.9 U	6.9 U
RDX	3.4 U	3.4 U	3.4 U	3.7 U	3.4 U	3.4 U	3.7 U	3.4 U	3.4 U
1,3,5-Trinitrobenzene	0.78 U	0.78 U	0.78 U	0.86 U	0.78 U	0.78 U	0.84 U	0.78 U	0.78 U
1,3-Dinitrobenzene	0.78 U	0.78 U	0.78 U	0.86 U	0.78 U	0.78 U	0.84 U	0.78 U	0.78 U
Nitrobenzene	0.81 U	0.81 U	0.81 U	0.89 U	0.81 U	0.81 U	0.88 U	0.81 U	0.81 U
Tetryl	2.3 U	2.3 U	2.3 U	2.6 U	2.3 U	2.3 U	2.5 U	2.3 U	2.3 U
Amino DNTs	1.6 U	1.6 U	1.6 U	1.7 U	1.6 U	1.6 U	1.7 U	1.6 U	1.6 U
2,4,6-Trinitrotoluene	0.78 U	0.78 U	0.78 U	0.86 U	0.78 U	0.78 U	0.84 U	0.78 U	0.78 U
2,6-Dinitrotoluene	0.81 U	0.81 U	0.81 U	0.89 U	0.81 U	0.81 U	0.88 U	0.81 U	0.81 U
2,4-Dinitrotoluene	0.78 U	0.78 U	0.78 U	0.86 U	0.78 U	0.78 U	0.84 U	0.78 U	0.78 U
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

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USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX
DATE:		10-Oct-94			11-Oct-94			12-Oct-94	
SAMPLE NAME:	ULT10101	ULT10102	ULT10103	ULT10111	ULT10112	ULT10113	ULT10121	ULT10122	ULT10123
SAMPLE TIME:	11:00	13:30	15:30	10:10	13:50	15:45	10:50	13:45	16:00
HMX	11 U	6.9 U	6.9 U	6.9 U	6.9 U	7.1 U	8.8 U	6.9 U	6.9 U
RDX	5.6 U	3.4 U	3.4 U	3.4 U	3.4 U	3.5 U	4.3 U	3.4 U	3.4 U
1,3,5-Trinitrobenzene	6.6	0.78 U	0.78 U	0.78 U	0.78 U	0.80 U	1.0 U	0.78 U	0.78 U
1,3-Dinitrobenzene	1.3 U	0.78 U	0.78 U	0.78 U	0.78 U	0.80 U	1.0 U	0.78 U	0.78 U
Nitrobenzene	1.3 U	0.81 U	0.81 U	0.81 U	0.81 U	0.84 U	1.0 U	0.81 U	0.81 U
Tetryl	3.9 U	2.3 U	2.3 U	2.3 U	2.3 U	2.4 U	3.0 U	2.3 U	2.3 U
Amino DNTs	2.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	2.0 U	1.6 U	1.6 U
2,4,6-Trinitrotoluene	1.3 U	0.78 U	0.78 U	0.78 U	0.78 U	0.80 U	1.0 U	0.78 U	0.78 U
2,6-Dinitrotoluene	1.3 U	0.81 U	0.81 U	0.81 U	0.81 U	0.84 U	1.0 U	0.81 U	0.81 U
2,4-Dinitrotoluene	1.3 U	0.78 U	0.78 U	0.78 U	0.78 U	0.80 U	1.0 U	0.78 U	0.78 U
Hardness (in mg/L)	-	-	-	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-	-	-	-
Iron	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-

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USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX	ULTROX
DATE:		13-Oct-94			14-Oct-94	
SAMPLE NAME:	ULT10131	ULT10132	ULT10133	ULT10141	ULT10142	ULT10143
SAMPLE TIME:	11:20	14:35	14:35	10:10	13:15	14:45
HMX	6.9 U	6.9 U	6.9 U	6.9 U	6.9 U	9.7 U
RDX	3.4 U	3.4 U	3.4 U	3.4 U	3.4 U	4.8 U
1,3,5-Trinitrobenzene	0.78 U	0.78 U	0.78 U	0.78 U	0.78 U	1.1 U
1,3-Dinitrobenzene	0.78 U	0.78 U	0.78 U	0.78 U	0.78 U	1.1 U
Nitrobenzene	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U	1.1 U
Tetryl	2.3 U	2.3 U	2.3 U	2.3 U	2.3 U	3.3 U
Amino DNTs	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	2.2 U
2,4,6-Trinitrotoluene	0.78 U	0.78 U	0.78 U	0.78 U	0.78 U	1.1 U
2,6-Dinitrotoluene	0.81 U	0.81 U	0.81 U	0.81 U	0.81 U	1.1 U
2,4-Dinitrotoluene	0.78 U	0.78 U	0.78 U	0.78 U	0.78 U	1.1 U
Hardness (in mg/L)	-	-	-	-	-	-
Alkalinity (in mg/L)	-	-	-	-	-	-
Iron	-	-	-	-	-	-
Manganese	-	-	-	-	-	-

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USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT
DATE:		27-Sep-94			28-Sep-94			29-Sep-94	
SAMPLE NAME:	IN09271	IN09272	IN09273	IN09281	IN09282	IN09283	IN09291	IN09292	IN09293
SAMPLE TIME:	12:10		18:03	10:16	13:30	15:45	10:00	13:17	16:20
HMX	55 U	BROKEN	51 U	69 U	14 U	17 U	13 U	6.9 U	10 U
RDX	27 U	DURING	25 U	34 U	6.7 U	8.3 U	6.5 U	3.4 U	5.1 U
1,3,5-Trinitrobenzene	550	SHIPMENT	760	730	1100	640	650	750	740
1,3-Dinitrobenzene	25	-	25	10	16	24	25	6.6	18
Nitrobenzene	6.5 U	-	6.1 U	8.1 U	1.6 U	2.0 U	1.6 U	0.81 U	1.2 U
Tetryl	19 U	-	18 U	23 U	4.7 U	5.8 U	4.5 U	2.3 U	3.5 U
Amino DNTs	29	-	12 U	16 U	70	3.8 U	21	22	60 J
2,4,6-Trinitrotoluene	750	-	970	940	1500	830	840	920	910
2,6-Dinitrotoluene	9.8	-	6.1 U	8.1 U	1.6 U	2.0 U	7.9	2.7	7.4
2,4-Dinitrotoluene	64	-	68	28	120	49	54 J	17	84
Hardness (in mg/L)	-	-	343	-	-	304	-	-	353
Alkalinity (in mg/L)	-	-	168	-	-	182	-	-	196
Iron	-	-	665	-	-	570	-	-	394
Manganese	-	-	1770	-	-	1930	-	-	1760

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USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT
DATE:		30-Sep-94			3-Oct-94			4-Oct-94	
SAMPLE NAME:	IN09301	IN09302	IN09303	IN10031	IN10032	IN10033	IN10041	IN10042	IN10043
SAMPLE TIME:	10:10	12:49	15:15	9:59	13:25	16:10	9:10	12:10	14:40
HMX	9.2 U	12 U	10 U	26 U	9.2 U	6.0 U	13 U	15 U	17 U
RDX	4.5 U	6.0 U	5.1 U	13 U	4.5 U	2.9 U	6.3 U	7.2 U	8.2 U
1,3,5-Trinitrobenzene	730	730	730	610	460	500	610	620	610
1,3-Dinitrobenzene	17	8.8	8.9	40	9.4	18 J	9.3	14	19
Nitrobenzene	1.1 U	1.4 U	1.2 U	3.1 U	1.1 U	0.71 U	1.5 U	1.7 U	2.0 U
Tetryl	3.1 U	4.1 U	3.5 U	9.0 U	3.1 U	2.0 U	4.4 U	5.0 U	5.7 U
Amino DNTs	54	31	29	35	8.9	52	75	42	34
2,4,6-Trinitrotoluene	890	900	870	750	560	600	750	770	760
2,6-Dinitrotoluene	8.0	3.3	3.0	12	2.9	9.0	3.8	7.0	8.6
2,4-Dinitrotoluene	72	21	19	25	8.8	33	8.1	5.3	5.1
Hardness (in mg/L)	-	-	353	-	325	-	-	343	-
Alkalinity (in mg/L)	-	-	186	-	186	-	-	194	-
Iron	-	-	316	-	284	-	-	241	-
Manganese	-	-	1790	-	1700	-	-	1820	-

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USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT
DATE:		5-Oct-94			6-Oct-94			7-Oct-94	
SAMPLE NAME:	IN10051	IN10052	IN10053	IN10061	IN10062	IN10063	IN10071	IN10072	IN10073
SAMPLE TIME:	9:52	12:50	15:05	9:55	12:10	15:00	8:45	11:30	13:55
HMX	15 U	14 U	14 U	14 U	14 U	14 U	14 U	14 U	14 U
RDX	7.2 U	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	7.0 U	6.7 U
1,3,5-Trinitrobenzene	610	660	670	650	650	650	590	590	590
1,3-Dinitrobenzene	11	16	18	17	19	21	12	4.6	14
Nitrobenzene	1.7 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.7 U	1.6 U
Tetryl	5.0 U	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	4.8 U	4.7 U
Amino DNTs	32	52	76	53	82	84	45	34	55
2,4,6-Trinitrotoluene	740	820	810	800	790	790	690	700	680
2,6-Dinitrotoluene	5.5	8.3	8.3	8.6	6.5	6.3	4.4	3.3	5.2
2,4-Dinitrotoluene	3.9	2.3	2.6	2.5	1.3	1.2	0.67	0.80	1.4
Hardness (in mg/L)	-	343	-	-	333	-	-	343	-
Alkalinity (in mg/L)	-	188	-	-	2.0 U	-	-	196	-
Iron	-	191	-	-	183	-	-	147	-
Manganese	-	1790	-	-	1820	-	-	1690	-

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USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT
DATE:		10-Oct-94			11-Oct-94			12-Oct-94	
SAMPLE NAME:	IN10101	IN10102	IN10103	IN10111	IN10112	IN10113	IN10121	IN10122	IN10123
SAMPLE TIME:	11:00	13:30	15:30	10:10	13:55	15:45	10:50	13:45	16:00
HMX	14 U	14 U	14 U	14 U	14 U	14 U	18 U	14 U	14 U
RDX	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	6.7 U	8.9 U	6.7 U	6.7 U
1,3,5-Trinitrobenzene	610	520	560	560	550	600	430	590	560
1,3-Dinitrobenzene	15	13	18	15	10	14	16	16	16
Nitrobenzene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	2.1 U	1.6 U	1.6 U
Tetryl	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	6.2 U	4.7 U	4.7 U
Amino DNTs	84	54	60	56	44	52	54	62	63
2,4,6-Trinitrotoluene	720	690	700	690	670	700	530	690	670
2,6-Dinitrotoluene	4.8	1.6 U	1.6 U	5.2	4.4	4.6	5.2	5.8	6.1
2,4-Dinitrotoluene	1.2	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	2.0 U	1.6 U	1.6 U
Hardness (in mg/L)	-	332	-	-	335	-	-	335	-
Alkalinity (in mg/L)	-	168	-	-	192	-	-	184	-
Iron	-	149	-	-	216	-	-	124	-
Manganese	-	1710	-	-	1630	-	-	1650	-

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USAEC UV/OX PILOT-SCALE DEMONSTRATION EXPLOSIVES AND INORGANIC DATA (in ug/L unless otherwise noted)

VENDOR:	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT	INFLUENT
DATE:		13-Oct-94			14-Oct-94	
SAMPLE NAME:	IN10131	IN10132	IN10133	IN10141	IN10142	IN10143
SAMPLE TIME:	11:20	14:35	14:35	10:30	13:15	14:45
HMX	14 U	14 U	14 U	14 U	14 U	14 U
RDX	6.7 U	6.7 U	6.7 U	6.7 U	5.8	6.4
1,3,5-Trinitrobenzene	570	560	560	560	550	540
1,3-Dinitrobenzene	1.6 U	1.6 U	1.6 U	1.6 U	12	1.6 U
Nitrobenzene	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U	1.6 U
Tetryl	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U	4.7 U
Amino DNTs	48	3.1 U	52	54	53	60
2,4,6-Trinitrotoluene	680	690	670	670	680	660
2,6-Dinitrotoluene	6.0	4.2	4.0	4.9	6.2	6.4
2,4-Dinitrotoluene	1.6 U	1.6 U	1.6 U	1.6 U	1.4	1.4
Hardness (in mg/L)	-	-	333	-	330	-
Alkalinity (in mg/L)	-	-	226	-	204	-
Iron	-	-	428	-	563	-
Manganese	-	-	1680	-	1640	-

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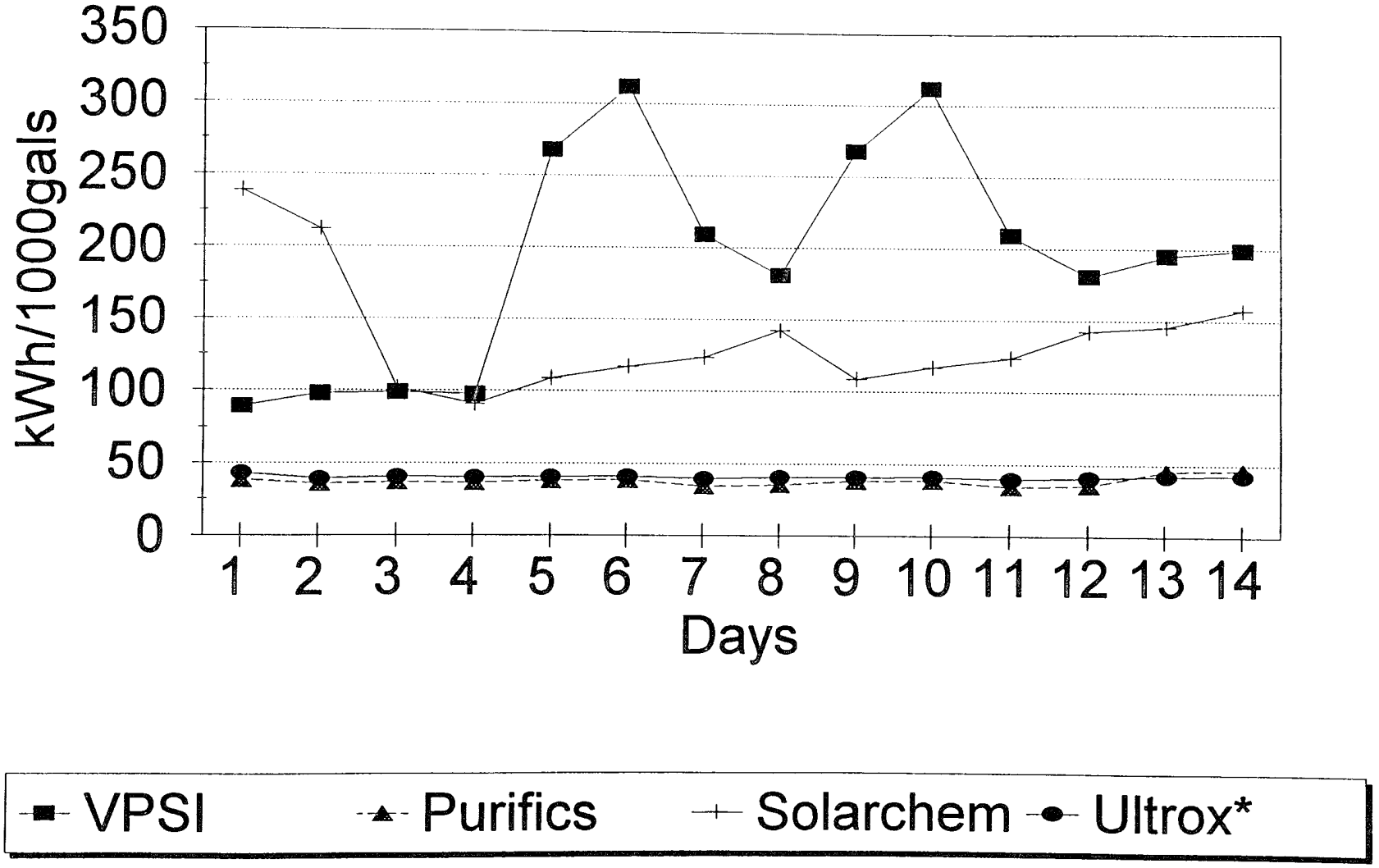
Savanna Army Depot Pilot Study

Company	VPSI				Purifics		
Date	Gallons	kWh	kWh/1000 gal		Gallons	kWh	kWh/1000 gal
9/27/94	2370	211	89.0		473	18	38.1
9/28/94	2022	198	97.9		535	19	35.5
9/29/94	2326	230	98.9		545	20	36.7
9/30/94	2245	219	97.6		525	19	36.2
10/03/94	830	222	267.5		502	19	37.8
10/04/94	741	231	311.7		500	19	38.0
10/05/94	1081	226	209.1		528	18	34.1
10/06/94	1243	225	181.0		542	19	35.1
10/07/94	830	222	267.5		502	19	37.8
10/10/94	741	231	311.7		500	19	38.0
10/11/94	1081	226	209.1		528	18	34.1
10/12/94	1243	225	181.0		542	19	35.1
10/13/94	1203	235	195.3		438	20	45.7
10/14/94	798	159	199.2		410	19	46.3
Average	1339.6	218.6	194.0		505.0	18.9	37.7
Company	**Solarchem**				**Ultrox**		
Date	Gallons	kWh	kWh/1000 gal		Gallons	kWh	kWh/1000 gal
9/27/94	390	93	238.5		1516	65	42.9
9/28/94	934	198	212.0		1722	67	38.9
9/29/94	982	100	101.8		1665	67	40.2
9/30/94	1010	92	91.1		1720	69	40.1
10/03/94	844	92	109.0		1692	68	40.2
10/04/94	819	96	117.2		1674	68	40.6
10/05/94	760	94	123.7		1627	64	39.3
10/06/94	695	99	142.4		1688	68	40.3
10/07/94	844	92	109.0		1692	68	40.2
10/10/94	819	96	117.2		1674	68	40.6
10/11/94	760	94	123.7		1627	64	39.3
10/12/94	695	99	142.4		1688	68	40.3
10/13/94	645	94	145.7		1645	69	41.9
10/14/94	616	97	157.5		1612	68	42.2
Average	772.4	102.6	137.9		1660.1	67.2	40.5

Power Consumption



*No explosives were detected in Ultrox'sTreated samples. Other vendor's results are unknown

ULTROX DIVISION OF ZIMPRO ENVIRONMENTAL
SAVANNA ARMY DEPOT PILOT DEMONSTRATION

Date: 9/27/94

Time	10:30	11:30	13:00	14:00	15:00	16:00	17:00	18:00		TOTAL
pH 11 Caustic Level (ml)	3680	2540	680	2950	2080	1350	n/r	3420		
Caustic Conc. (ml/l)	50 ml/liter	1 liter to make 4 liter								
Caustic Mix Added (ml)	0	0	0	3400	0	0	3500	0		
Caustic Used Last Hr. (ml)	0	1140	1860	1130	870	730	n/r	1430		7160
Filter Change (no. of filters)	1	1	1	1	1	1	1	0		7
pH 4 Acid Level (ml)	3400	1700	1080	2050	3600	2100	0	1250		
Acid Conc. (ml/l)	100 ml of 93% solution/liter									
Acid Mix Added (ml)	0	0	4000	3000	3500	0	1150	1100		
Acid Used Last Hr. (ml)	0	1700	4620	n/r	n/r	1500	n/r	3100		10920
Flow Rate (gpm)	3.6	3.6	3.6	3.6	3.7	3.7	n/r	3.6		3.63
UV Retention Time (min.)	90.3	90.3	90.3	90.3	87.8	87.8	n/r	90.3		89.6
Totalizer, gal (Ultrox)	58	268	600	818	1034	1180	n/r	1611		1553
Gallons last hr.	0	210	332	218	216	146	n/r	431		1553
Air Flow to Ozone Generator (SCFH)	105	105	105	105	105	105	n/r	108		
Ozone Conc. (%)	2.06	1.91	2.07	2.06	2.06	2.06	n/r	2.04		
Ozone Dosage (mg/l)	127.8	118.5	128.4	127.8	124.3	124.3	n/r	130.2		125.9
Labor (minutes UV/Ox)										0
Labor (minutes Pre/Post Treatment)										34
Totalizers (Client)										
Ultrox (gal)	3177	3389	3706	3910	4116	4290	n/r	4693		1516
Ultrox (kWh)	176	184	198	207	216	224	n/r	241		65

n/r = Data not recorded

PARAMETER	*Units*	*Consumption*
Electrical Consumption	kWh/1000 gal	42.9
NaOH (50%)	liters/1000 gal	1.417
H2SO4 (93%)	liters/1000 gal	1.080
Filters	filters/1000 gal	4.6
Upsets/Restarts	per 1000 gal	0
Down Time	per 1000 gal	0
UV/Ox Labor	min/1000 gal	0.0
Pre/Post Treat Labor	min/1000 gal	22.4

ULTROX DIVISION OF ZIMPRO ENVIRONMENTAL
SAVANNA ARMY DEPOT PILOT DEMONSTRATION

Date: 9/28/94

Time	8:35	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	TOTAL
pH 11 Caustic Level (ml)	4000	3400	2500	1925	1250	550	3450	2750	1900	
Caustic Conc. (ml/l)	300 ml of 50% solution/liter									
Caustic Mix Added (ml)	0	0	0	0	0	3450	0	0	0	
Caustic Used Last Hr. (ml)	0	600	900	575	675	706	550	700	850	5556
Filter Change (no. of filters)	0	0	1	2	1	1	1	1	2	9
pH 4 Acid Level (ml)	3850	2800	1425	3100	2000	850	3050	1000	250	
Acid Conc. (ml/l)	150 ml of 93% solution/liter									
Acid Mix Added (ml)	0	0	2475	0	0	3150	0	0	0	
Acid Used Last Hr. (ml)	0	1050	825	900	900	1150	950	1250	1550	8575
Flow Rate (gpm)	3.7	3.6	3.8	3.4	3.7	3.8	3.9	3.7	3.7	3.70
UV Retention Time (min.)	87.8	90.3	85.5	95.6	87.8	85.5	83.3	87.8	87.8	88.0
Totalizer, gal (Ultrox)	9647	9695	10020	10298	10580	10878	11137	11417	11669	2022
Gallons last hr.	0	48	325	278	282	298	259	280	252	2022
Air Flow to Ozone Generator (SCFH)	108	105	108	106	108	108	108	108	108	
Ozone Conc. (%)	2.06	2.05	2	1.99	2	2.01	2.02	2.02	2.03	
Ozone Dosage (mg/l)	127.9	127.2	120.9	132.0	124.2	121.5	119.0	125.4	126.0	124.9
Labor (minutes UV/Ox)										0
Labor (minutes Pre/Post Treatment)										23
Totalizers (Client)										
Ultrox (gal)	4733	4947	5187	5387	5600	5829	6047	6242	6455	1722
Ultrox (kWh)	249	256	265	273	281	291	299	308	316	67

n/r = Data not recorded

PARAMETER	*Units*	*Consumption*
Electrical Consumption	kWh/1000 gal	38.9
NaOH (50%)	liters/1000 gal	0.968
H2SO4 (93%)	liters/1000 gal	0.747
Filters	filters/1000 gal	5.2
Upsets/Restarts	per 1000 gal	0
Down Time	per 1000 gal	0
UV/Ox Labor	min/1000 gal	0.0
Pre/Post Treat Labor	min/1000 gal	13.4

ULTROX DIVISION OF ZIMPRO ENVIRONMENTAL
SAVANNA ARMY DEPOT PILOT DEMONSTRATION

Date: 9/29/94

Time	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:38	16:30	TOTAL
pH 11 Caustic Level (ml)	4000	3425	2750	2225	1700	1150	550	3475	2875	
Caustic Conc. (ml/l)	300 ml of 50% solution/liter									
Caustic Mix Added (ml)	0	0	0	0	0	0	3450	0	0	
Caustic Used Last Hr. (ml)	0	575	675	525	525	550	600	525	600	4575
Filter Change (no. of filters)	0	1	1	1	1	1	2	1	1	9
pH 4 Acid Level (ml)	3900	2975	1825	900	3100	2125	1200	3000	2100	
Acid Conc. (ml/l)	150 ml of 93% solution/liter									
Acid Mix Added (ml)	0	0	0	3100	0	0	2800	0	0	
Acid Used Last Hr. (ml)	0	925	1150	925	900	975	1025	1000	900	7800
Flow Rate (gpm)	3.7	3.8	3.9	3.9	3.7	3.6	n/r	3.7	3.7	3.75
UV Retention Time (min.)	87.8	85.5	83.3	83.3	87.8	90.3	n/r	87.8	87.8	77.1
Totalizer, gal (Ultrox)	0	197	439	645	848	1059	n/r	1476	1665	1665
Gallons last hr.	0	197	242	206	203	211	n/r	417	189	1665
Air Flow to Ozone Generator (SCFH)	110	110	110	110	110	105	n/r	105	110	
Ozone Conc. (%)	2.14	1.99	1.98	1.96	2.02	2.02	n/r	2.02	2.02	
Ozone Dosage (mg/l)	135.3	122.5	118.8	117.6	127.7	125.3	n/r	121.9	127.7	124.6
Labor (minutes UV/Ox)										0
Labor (minutes Pre/Post Treatment)										21
Totalizers (Client)										
Ultrox (gal)	6498	6732	6965	7166	7371	7561	7898	8000	8163	1665
Ultrox (kWh)	320	329	338	346	354	363	373	382	388	68

n/r = Data not recorded

PARAMETER	*Units*	*Consumption*
Electrical Consumption	kWh/1000 gal	40.8
NaOH (50%)	liters/1000 gal	0.824
H2SO4 (93%)	liters/1000 gal	0.703
Filters	filters/1000 gal	5.4
Upsets/Restarts	per 1000 gal	0
Down Time	per 1000 gal	0
UV/Ox Labor	min/1000 gal	0.0
Pre/Post Treat Labor	min/1000 gal	12.6

ULTROX DIVISION OF ZIMPRO ENVIRONMENTAL
SAVANNA ARMY DEPOT PILOT DEMONSTRATION

Date: 9/30/94

Time	8:30	9:33	10:30	11:30	12:30	13:30	14:30	15:30	16:30	TOTAL
pH 11 Caustic Level (ml)	3825	3050	2375	1775	1100	3400	2700	2050	1250	
Caustic Conc. (ml/l)	300 ml of 50% solution/liter									
Caustic Mix Added (ml)	0	0	0	0	2900	0	0	0	0	
Caustic Used Last Hr. (ml)	0	775	675	600	675	600	700	650	800	5475
Filter Change (no. of filters)	1	1	1	1	1	1	1	1	1	9
pH 4 Acid Level (ml)	3800	2600	1450	375	3100	2075	975	2950	1650	
Acid Conc. (ml/l)	150 ml of 93% solution/liter									
Acid Mix Added (ml)	0	0	0	0	0	0	3025	0	0	
Acid Used Last Hr. (ml)	0	1200	1150	900	900	1025	1100	1050	1300	8625
Flow Rate (gpm)	3.53	3.63	3.58	3.38	3.38	3.53	3.82	3.63	3.72	3.58
UV Retention Time (min.)	92.1	89.5	90.8	96.2	96.2	92.1	85.1	89.5	87.4	91.0
Totalizer, gal (Ultrox)	1823	1925	2142	2381	2585	2700	3030	3204	3367	1544
Gallons last hr.	0	102	217	239	204	115	330	174	163	1544
Air Flow to Ozone Generator (SCFH)	110	110	110	110	110	110	110	115	110	
Ozone Conc. (%)	2.03	2.01	1.98	1.97	2	1.98	1.92	2	1.99	
Ozone Dosage (mg/l)	134.6	129.6	129.4	136.4	138.4	131.2	117.6	134.8	125.2	130.8
Labor (minutes UV/Ox)										0
Labor (minutes Pre/Post Treatment)										21
Totalizers (Client)										
Ultrox (gal)	8184	8427	8652	8883	9080	9252	9503	9718	9904	1720
Ultrox (kWh)	392	402	411	420	428	435	444	452	461	69

n/r = Data not recorded

PARAMETER	*Units*	*Consumption*
Electrical Consumption	kWh/1000 gal	40.1
NaOH (50%)	liters/1000 gal	0.955
H2SO4 (93%)	liters/1000 gal	0.752
Filters	filters/1000 gal	5.2
Upsets/Restarts	per 1000 gal	0
Down Time	per 1000 gal	0
UV/Ox Labor	min/1000 gal	0.0
Pre/Post Treat Labor	min/1000 gal	12.2

ULTROX DIVISION OF ZIMPRO ENVIRONMENTAL
SAVANNA ARMY DEPOT PILOT DEMONSTRATION

Date: 10/3/94

Time	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	TOTAL
pH 11 Caustic Level (ml)	3400	2750	2150	1500	3450	2800	2250	1475	675	
Caustic Conc. (ml/l)	300 ml of 50% solution/liter									
Caustic Mix Added (ml)	0	0	0	2500	0	0	0	0	0	
Caustic Used Last Hr. (ml)	0	650	600	650	550	650	550	775	800	5225
Filter Change (no. of filters)	0	1	1	1	0	1	1	1	0	6
pH 4 Acid Level (ml)	3150	1850	2775	1350	2850	1700	575	2775	1450	
Acid Conc. (ml/l)	150 ml of 93% solution/liter									
Acid Mix Added (ml)	0	2150	0	2650	0	0	3425	0	0	
Acid Used Last Hr. (ml)	0	1300	1225	1425	1150	1150	1125	1225	1325	9925
Flow Rate (gpm)	3.58	3.63	3.53	3.63	3.63	3.63	3.68	3.68	3.58	3.62
UV Retention Time (min.)	90.8	89.5	92.1	89.5	89.5	89.5	88.3	88.3	90.8	89.8
Totalizer, gal (Ultrox)	3584	3796	4031	4233	4443	4647	4903	5079	5278	1694
Gallons last hr.	0	212	235	202	210	204	256	176	199	1694
Air Flow to Ozone Generator (SCFH)	110	110	115	115	115	120	120	120	120	
Ozone Conc. (%)	1.99	1.97	2.01	2.05	2.02	2	1.95	1.98	1.98	
Ozone Dosage (mg/l)	130.1	127.0	139.3	138.1	136.1	140.6	135.3	137.3	141.2	136.1
Labor (minutes UV/Ox)										10
Labor (minutes Pre/Post Treatment)										15
Totalizers (Client)										
Ultrox (gal)	10099	10303	10524	10754	10949	11155	11400	11592	11791	1692
Ultrox (kWh)	472	480	490	499	506	515	525	532	540	68

n/r = Data not recorded

PARAMETER	*Units*	*Consumption*
Electrical Consumption	kWh/1000 gal	40.2
NaOH (50%)	liters/1000 gal	0.926
H2SO4 (93%)	liters/1000 gal	0.880
Filters	filters/1000 gal	3.5
Upsets/Restarts	per 1000 gal	0
Down Time	per 1000 gal	0
UV/Ox Labor	min/1000 gal	5.9
Pre/Post Treat Labor	min/1000 gal	8.9

ULTROX DIVISION OF ZIMPRO ENVIRONMENTAL
SAVANNA ARMY DEPOT PILOT DEMONSTRATION

Date: 10/4/94

Time	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	TOTAL
pH 11 Caustic Level (ml)	3900	3200	2750	2150	1450	3700	3000	2400	1908	
Caustic Conc. (ml/l)	300 ml of 50% solution/liter									
Caustic Mix Added (ml)	0	0	0	0	2575	0	0	0	0	
Caustic Used Last Hr. (ml)	0	700	450	600	700	300	700	600	492	4542
Filter Change (no. of filters)	1	0	1	1	0	1	1	1	1	7
pH 4 Acid Level (ml)	3775	2500	1675	2950	1625	3150	2050	925	3300	
Acid Conc. (ml/l)	150 ml of 93% solution/liter									
Acid Mix Added (ml)	0	0	2325	0	2400	0	0	3075	0	
Acid Used Last Hr. (ml)	0	1275	825	1150	1325	850	1100	1125	700	8350
Flow Rate (gpm)	3.58	3.63	3.58	3.58	3.63	3.68	3.63	3.58	3.48	3.60
UV Retention Time (min.)	90.8	89.5	90.8	90.8	89.5	88.3	89.5	90.8	93.4	90.4
Totalizer, gal (Ultrox)	5341	5570	5832	5985	6220	6431	6624	6871	7051	1710
Gallons last hr.	0	229	262	153	235	211	193	247	180	1710
Air Flow to Ozone Generator (SCFH)	115	115	115	115	115	115	110	110	110	
Ozone Conc. (%)	2.1	2.01	2.01	1.995	1.99	2.02	2.02	2.03	2.04	
Ozone Dosage (mg/l)	143.5	135.4	137.3	136.3	134.1	134.3	130.2	132.7	137.2	135.7
Labor (minutes UV/Ox)										0
Labor (minutes Pre/Post Treatment)										25
Totalizers (Client)										
Ultrox (gal)	11840	12079	12236	12499	12707	12925	13128	13353	13514	1674
Ultrox (kWh)	547	557	564	573	581	590	598	607	615	68

n/r = Data not recorded

PARAMETER	*Units*	*Consumption*
Electrical Consumption	kWh/1000 gal	40.6
NaOH (50%)	liters/1000 gal	0.814
H2SO4 (93%)	liters/1000 gal	0.748
Filters	filters/1000 gal	4.2
Upsets/Restarts	per 1000 gal	0
Down Time	per 1000 gal	0
UV/Ox Labor	min/1000 gal	0.0
Pre/Post Treat Labor	min/1000 gal	14.9

ULTROX DIVISION OF ZIMPRO ENVIRONMENTAL
SAVANNA ARMY DEPOT PILOT DEMONSTRATION

Date: 10/5/94

Time	8:49	9:30	10:30	11:30	12:30	13:30	14:30	15:38	16:30	TOTAL
pH 11 Caustic Level (ml)	3700	3200	2650	1900	3600	2950	2350	1550	3650	
Caustic Conc. (ml/l)	300 ml of 50% solution/liter									
Caustic Mix Added (ml)	0	0	0	2100	0	0	0	2450	0	
Caustic Used Last Hr. (ml)	0	500	550	750	400	650	600	800	350	4600
Filter Change (no. of filters)	0	2	0	1	1	1	2	2	0	9
pH 4 Acid Level (ml)	3400	2500	1250	2850	1950	850	3200	1600	3175	
Acid Conc. (ml/l)	150 ml of 93% solution/liter									
Acid Mix Added (ml)	0	0	2750	0	0	3150	0	2400	0	
Acid Used Last Hr. (ml)	0	900	1250	1150	900	1100	800	1600	825	8525
Flow Rate (gpm)	3.58	3.68	3.63	3.58	3.53	3.43	3.58	3.58	3.58	3.57
UV Retention Time (min.)	90.8	88.3	89.5	90.8	92.1	94.8	90.8	90.8	90.8	91.0
Totalizer, gal (Ultrox)	7118	7300	7518	7727	7936	8156	8343	8572	8780	1662
Gallons last hr.	0	182	218	209	209	220	187	229	208	1662
Air Flow to Ozone Generator (SCFH)	112	115	115	115	115	115	115	115	115	
Ozone Conc. (%)	2.05	2.05	2.04	2.04	2.03	2.02	2	2.02	2	
Ozone Dosage (mg/l)	136.4	136.3	137.5	139.4	140.7	144.1	136.7	138.0	136.7	138.4
Labor (minutes UV/Ox)										0
Labor (minutes Pre/Post Treatment)										12
Totalizers (Client)										
Ultrox (gal)	13630	13786	14010	14222	14414	n/r	14819	15083	15257	1627
Ultrox (kWh)	623	628	637	645	653	n/r	670	681	687	64

n/r = Data not recorded

PARAMETER	*Units*	*Consumption*
Electrical Consumption	kWh/1000 gal	39.3
NaOH (50%)	liters/1000 gal	0.848
H2SO4 (93%)	liters/1000 gal	0.786
Filters	filters/1000 gal	5.5
Upsets/Restarts	per 1000 gal	0
Down Time	per 1000 gal	0
UV/Ox Labor	min/1000 gal	0.0
Pre/Post Treat Labor	min/1000 gal	7.4

ULTROX DIVISION OF ZIMPRO ENVIRONMENTAL
SAVANNA ARMY DEPOT PILOT DEMONSTRATION

Date: 10/6/94

Time	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	TOTAL
pH 11 Caustic Level (ml)	3900	3400	2650	2000	1300	3450	2600	1875	1350	
Caustic Conc. (ml/l)	300 ml of 50% solution/liter									
Caustic Mix Added (ml)	0	0	0	0	2700	0	0	0	0	
Caustic Used Last Hr. (ml)	0	500	750	650	700	550	850	725	525	5250
Filter Change (no. of filters)	0	2	0	2	1	1	0	2	0	8
pH 4 Acid Level (ml)	3850	2850	1400	2900	1700	3000	1600	2800	1700	
Acid Conc. (ml/l)	150 ml of 93% solution/liter									
Acid Mix Added (ml)	0	0	2600	0	2300	0	2400	0	0	
Acid Used Last Hr. (ml)	0	1000	1450	1100	1200	1000	1400	1200	1100	9450
Flow Rate (gpm)	3.58	3.58	3.68	3.58	3.58	3.68	3.58	3.58	3.53	3.60
UV Retention Time (min.)	90.8	90.8	88.3	90.8	90.8	88.3	90.8	90.8	92.1	90.4
Totalizer, gal (Ultrox)	8820	9032	9246	9467	9678	9895	10105	10324	10536	1716
Gallons last hr.	0	212	214	221	211	217	210	219	212	1716
Air Flow to Ozone Generator (SCFH)	115	115	115	112	115	110	110	110	110	
Ozone Conc. (%)	2.08	2.03	2.03	2.01	2.03	2.02	2.03	2.01	2.01	
Ozone Dosage (mg/l)	142.1	138.7	134.9	133.8	138.7	128.4	132.7	131.4	133.2	134.9
Labor (minutes UV/Ox)										0
Labor (minutes Pre/Post Treatment)										10
Totalizers (Client)										
Ultrox (gal)	15303	15503	15718	15938	16143	16356	16569	16789	16991	1688
Ultrox (kWh)	692	701	710	718	726	735	743	752	760	68

n/r = Data not recorded

PARAMETER	*Units*	*Consumption*
Electrical Consumption	kWh/1000 gal	40.3
NaOH (50%)	liters/1000 gal	0.933
H2SO4 (93%)	liters/1000 gal	0.840
Filters	filters/1000 gal	4.7
Upsets/Restarts	per 1000 gal	0
Down Time	per 1000 gal	0
UV/Ox Labor	min/1000 gal	0.0
Pre/Post Treat Labor	min/1000 gal	5.9

ULTROX DIVISION OF ZIMPRO ENVIRONMENTAL
SAVANNA ARMY DEPOT PILOT DEMONSTRATION

Date: 10/7/94

Time	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	TOTAL
pH 11 Caustic Level (ml)	3850	3400	2700	2150	1600	1050	3400	2800	3100	
Caustic Conc. (ml/l)	300 ml of 50% solution/liter									
Caustic Mix Added (ml)	0	0	0	0	0	2950	0	1200	0	
Caustic Used Last Hr. (ml)	0	450	700	550	550	550	600	600	900	4900
Filter Change (no. of filters)	0	3	0	2	0	2	0	3	2	12
pH 4 Acid Level (ml)	3600	2600	1350	3000	2000	1000	2900	1750	2550	
Acid Conc. (ml/l)	150 ml of 93% solution/liter									
Acid Mix Added (ml)	0	0	2650	0	0	3000	0	2250	0	
Acid Used Last Hr. (ml)	0	1000	1250	1000	1000	1000	1100	1150	1450	8950
Flow Rate (gpm)	3.48	3.43	3.63	3.33	3.53	3.58	3.58	3.53	3.53	3.51
UV Retention Time (min.)	93.4	94.8	89.5	97.6	92.1	90.8	90.8	92.1	92.1	92.6
Totalizer, gal (Ultrox)	10584	10806	11028	11224	11440	11643	11850	12072	12291	1707
Gallons last hr.	0	222	222	196	216	203	207	222	219	1707
Air Flow to Ozone Generator (SCFH)	110	110	110	110	112	112	110	110	110	
Ozone Conc. (%)	2.1	2.04	2.02	2.01	2	1.98	1.99	2.01	2.04	
Ozone Dosage (mg/l)	141.2	139.2	130.2	141.2	135.0	131.8	130.1	133.2	135.2	135.2
Labor (minutes UV/Ox)										0
Labor (minutes Pre/Post Treatment)										10
Totalizers (Client)										
Ultrox (gal)	17075	17286	17493	17673	17898	18078	18269	18508	18714	1639
Ultrox (kWh)	765	774	782	790	799	807	814	824	832	67

n/r = Data not recorded

PARAMETER	*Units*	*Consumption*
Electrical Consumption	kWh/1000 gal	40.9
NaOH (50%)	liters/1000 gal	0.897
H2SO4 (93%)	liters/1000 gal	0.819
Filters	filters/1000 gal	7.3
Upsets/Restarts	per 1000 gal	0
Down Time	per 1000 gal	0
UV/Ox Labor	min/1000 gal	0.0
Pre/Post Treat Labor	min/1000 gal	6.1

ULTROX DIVISION OF ZIMPRO ENVIRONMENTAL
SAVANNA ARMY DEPOT PILOT DEMONSTRATION

Date: 10/10/94

Time	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	TOTAL
pH 11 Caustic Level (ml)	3900	3350	2675	1950	1400	3500	2700	2300	1750	
Caustic Conc. (ml/l)	300 ml of 50% solution/liter									
Caustic Mix Added (ml)	0	0	0	0	2600	0	0	0	0	
Caustic Used Last Hr. (ml)	0	550	675	725	550	500	800	400	550	4750
Filter Change (no. of filters)	0	1	0	1	0	2	2	0	1	7
pH 4 Acid Level (ml)	3775	2700	1775	2700	1800	3050	1725	3250	2350	
Acid Conc. (ml/l)	150 ml of 93% solution/liter									
Acid Mix Added (ml)	0	0	2225	0	2200	0	2275	0	0	
Acid Used Last Hr. (ml)	0	1075	925	1300	900	950	1325	750	900	8125
Flow Rate (gpm)	3.48	3.58	3.58	3.63	3.58	3.58	3.63	3.63	3.53	3.58
UV Retention Time (min.)	93.4	90.8	90.8	89.5	90.8	90.8	89.5	89.5	92.1	90.8
Totalizer, gal (Ultrox)	12361	12565	12795	12997	13201	13427	13653	13808	13983	1622
Gallons last hr.	0	204	230	202	204	226	226	155	175	1622
Air Flow to Ozone Generator (SCFH)	110	110	110	110	110	110	110	112	110	
Ozone Conc. (%)	2.11	2.1	1.96	2	2.02	2.01	2.02	2.02	2.02	
Ozone Dosage (mg/l)	141.9	137.2	128.1	128.9	132.0	131.4	130.2	132.6	133.9	132.9
Labor (minutes UV/Ox)										0
Labor (minutes Pre/Post Treatment)										15
Totalizers (Client)										
Ultrox (gal)	18779	18993	19212	19401	n/r	19827	20051	20205	20360	1581
Ultrox (kWh)	840	848	857	864	n/r	881	890	898	905	65

n/r = Data not recorded

PARAMETER	*Units*	*Consumption*
Electrical Consumption	kWh/1000 gal	41.1
NaOH (50%)	liters/1000 gal	0.901
H2SO4 (93%)	liters/1000 gal	0.771
Filters	filters/1000 gal	4.4
Upsets/Restarts	per 1000 gal	0
Down Time	per 1000 gal	0
UV/Ox Labor	min/1000 gal	0.0
Pre/Post Treat Labor	min/1000 gal	9.5

ULTROX DIVISION OF ZIMPRO ENVIRONMENTAL
SAVANNA ARMY DEPOT PILOT DEMONSTRATION

Date: 10/11/94

Time	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	TOTAL
pH 11 Caustic Level (ml)	3925	3375	2850	2225	1750	1275	3350	2650	2000	
Caustic Conc. (ml/l)	300 ml of 50% solution/liter									
Caustic Mix Added (ml)	0	0	0	0	0	2725	0	0	0	
Caustic Used Last Hr. (ml)	0	600	525	625	475	475	650	700	650	4700
Filter Change (no. of filters)	0	1	1	2	0	2	1	0	1	8
pH 4 Acid Level (ml)	3600	2500	1525	450	3150	2250	950	3050	1850	
Acid Conc. (ml/l)	150 ml of 93% solution/liter									
Acid Mix Added (ml)	0	0	0	3550	0	0	3050	0	0	
Acid Used Last Hr. (ml)	0	1100	975	1075	850	900	1300	950	1200	8350
Flow Rate (gpm)	3.48	3.68	3.58	3.58	3.53	3.58	3.58	3.58	3.58	3.57
UV Retention Time (min.)	93.4	88.3	90.8	90.8	92.1	90.8	90.8	90.8	90.8	90.9
Totalizer, gal (Ultrox)	14036	14251	14454	14676	14879	15053	15258	15495	15696	1660
Gallons last hr.	0	215	203	222	203	174	205	237	201	1660
Air Flow to Ozone Generator (SCFH)	112	110	110	110	110	110	110	110	110	
Ozone Conc. (%)	2.07	1.99	2	2.01	2.02	2.03	2.03	2.02	2.02	
Ozone Dosage (mg/l)	141.7	126.5	130.7	131.4	133.9	132.7	132.7	132.0	132.0	132.6
Labor (minutes UV/Ox)										0
Labor (minutes Pre/Post Treatment)										28
Totalizers (Client)										
Ultrox (gal)	20424	20648	20848	21062	21260	21459	21591	21822	22025	1601
Ultrox (kWh)	911	920	929	938	946	955	962	971	978	67

n/r = Data not recorded

PARAMETER	*Units*	*Consumption*
Electrical Consumption	kWh/1000 gal	41.8
NaOH (50%)	liters/1000 gal	0.881
H2SO4 (93%)	liters/1000 gal	0.782
Filters	filters/1000 gal	5.0
Upsets/Restarts	per 1000 gal	0
Down Time	per 1000 gal	0
UV/Ox Labor	min/1000 gal	0.0
Pre/Post Treat Labor	min/1000 gal	17.5

ULTROX DIVISION OF ZIMPRO ENVIRONMENTAL
SAVANNA ARMY DEPOT PILOT DEMONSTRATION

Date: 10/12/94

Time	8:30	9:25	10:30	11:30	12:30	13:30	14:30	15:30	16:30	TOTAL
pH 11 Caustic Level (ml)	3875	3250	2700	2000	1550	3500	2900	2425	1650	
Caustic Conc. (ml/l)	300 ml of 50% solution/liter									
Caustic Mix Added (ml)	0	0	0	0	2450	0	0	0	0	
Caustic Used Last Hr. (ml)	0	625	550	700	450	500	600	475	775	4675
Filter Change (no. of filters)	2	0	2	0	1	1	2	0	2	10
pH 4 Acid Level (ml)	3600	2525	1375	2800	1800	3200	2100	1000	2750	
Acid Conc. (ml/l)	150 ml of 93% solution/liter									
Acid Mix Added (ml)	0	0	2625	0	2300	0	0	3000	0	
Acid Used Last Hr. (ml)	0	1075	1150	1200	1000	800	1100	1100	1250	8675
Flow Rate (gpm)	3.48	3.58	3.58	3.58	3.68	3.58	3.58	3.63	3.68	3.60
UV Retention Time (min.)	93.4	90.8	90.8	90.8	88.3	90.8	90.8	89.5	88.3	90.4
Totalizer, gal (Ultrox)	15699	15902	16115	16335	16535	16731	16936	17156	17369	1670
Gallons last hr.	0	203	213	220	200	196	205	220	213	1670
Air Flow to Ozone Generator (SCFH)	110	110	110	110	110	110	110	110	110	
Ozone Conc. (%)	2.1	2.07	2.04	2	2.04	2.01	2.02	2.02	2.02	
Ozone Dosage (mg/l)	141.2	135.3	133.3	130.7	129.7	131.4	132.0	130.2	128.4	132.5
Labor (minutes UV/Ox)										0
Labor (minutes Pre/Post Treatment)										20
Totalizers (Client)										
Ultrox (gal)	22066	22238	22480	22698	22912	23104	23284	23516	23728	1662
Ultrox (kWh)	982	990	1000	1007	1017	1025	1032	1041	1049	67

n/r = Data not recorded

PARAMETER	*Units*	*Consumption*
Electrical Consumption	kWh/1000 gal	40.3
NaOH (50%)	liters/1000 gal	0.844
H2SO4 (93%)	liters/1000 gal	0.783
Filters	filters/1000 gal	6.0
Upsets/Restarts	per 1000 gal	0
Down Time	per 1000 gal	0
UV/Ox Labor	min/1000 gal	0.0
Pre/Post Treat Labor	min/1000 gal	12.0

ULTROX DIVISION OF ZIMPRO ENVIRONMENTAL
SAVANNA ARMY DEPOT PILOT DEMONSTRATION

Date: 10/13/94

Time	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	TOTAL
pH 11 Caustic Level (ml)	3850	3300	2800	2150	3300	2875	2350	1625	3350	
Caustic Conc. (ml/l)	300 ml of 50% solution/liter									
Caustic Mix Added (ml)	0	0	0	1850	0	0	0	2375	0	
Caustic Used Last Hr. (ml)	0	550	500	650	700	425	525	725	650	4725
Filter Change (no. of filters)	0	1	1	2	0	2	1	0	1	8
pH 4 Acid Level (ml)	3700	2750	1700	2800	1750	600	3250	2225	2900	
Acid Conc. (ml/l)	150 ml of 93% solution/liter									
Acid Mix Added (ml)	0	0	2300	0	0	3400	0	1775	0	
Acid Used Last Hr. (ml)	0	950	950	1200	1050	1150	750	1025	1100	8175
Flow Rate (gpm)	3.53	3.58	3.63	3.53	3.68	3.48	3.53	3.63	3.53	3.57
UV Retention Time (min.)	92.1	90.8	89.5	92.1	88.3	93.4	92.1	89.5	92.1	91.1
Totalizer, gal (Ultrox)	17448	17654	17854	18069	18283	18492	18700	18925	19129	1681
Gallons last hr.	0	206	200	215	214	209	208	225	204	1681
Air Flow to Ozone Generator (SCFH)	110	110	110	110	110	110	110	110	110	
Ozone Conc. (%)	2.11	2	1.99	1.99	2	1.97	1.97	2.02	2.03	
Ozone Dosage (mg/l)	139.9	130.7	128.3	131.9	127.2	132.5	130.6	130.2	134.6	131.7
Labor (minutes UV/Ox)										0
Labor (minutes Pre/Post Treatment)										16
Totalizers (Client)										
Ultrox (gal)	23781	23990	24200	24385	24623	24814	25004	25248	25426	1645
Ultrox (kWh)	1055	1065	1073	1081	1091	1099	1107	1115	1124	69

n/r = Data not recorded

PARAMETER	*Units*	*Consumption*
Electrical Consumption	kWh/1000 gal	41.9
NaOH (50%)	liters/1000 gal	0.862
H2SO4 (93%)	liters/1000 gal	0.745
Filters	filters/1000 gal	4.9
Upsets/Restarts	per 1000 gal	0
Down Time	per 1000 gal	0
UV/Ox Labor	min/1000 gal	0.0
Pre/Post Treat Labor	min/1000 gal	9.7

ULTROX DIVISION OF ZIMPRO ENVIRONMENTAL
SAVANNA ARMY DEPOT PILOT DEMONSTRATION

Date: 10/14/94

Time	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	TOTAL
pH 11 Caustic Level (ml)	3875	3375	2800	2200	1550	3400	2875	2100	1500	
Caustic Conc. (ml/l)	300 ml of 50% solution/liter									
Caustic Mix Added (ml)	0	0	0	0	2450	0	0	0	0	
Caustic Used Last Hr. (ml)	0	500	575	600	0	600	525	775	600	4175
Filter Change (no. of filters)	2	2	1	1	2	2	1	0	0	11
pH 4 Acid Level (ml)	3775	2750	1650	2900	1925	2900	1875	1775	850	
Acid Conc. (ml/l)	150 ml of 93% solution/liter									
Acid Mix Added (ml)	0	0	2350	0	2075	0	1100	0	0	
Acid Used Last Hr. (ml)	0	1050	1100	1100	1075	1100	1025	1100	925	8475
Flow Rate (gpm)	3.43	3.48	n/r	n/r	n/r	3.68	3.58	3.63	n/r	3.6
UV Retention Time (min.)	94.8	93.4	n/r	n/r	n/r	88.3	90.8	89.5	n/r	91.4
Totalizer, gal (Ultrox)	19207	19428	n/r	n/r	n/r	19883	20081	20300	n/r	1093
Gallons last hr.	0	221	n/r	n/r	n/r	455	198	219	n/r	1093
Air Flow to Ozone Generator (SCFH)	110	110	110	110	110	110	110	112	112	
Ozone Conc. (%)	2.08	2.05	1.99	1.99	1.97	2.01	2.01	2	2.02	
Ozone Dosage (mg/l)	141.9	137.8	n/r	n/r	n/r	127.8	131.4	131.3	n/r	134.0
Labor (minutes UV/Ox)										0
Labor (minutes Pre/Post Treatment)										22
Totalizers (Client)										
Ultrox (gal)	25507	25726	n/r	26142	26344	26538	26739	26948	27119	1612
Ultrox (kWh)	1130	1139	n/r	1156	1165	1173	1181	1190	1198	68

n/r = Data not recorded

PARAMETER	*Units*	*Consumption*
Electrical Consumption	kWh/1000 gal	42.2
NaOH (50%)	liters/1000 gal	0.777
H2SO4 (93%)	liters/1000 gal	0.789
Filters	filters/1000 gal	6.8
Upsets/Restarts	per 1000 gal	0
Down Time	per 1000 gal	0
UV/Ox Labor	min/1000 gal	0.0
Pre/Post Treat Labor	min/1000 gal	13.6

Consumables

Field Demonstration Operating and Maintenance Costs

Consumable	Units	Cost ($/unit)	Average* Units/1000 gallons	Gallons/Day	Cost $/day	Cost $/yr
Electricity	kWh	$0.06	40.8	72,000	$176.26	$64,333.44
NaOH	lbs	$0.10	0.9789	72,000	$7.05	$2,572.55
H2SO4	lbs	$0.07	0.113	72,000	$0.57	$207.87
UV Lamps	lamps	$50.00	NA	72,000	$68.49	$25,000.00
Filters	filters	$1.00	5.2	72,000	$374.40	$136,656.00
Upsets/Restarts	no. occurances	$0.00	0	72,000	$0.00	$0.00
Down Time	minutes	$0.00	0	72,000	$0.00	$0.00
UV/Ox Labor	minutes	$0.248	0.0059	72,000	$0.11	$38.45
Pre/Post Treat Labor	minutes	$0.248	11.9	72,000	$212.49	$77,557.54
Totals				72,000	$839.36	$306,365.85

*Except for labor, averages are calculated by deleting the highest and lowest values and averaging remaining values

Ultrox UV lamps are rated for 1 year continuous operation

Full Scale System Operating and Maintenance Costs

(Without Manganese Removal Pretreatment)

Consumable	Units	Cost ($/unit)	Average* Units/1000 gallons	Gallons/Day	Cost $/day	Cost $/yr
Electricity	kWh	$0.06	40.8	72,000	$176.26	$64,333.44
NaOH	lbs	$0.10	0.1681	72,000	$1.21	$441.77
H2SO4	lbs	$0.07	2.9495	72,000	$14.87	$5,425.90
UV Lamps	lamps	$50.00	NA	72,000	$68.49	$25,000.00
Air Filters	filters	$30.00	NA	72,000	$0.74	$270.10
Compressor Filter	filters	$100.00	NA	72,000	$0.27	$100.00
Compressor Oil	volumes	$50.00	NA	72,000	$0.14	$50.00
Upsets/Restarts	no. occurances	$0.00	0	72,000	$0.00	$0.00
Down Time	minutes	$0.00	0	72,000	$0.00	$0.00
UV/Ox Labor	minutes	$0.248	0.0059	72,000	$0.11	$38.45
Pre/Post Treat Labor	minutes	$0.248	0.14	72,000	$2.50	$912.44
Lamp Replacement Labor	minutes	$0.248	NA	72,000	$0.68	$249.98
Totals					$265.26	$96,822.08

*Except for labor, averages are calculated by deleting the highest and lowest values and averaging remaining values

Ultrox UV lamps are rated for 1 year continuous operation and require 2 minutes per lamp labor to change

Full Scale System Operating and Maintenance Costs

(With Manganese Removal Pretreatment)

Consumable	Units	Cost ($/unit)	Average* Units/1000 gallons	Gallons/Day	Cost $/day	Cost $/yr
Electricity	kWh	$0.06	40.8	72,000	$176.26	$64,333.44
NaOH	lbs	$0.10	1.4927	72,000	$10.75	$3,922.82
H2SO4	lbs	$0.07	2.9495	72,000	$14.87	$5,425.90
UV Lamps	lamps	$50.00	NA	72,000	$68.49	$25,000.00
Air Filters	filters	$30.00	NA	72,000	$0.74	$270.10
Compressor Filter	filters	$100.00	NA	72,000	$0.27	$100.00
Compressor Oil	volumes	$50.00	NA	72,000	$0.14	$50.00
Upsets/Restarts	no. occurances	$0.00	0	72,000	$0.00	$0.00
Down Time	minutes	$0.00	0	72,000	$0.00	$0.00
UV/Ox Labor	minutes	$0.248	0.0059	72,000	$0.11	$38.45
Pre/Post Treat Labor	minutes	$0.248	0.363	72,000	$6.48	$2,365.83
Lamp Replacement Labor	minutes	$0.248	NA	72,000	$0.68	$249.98
Sludge Disposal	lbs	$1.00	0.459	72,000	$33.05	$12,062.52
Totals				72,000	$311.82	$113,819.04

*Except for labor, averages are calculated by deleting the highest and lowest values and averaging remaining values

Ultrox UV lamps are rated for 1 year continuous operation and require 2 minutes per lamp labor to change

Full Scale System Specification

ULTROX

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S030
Revision 1
4/7/95

ULTROX® F-4500
UV/OXIDATION SYSTEM SPECIFICATION
for
TREATMENT OF GROUNDWATER
at the
SAVANNA ARMY DEPOT ACTIVITY
GROUNDWATER TREATMENT SITE

Prepared by: William S. Himebaugh
1/20/95
Revised 4/7/95

Date	*Rev*	*Description*	*Engineering Approval*	*Q.A. Approval*
1/20/95		Initial Release		
4/7/95	1	Modified per Comments from Client		

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1.0 SCOPE

1.1 Purpose

This specification addresses the overall design of the Ultrox® UV/Oxidation system for the destruction of explosive compounds in groundwater from the Savanna Army Depot Activity site. The proposed system (budgetary) is designed for long life continuous operation and is covered by one or more of the following U.S. Patents: 4,941,957; 4,849,114; 4,792,407; 4,780,287. The system shall include equipment and accessories as required for the controlled addition of ozone and UV light to treat groundwater. The supplier of said equipment shall be Ultrox, hereafter referred to as the "vendor". The customer of said equipment shall be hereafter referred to as the "client".

1.2 Equipment

The Ultrox® UV/Oxidation system proposed for this project includes an Ultrox® F-4500 UV treatment tank, ozone generator and its associated air preparation system, and a residual ozone treatment system.

1.2.1 The UV/Oxidation system is of U.S. origin and consists of the following major deliverable components:

Pretreatment

a. Acidification System
b. Manganese Removal System (Optional)

UV/Oxidation

a. One Ultrox® F-4500 UV/Oxidation Process Tank
b. One Master Control Panel Assembly
c. Ballast Enclosure Assembly (7)
d. One Ozone Generator Assembly
e. One Decompozon™ Assembly
f. One Air Preparation System

Post Treatment

a. pH Neutralization System

2.0 REQUIREMENTS

2.1 Performance Requirements

The budgetary UV/Oxidation system is designed to achieve the "Discharge Limits for Treated Groundwater Daily Average" as defined in Table 1 of Client's RFP, at a flow rate no greater than 50 gallons per minute (gpm) provided that the organic and inorganic influent concentrations do not exceed those detected in the influent samples at the SADA site during the pilot demonstration program.

2.2 Hydraulic Requirements

2.2.1 The system design influent flow rate shall be 50 gpm, with a hydraulic capacity of 75 gpm.

2.2.2 The pretreatment, post treatment and Ultrox® UV/Oxidation process tank operates near atmospheric pressure. The UV treatment tank operates with an elevation head requirement of 65" W.C. and a head loss less than 6" W.C., as designed by the Vendor.

2.2.3 The effluent discharge shall be by gravity flow from a 4 ft. high Weir assembly on the F-4500 UV/Oxidation process tanks effluent port.

2.3 Electrical Requirements

2.3.1 Wiring and electrical components have been fabricated in accordance with the latest edition of the National Electrical Code.

2.3.2 Wiring and electrical connections exposed to UV light are adequately protected according to the environment in which the system is to be installed.

2.3.3 Client shall provide six (6) separate electrical power services with the following voltage ratings:

a. Ozone Generator: 480 VAC, 3ϕ, 60 Hz
b. Air Compressor: 480 VAC, 3ϕ, 60 Hz
c. Decompozon™: 480 VAC, 3ϕ, 60 Hz
d. BE System: 480 VAC, 3ϕ, 60 Hz
e. Pretreatment: 120 VAC, 1ϕ, 60 Hz
f. Post Treatment: 120 VAC, 1ϕ, 60 Hz

2.3.4 The MCP (Master Control Panel) is furnished with its own terminal strips, which shall be appropriately labeled for proper identification.

2.4 Corrosion Resistance Requirements

2.4.1 Welded components which are wetted are 304L or 316L stainless steel.

2.4.2 Non-welded, metallic components which are wetted are 304L or 316 stainless steel.

2.4.3 Stainless steel surfaces are not painted.

2.4.4 Gaskets are silicone rubber, viton or teflon.

2.4.5 Iron and steel surfaces have been be painted per Ultrox specifications.

2.5 Workmanship

All workmanship has been performed in a professional manner. All materials shall be previously manufactured and used and as specified by the documentation.

2.6 Reliability

The UV/Oxidation system shall be designed for continuous operation.

2.7 Design Documentation

2.7.1 Certified documentation shall be provided which shall include the following:

a. System Major Component Specifications
b. System Process and Instrumentation Diagram
c. System Layout Plan
d. System Electrical Schematics
e. Assembly Drawings
f. Operations and Maintenance Manual

2.7.2 The delivery schedule for documentation shall be within 8 weeks of receipt of contract. O&M manual shall include system O&M instructions, manufacturer O&M brochures and be submitted with equipment provided.

2.8 F-4500 UV/Oxidation Process Tank

2.8.1 The UV/Oxidation tanks shall be designed to efficiently and adequately distribute and process the groundwater through the entire process tank as necessary to eliminate any uneven flow pattern or short circuiting.

2.8.2 UV sensitive materials shall be completely shielded from direct or indirect contact with UV light.

2.8.3 The UV/Oxidation process tank shall contain 504 Ultrox® UV/oxidation lamps. These lamps are high efficiency, low intensity lamps rated at 65 Watts each.

2.8.4 The UV lamps shall be capable of converting a minimum of 35% of lamp input power to UV output.

2.8.5 The UV lamps shall be protected by quartz sheaths and shall not contact the fluid being treated. Quartz sheaths shall not require mechanical cleaning.

2.8.6 The UV lamps shall be vertically mounted and individually removable from the UV/Oxidation process tank without draining or diverting flow of the water from the tank.

2.8.7 The UV/Oxidation process tank material of construction shall be 316L stainless steel with the following dimensions: 24' x 6' x 6' (L x W x H).

2.8.8 A manifold shall be used to distribute ozone through individual flow meters to each stage in the process tank. Each of the stages shall be equipped with ozone inlet connections to permit introduction of ozone gas through distribution spargers at the bottom of the process tank.

2.8.9 The UV/Oxidation process tank shall contain twelve (12) Ultrox® stainless steel spargers to effectively diffuse ozone into the water within the UV/Oxidation process tank.

2.8.10 The UV/Oxidation process tank shall be provided with an ozone offgas collection manifold above the water level and along one side of the tank.

2.8.11 The UV/Oxidation process tank shall be equipped with NPT fittings and valves for the influent and effluent sampling ports.

2.8.12 The UV/Oxidation process tank and UV lamp system shall be designed such that the maximum water temperature rise through each tank shall not exceed 2°F at 50 gpm.

2.8.13 A valved drain shall be provided on the UV/Oxidation process tank.

2.8.14 The UV lamps shall have a rated service life of 9,000 hours based on no more than 3 On-Off cycles per day. Frequent cycling of lamps can limit UV lamp service life.

2.8.15 The UV/Oxidation process tank shall operate at 0.25 to 1 inch W.C. below atmospheric pressure. A pressure switch shall open a set of dry contacts if the pressure in the offgas manifold exceeds atmospheric pressure.

2.9 Ballast Enclosure Assemblies

2.9.1 Ballast enclosures shall allow access to each major component without removal of any other component.

2.9.2 Ballasts shall be of the high-power factor type and have a minimum of 92% efficiency and a minimum power factor of 0.9.

2.9.3 Control shall be provided to allow On/Off operation of individual banks of UV lamps.

2.9.4 A system to indicate the operating status of each lamp shall be provided.

2.9.5 The ballast enclosures shall have limit switches which close when the ballast enclosure doors are closed.

2.9.6 The ballast enclosures shall have temperature activated switches which open when a ballast enclosure exceeds its maximum operating temperature.

2.9.7 Each set of ballast enclosures shall be powered and controlled through a NEMA 12 electrical cabinet containing appropriate motor starters, AC contactors, phase loss detector, safety disconnect switch and complementary hardware.

2.9.8 One elapsed time meter shall be provided to measure operation of each bank of UV lamps in hours for the UV/oxidation tank.

2.10 Master Control Panel (MCP) Assembly

2.10.1 Control shall be provided to allow On/Off/Auto operation of each individual UV cell.

2.10.2 Control shall be provided to allow On/Off/Auto operation of the air handling/ozone generation system.

2.10.3 Indications shall be provided for each of the following conditions:

a. Ballast enclosure access door open
b. UV System Phase Loss
c. Ballast Overheat
d. High dewpoint

e. Low Decompozon™ temperature
f. Decompozon™ System Phase Loss
g. Ozone generator failure
h. High tank pressure
i. Low influent water flow
j. Low ozone cooling water flow
k. High ambient air ozone concentration
l. UV light shield open
m. Emergency stop

2.10.4 MCP shall have a system shut down button which will stop all MCP controlled components.

2.10.5 MCP shall control the following:

a. UV Systems
b. Decompozon™ System
c. Ozone Production System (ozone generator, compressor, dryer and filter)

2.10.6 MCP shall provide 120 VAC, 1 Amp control signal for client activation of influent transfer pumps and/or other client controlled equipment.

2.10.7 MCP shall not activate any of its systems in the automatic mode of operation until it receives a 120 VAC, 1 Amp control signal from client controlled equipment.

2.10.8 MCP shall provide a Programmable Logic Controller (PLC).

2.10.9 Electrical input power to the MCP shall be 120 VAC, single phase, 3 wire, 20 Amp, 60 Hertz service.

2.10.10 MCP enclosure is NEMA 12.

2.11 Ozone Generator Assembly

2.11.1 System shall require a minimum of 33 SCFM of clean dry compressed air at a pressure of 15 psig.

2.11.2 Dial gauges shall measure the temperature of the inlet and outlet cooling water.

2.11.3 Generator shall be capable of producing a minimum output of 75 lbs/day of ozone with 2.0% concentration by weight with compressed air as feed gas.

2.11.4 Ozone production shall be based on a cooling water temperature between 45°F and 70°F at a flow of approximately 20 gpm. Cooling water should be of uncontaminated quality, suitable for ozone generator use. Ozone generator cooling water temperature rise is 8°F. A heat exchange is provided which will employ the treated groundwater as a medium of heat exchange.

2.11.5 The ozone generator shall be designed for automatic remote operation. Electrical input power shall be 480 VAC, 3 phase, 4 wire, 70 Amp, 60 Hz delta service consisting of three (3) each, 3 phase conductors and one (1) ground conductor. Generator shall comply with NEMA Type 1 requirements.

2.11.6 Start-up and shutdown of ozone generator shall be controlled automatically by MCP and/or manually at the control panel of the ozone generator.

2.11.7 Safety interlocks shall be provided to identify a malfunction within the ozone generator and also to signal the MCP for a system shutdown.

2.11.8 Ozone generator to have minimum ozone production turn down ratio of 10:1.

2.11.9 Ozone generator dimensions: 8'4" x 7'6" x 6'8".

2.12 Air Preparation System

2.12.1 A rotary vane air compressor shall provide sufficient compressed air for the air filter and dryer to provide 33 SCFM at 15 psi.

2.12.2 A heatless regenerative dryer shall provide dry air with an acceptable dewpoint for continuous system operation.

2.12.3 A dewpoint monitor shall have a set of contacts which open when the dewpoint rises above acceptable limits.

2.12.4 An air filtration assembly shall remove oil and particulates from the compressed air for continuous system operation.

2.12.5 Electrical service for heatless regenerative dryer shall be provided by ozone generator.

2.12.6 Air Preparation System Dimensions: 6' x 5' x 6'8" (L x W x H)

2.13 DECOMPOZON™ Assembly

2.13.1 The Decompozon™ assembly shall reduce residual ozone from the oxidation process tank off gas below 0.1 ppm ozone by weight.

2.13.2 The Decompozon™ unit shall be fabricated from low carbon 300 series stainless steel.

2.13.3 The destruction unit shall be equipped with electrical inlet air pre-heater capable of heating 33 scfm of saturated air to 140°F.

2.13.4 Electrical input shall be 480 VAC, 3 phase, 4 wire, 60 Hertz service, consisting of three (3) phase conductors and (1) one ground conductor.

2.13.5 The Decompozon™ assembly shall be powered and controlled through an electrical cabinet containing appropriate motor starters, AC contactors, safety disconnect switch, phase loss detector.

2.13.6 The Decompozon™ assembly dimensions are: 3' x 3' x 8' (L x W x H).

2.14 Acidification System

The Acidification System is designed to adjust and maintain a pH of 4 in the groundwater prior to entering the UV treatment tank.

2.14.1 The Acidification System shall include a 2,000 gallon tank constructed of material and designed for storage of a 30 day supply of sulfuric acid solution.

2.14.2 The Acidification System shall include a chemical metering pump appropriately sized and designed to be proportionally controlled by a pH monitor to feed the required sulfuric acid solution to maintain a pH of 4 in the groundwater.

2.14.3 The Acidification System shall include an in-line static mixer capable of adequately mixing the sulfuric acid solution into the groundwater such that the pH is adjusted and can be monitored downstream.

2.14.4 The Acidification System shall include a pH monitor capable of detecting the pH in the UV treatment tank influent line and sending a signal to control the metering rate of the sulfuric acid chemical metering pump such that a pH of 4 is maintained in the groundwater.

2.15 Manganese Removal System (Optional)

The Manganese Removal System is designed to reduce the manganese concentration in the groundwater from 3.5 mg/l to below 1 mg/l prior to the Acidification System.

2.15.1 The Manganese Removal System shall include a 2,000 gallon tank constructed of material and designed for storage of a 30 day supply of caustic soda solution.

2.15.2 The Manganese Removal System shall include a chemical metering pump appropriately sized and designed to be proportionally controlled by a pH monitor to feed the required caustic soda solution to maintain a pH of 4 in the groundwater.

2.15.3 The Manganese Removal System shall include a pH monitor capable of detecting the pH of the groundwater in the LME separator and sending a signal to control the metering rate of the caustic soda chemical metering pump such that required pH is maintained in the groundwater for separation of manganese.

2.15.4 The Manganese Removal System shall include a 1,000 gallon floc tank designed to allow for aeration of the manganese in the groundwater from a line from the compressor provided with the Air Preparation System.

2.15.5 The Manganese Removal System shall include a LME model DRH-220 separator capable of separating the precipitated manganese from the groundwater and discharging the separated sludge.

2.15.6 The Manganese Removal System shall include a filter press. Filter press shall accept sludge from the LME separator and press the sludge to a 30% cake.

3.0 QUALITY ASSURANCE (QA) PROVISIONS

3.1 QA Measures by Vendor. Vendor shall be responsible for quality assurance of all deliverable items. Tests and examinations shall be performed at the discretion of Vendor to establish confidence in compliance with the requirements specified in 2.0.

3.1.1 Special tests and inspections. Vendor shall deliver copies of the certifications of materials used.

3.1.2 Operational tests. Vendor shall complete operational tests on equipment to verify compliance with electrical and mechanical functional requirements.

3.1.3 Discrete Interfaces. Mechanical and electrical interfaces shall be visually inspected for compliance with Engineering Documentation.

3.2 QA Measures by Client. Client shall be responsible for verifying compliance with the requirements as specified.

3.2.1 Acceptance Test.

An Acceptance Test ("Test") shall be conducted to determine that the system, when operated under the design conditions and in accord with Vendor operating and maintenance practices, is functioning properly. Influent water quality shall contain organic and inorganic constituents no greater than those listed under Section 2.0. The Test will commence after completion of satisfactory system check-out and initial start-up operations. The system shall be operated for a four (4) hour period during which it will be tested to verify performance requirements. During the Test, Client personnel shall perform operation and maintenance under Vendor surveillance. Vendor shall provide a plan to define instrument calibration requirements, chemical addition rates and measurement points no later than ten (10) working days prior to the Test. The Test Plan shall include provisions for taking of split samples as requested by Vendor (any analysis of Vendor split is at Vendor expense). The client is responsible for the analytical expenses they incur during the acceptance test. The Acceptance Test shall be conducted within thirty (30) days of start-up of the system or the system shall be deemed to be accepted.

4.0 JUSTIFICATION FOR DESIGN AND PERFORMANCE GUARANTEE

This Ultrox® UV/Oxidation system is estimated to achieve the treatment requirements listed under Section 2.0 Basis of Design. These are conservative estimates based upon Ultrox's field pilot demonstration of the treatment of the SADA groundwater.

5.0 PREPARATION FOR DELIVERY AND INSTALLATION

5.1 Shipping and Packaging

The system shall be packaged by the vendor to avoid damage due to normal shipping and handling practices for intercontinental transportation of industrial hardware. The design and fabrication of the packaging containers shall be the responsibility of the vendor. The system may be shipped partially assembled as defined below.

a. UV/Oxidation Process Tank
b. MCP Assembly (1)
c. Ballast Enclosure Assembly (7)
d. Ozone Generator Assembly (1)
e. Decompozon™ Assembly (1)
f. Air Preparation System (1)
g. Optional LME Separator (1)
h. Optional Floc Tank (1)
i. Acidification System (1)
j. pH Neutralization System (1)

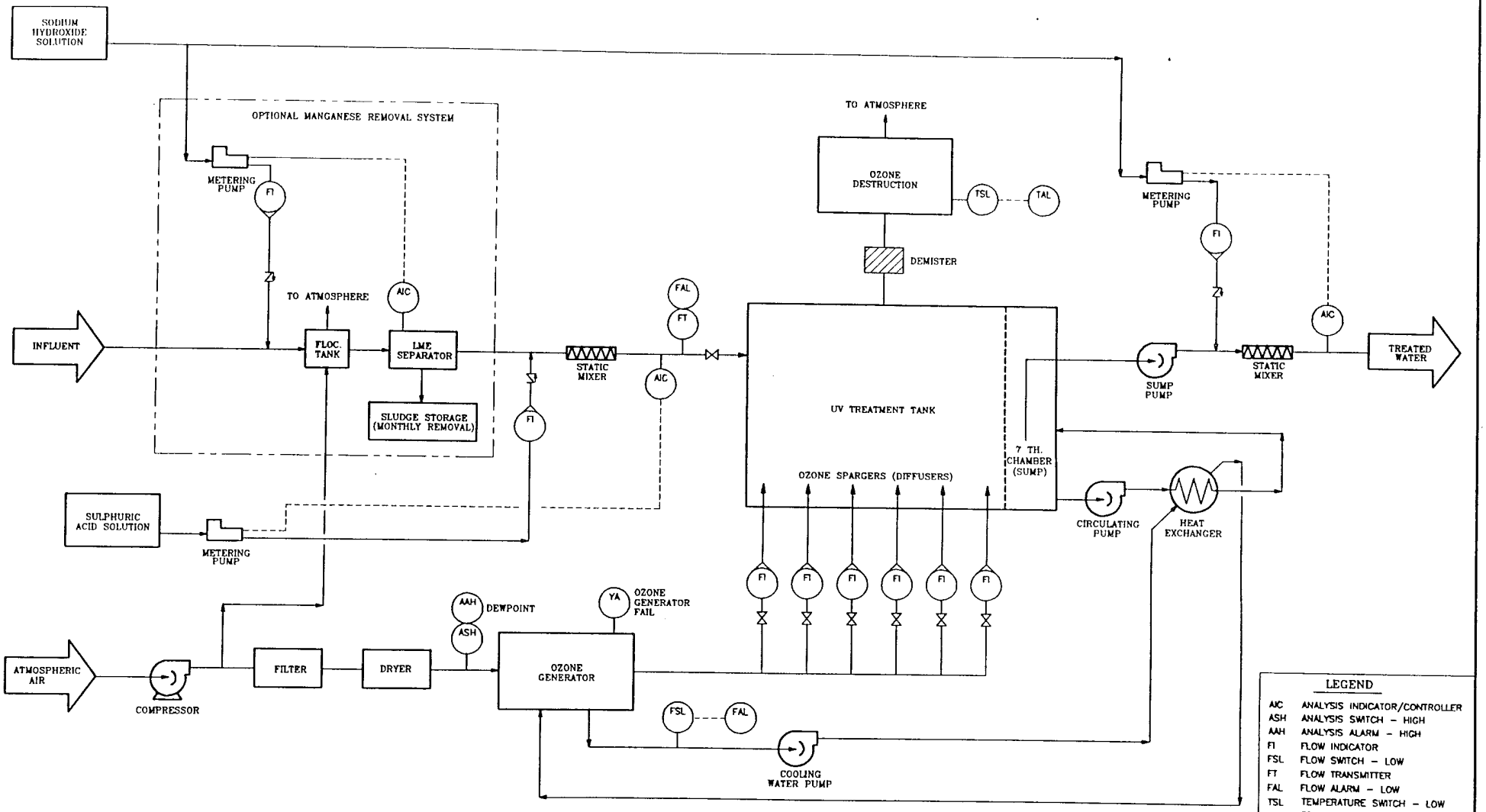
5.2 Client and Vendor Responsibilities prior to and during delivery, installation and set-up are as follows:

5.2.1 Equipment Delivery. Unless otherwise negotiated, equipment is F.O.B. Rothschild, WI.

5.2.2 Equipment Installation, System Start-up, and Training. Client shall arrange for arriving equipment at site to be transported from transport vehicle to location of operation and set and secure same equipment. Technical assistance shall be made available at vendor published rates for system start-up and training.

5.2.3 System Interface Connections. Vendor shall provide piping, tubing, and electrical connections internal to each major system component supplied by vendor. Vendor shall provide hardware and complete electrical connections between ballast enclosures and UV/oxidation process tanks. Client shall provide all other piping, tubing, and electrical installations between major system components, and shall provide all utilities to and from equipment.

Process Flow Diagram



LEGEND

AIC	ANALYSIS INDICATOR/CONTROLLER
ASH	ANALYSIS SWITCH – HIGH
AAH	ANALYSIS ALARM – HIGH
FI	FLOW INDICATOR
FSL	FLOW SWITCH – LOW
FT	FLOW TRANSMITTER
FAL	FLOW ALARM – LOW
TSL	TEMPERATURE SWITCH – LOW
TAL	TEMPERATURE ALARM – LOW
YA	CONDITION ALARM

REV.	DATE	BY	DESCRIPTION	CHKED	APPR'D
0	2/95	GWD	PRELIMINARY		

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SAVANNA ARMY

ULTROX PROCESS FLOW SCHEMATIC

DRAWN	Garry W. Doepke
CHECKED	
APPROVED	
DATE	03/31/95
SCALE	NONE
SAVE NAME	1003
SHEET	1 OF 1

ZIMPRO ENVIRONMENTAL, INC.
An Affiliate of the Black Clawson Co.

DRAWING NUMBER 50.3-3895-D-1003 REV. 0

Spare Parts List

SPARE PARTS LIST

Part Description	Part Number	Manufacturer	System Assembly	Qty.
UV Lamp	3185-1	Ultrox	Process tank	20
Quartz Sheath	25 x 22 mm. 67½" length	Ultrox	Process tank	20
UV Lamp Ballast	VSH-275-S-TP	Advance	Ballast Enclosure	5
Delrin Compression Nut	3151	Ultrox	Process tank	10
Compression Nut Tightener	3153	Ultrox	Service tool	1
Viton O-Ring, 1" O.D.	ARP568-214	Ultrox	Process tank	20
Desiccant		Hankison	Air Dryer	500 lbs
Low Concentration Ozone Monitor UV Bulb		PCI	LC-12 Monitor	1
Decompozon Catalyst	CMPAD10 8010-001	Ultrox	Catalytic Destruction System	2.5 cu.ft.
Prefilter Cartridge	0731-9	Hankison	Air Prep	1
Coalescing Oil Filter Cartridge	0713-11	Hankison	Air Prep	2
After Filter Cartridge	0731-8	Hankison	Air Prep	1
Activated Carbon Filter Cartridge	0715-11	Hankison	Air Prep	1

SPARE PARTS LIST (Contd.)

Part Description	Part Number	Manufacturer	System Assembly	Qty.
Desiccant		Hankison	Air Dryer	500 lbs
Low Concentration Ozone Monitor UV Bulb		PCI	LC-12 Monitor	1
Mist Removal Element	3744	Ultrox	Process tank	4
Decompozon Catalyst	CMPAD10 8010-001	Ultrox	Catalytic Destruction System	2.5 cu. ft.
Prefilter Cartridge	0731-9	Hankison	Air Prep	24
Coalescing Oil Filter Cartridge	0713-11	Hankison	Air Prep	12
After Filter Cartridge	0731-81	Hankison	Air Prep	12
Activated Carbon Filter Cartridge	0715-11	Hankison	Air Prep	12

Terms and Conditions

ZIMPRO PASSAVANT

TERMS AND CONDITIONS OF SALE

This offer is made expressly subject to the following terms and conditions. Terms and conditions appearing in any order based on this offer which are in conflict with the following shall not be binding on Zimpro Passavant Environmental Systems, Inc. (Seller), unless specifically agreed to in writing by an authorized officer of Seller.

1. **GENERAL TERMS**—A. Written quotations are void after ninety (90) days. Prices and quotations are subject to change without written notice, unless specified otherwise. Acceptance of this offer is expressly limited to the exact terms contained herein and any attempt by Purchaser to alter or omit any of such terms shall be deemed a rejection or counter-offer. All orders are received subject to acceptance by Seller at Seller's main office in Rothschild, Wisconsin.

B. This Agreement includes only the equipment specified herein, and does not include erection, installation, accessory or associated materials such as controls, piping, etc., not specifically listed.

C. If applicable laws, ordinances, regulations or conditions require anything different from or in addition to that called for by Seller's drawings and specifications. Seller will satisfy such requirements at Purchaser's written request and expense upon receipt of proper specifications. Purchaser hereby agrees to indemnify and hold harmless Seller from any claims or losses arising due to alleged or actual insufficiency or inadequacy of the safety devices offered or supplied hereunder, whether specified by Seller or Purchaser, and from any damage resulting from use of the equipment supplied hereunder.

D. In addition, Purchaser shall be responsible for the installation of safety devices or guards which may be necessary as a result of any modification to the equipment or any change of any operating procedure by Purchaser, and Purchaser hereby agrees to indemnify and save the Seller harmless from any claims, liabilities, obligations, costs and expenses incurred by Seller resulting from any claim by any person injured directly or indirectly in connection with the operation of the equipment sold hereunder because of the lack of safety devices or guards on the equipment necessitated by any such modification or change or operating procedure.

E. There are no rights, warranties or conditions, express or implied, statutory or otherwise, other than those contained herein. This Agreement contains the entire agreement between Purchaser and Seller and can be modified or rescinded only by a writing signed by both parties. No waiver of any provisions of this Agreement shall be binding unless in writing signed by an authorized representative of the party against whom the waiver is asserted and unless expressly made generally applicable shall only apply to the specific case for which the waiver is given. Failure of either party to insist upon strict performance of this Agreement shall not be construed as a waiver of any terms or conditions hereof.

2. **PAYMENT**—A. Net amount of invoice shall be due in full within thirty (30) days of the date of invoice. If, in the opinion of Seller, the financial condition of Purchaser at any time does not justify continuance of production or shipment on the above payment terms, full or partial payment in advance may be required. All payments, unless otherwise specified, shall be in U.S. currency.

B. In the event Purchaser defaults in making any payment due and payable hereunder, Purchaser agrees to pay a late payment charge on the amount of said payment from and after the date of default at a rate of one-and-one-half percent (1½%) per month of the unpaid balance.

C. Final payment by Purchaser to Seller after settlement of contract back charges, if any, shall be prima facie evidence of Purchaser's acceptance of the equipment and products purchased hereunder and satisfactory performance by Seller of all of its obligations under this Agreement.

3. **TITLE AND OWNERSHIP**—Title to the equipment specified herein and any replacements or substitutes therefor, and the right of repossession remains with Seller until final payment is made by Purchaser. Said equipment or any part thereof shall not be considered fixtures or be incorporated into realty by reason of attachment thereto and may be separated from realty for the purpose of repossession. Purchaser agrees to do all things necessary to protect Seller's title and interest in and to such equipment. From date of shipment until full payment of invoice, Purchaser agrees to provide and maintain at its expense, but for the benefit of Seller, adequate insurance on the equipment against any loss of any nature whatsoever. In the event of default on any payment, the full amount unpaid shall become due and payable at any time during the continuance of the default, and Seller may repossess the products and retain the rights to collect the balance of the contract price.

4. **DELIVERY AND DELAYS**—A. Delivery dates are based on Seller's prompt receipt of all necessary information from Purchaser regarding the order. Seller shall not be liable for any delay in the performance of orders or contracts or in the delivery or shipment of goods or damages caused by such delay when such delay is directly or indirectly caused by or arises from fires, floods, accidents, acts of God, government requests, orders and regulations, labor disputes or strikes, fuel or materials shortages, delays in transportation, delays or failure to deliver by any of Seller's suppliers or subcontractors, or any other similar or dissimilar cause or causes beyond the control of Seller, and Seller's time for performance hereunder shall be extended accordingly. Such delay shall not be cause for cancellation of this Agreement.

B. Seller shall have the right to make partial shipments. Invoices covering same shall be due and payable by Purchaser in accordance with the payment terms described herein.

5. **SHIPMENT**—The equipment specified herein shall be delivered F.O.B. Seller's factory or its supplier's shipping points. Method and route of shipment are at the discretion of Seller, unless Purchaser furnishes explicit instructions. All shipments are to be insured at Purchaser's expense and made at Purchaser's risk. Claims for damages during transit shall be filed by Purchaser with the carrier.

6. **TAXES**—Prices on the equipment specified herein are exclusive of all taxes. The amount of the present or future sales, revenue, excise of other taxes applicable to said equipment shall be added to the purchase price and shall be paid by Purchaser. In lieu thereof, Purchaser shall provide a tax exemption certificate acceptable to the taxing authorities.

7. **PATENTS**—Seller will defend and hold Purchaser harmless against any charges of infringement of claims of United States patents issued at the time of acceptance of the order; provided such charges are based exclusively on infringement by equipment designed and manufactured by Seller, and Seller is notified promptly in writing of the institution or threatened institution of any suit or proceeding and is given full control of the defense, settlement or compromise of any such action; and Purchaser agrees to give Seller any and all needed information, assistance and authority to enable Seller to do so. Should the use of said equipment be enjoined in such suit or should Seller otherwise deem it advisable, Seller shall, at its own expense, either procure for Purchaser the right to continue using said equipment or replace same with non-infringing equipment or modify it so it becomes non-infringing or remove equipment and refund the purchase price, less freight charges and depreciation. Seller shall not be liable for use of said equipment in the conduct of any process not inherent therein nor for infringement resulting from compliance with designs furnished by Purchaser. The foregoing states the sole liability of Seller for patent infringement with respect to said equipment.

As to any equipment furnished by the Seller to the Purchaser and/or manufactured in accordance with the specifications supplied by the Purchaser or on behalf of the Purchaser, the Purchaser assumes full responsibility for the design, specifications and end-use of such equipment and hereby agrees to indemnify and hold Seller harmless against all claims, costs and expenses (including attorneys' fees) arising out of any claim initiated against Seller alleging infringement of any patent, trademark or copyright.

8. **CHANGES, DELAYS AND UNUSUAL COSTS**—A. Should Purchaser request or cause changes to be made in design or construction of the equipment, or if Purchaser delays the progress of work covered by this Agreement, the contract price and time shall be adjusted to reflect any increase or decrease. Additional charges may be made to cover any unforseen or unusual cost elements which have not been contemplated by Seller or Purchaer, and special packing, engineering and documentation.

B. If delivery is postponed by Purchaser or prevented by strike, accident or other cause beyond Seller's control, and occurring at a location other than Seller's factory or its supplier's shipping point, Seller may tender delivery at Seller's factory or its supplier's shipping point. If Purchaser refuses such delivery for any such cause, Purchaser shall be responsible for all costs and expenses incurred by Seller resulting from such failure to accept delivery, including charges to its suppliers and subcontractors, and Seller may store the equipment at Purchaser's expense and risk, and if such storage is on the premises of the Seller, Seller may charge at a rate similar to that charged by a public warehouse. For all purposes of this Agreement, such tender of delivery or storage shall constitute delivery.

9. **SUPERVISION OR INSPECTION**—A. Service of a factory representative to supervise or inspect installation and/or operation of the products specified herein will be furnished by Seller upon the request of Purchaser, upon the following conditions:

   1. Supervision or inspection within the continental limits of the United States per eight (8) hour day, Monday through Friday inclusive.
   2. Overtime worked Monday through Friday in excess of eight hours but less than twelve hours and up to eight hours on Saturday at time-and-one-half.
   3. Time worked in excess of twelve (12) hours on any one day or Sunday and holiday work, at double time.
   4. Traveling, living and incidental expenses at cost, including shipping charges on tools and other equipment which the factory representative has shipped to the construction site.
   5. Travel time will be charged to and from Purchaser's construction site, and overtime, weekend or holiday travel requested or required by Purchaser will be charged at the appropriate rates.

B. Except for the direct acts or omission of the factory representative, the responsibility for the installation and/or first operation shall be Purchaser's. Seller will assume responsibility for worker's compensation coverage of Seller's employees only. All other insurance coverage and necessary materials and labor to accomplish installation shall be provided by Purchaser.

WARRANTY—A. Seller warrants the equipment specified herein to be free from defects in material and workmanship. Subject to the provisions of Paragraph 10B., Seller shall replace or repair F.O.B. point of manufacture, parts which Seller's examination shall show to have failed under normal use and service by the original user within one (1) year from date of delivery; provided Purchaser gives prompt written notice of each defect to Seller. Such repair or replacement shall then be subject to a pro-rata charge based upon Seller's estimate of the percentage of normal service life realized from the part. Decomposition by chemical action and wear caused by the presence of abrasive materials shall not constitute defects. Liability of Seller under this warranty is limited to repair or replacement of the defective part, all damage claims of whatever nature, including without limitation Purchaser's labor costs, being excluded.

Correction by Seller of non-conformities whether patent or latent, in the manner and within the period of time provided above shall constitute fulfillment of all liabilities of Seller for such non-conformation, whether based on contract, warranty, negligence, indemnity, strict liability or otherwise with respect to or arising out of the sale or use of such equipment.

B. Commodities not manufactured by Seller are warranted or guaranteed to the extent and in the manner they may be warranted or guaranteed to Seller by the manufacturer thereof, and to the extent such warranty or guarantee may reasonably be enforced without litigation by Seller.

C. If Purchaser makes any modification to the equipment without Seller's prior written approval, or uses any spare part not manufactured or sold to the Purchaser by the Seller, which causes or contributes to a defect, then Seller shall be relieved of its warranty obligations hereunder.

D. THERE ARE NO WARRANTEES OF MERCHANTABILITY AND FITNESS FOR ANY PARTICULAR PURPOSE OF SAID EQUIPMENT OR ANY OTHER WARRANTEES (EXPRESS, IMPLIED OR STATUTORY) CONCERNING THE PERFORMANCE CAPABILITY THEREOF, OR ANY OTHER REPRESENTATIONS AND GUARANTEES, OTHER THAN THE WARRANTEES, REPRESENTATIONS AND GUARANTEES SET FORTH IN THIS SECTION, OR WHICH SHALL BE SPECIFICALLY DESIGNATED AS A GUARANTEE BY THE LEGEND "PERFORMANCE GUARANTEE" APPEARING THEREON.

LIMITATION OF LIABILITIES—Seller shall not be liable to Purchaser for any indirect, incidental, special or consequential damages arising out of or in connection with this Agreement, including any claim in tort, contract, strict liability, warranty or otherwise, including but not limited to, damages in the nature of:

1. loss of profits or revenues resulting from the failure of the equipment to meet specifications or warrantees;
2. damages suffered by Purchaser as a result of downtime, overhead, labor, loss of use of or damage to machinery, equipment or structures, spoilage or loss of production or profit;
3. cost of replacement equipment;
4. damages suffered by customers of Purchaser; or
5. any fines or penalties assessed for failure to comply with any law or governmental regulations.

DESIGN CHANGE—Seller reserves the right to change, discontinue or modify the design and construction of any product or to substitute materials equal to or superior to that originally specified.

CANCELLATION—This Agreement is not subject to cancellation unless requested by Purchaser and accepted in writing by Seller. In the event of any such cancellation, Purchaser shall pay to Seller, within 30 days of such cancellation, all reasonable costs and other expenses incurred by Seller prior to receipt of the request for cancellation (including but not limited to engineering, manufacturing expenses, all commitments to suppliers, subcontractors and others) plus 25% of the foregoing to compensate Seller for overhead and profit. No order may be cancelled after shipment.

14. **CONFIDENTIAL INFORMATION**—All information and data herein or furnished to Purchaser hereunder relating to price, size, type and design is submitted with the understanding that it is for Purchaser's own confidential use and is not to be shown or otherwise made known or available to any third party at any time without Seller's written consent.
15. **CLAIMS FOR SHORTAGES AND DAMAGES**—All claims for shortages and damaged equipment must be made in writing within 90 days after delivery or 30 days after arrival at destination, whichever is later. Purchaser shall file all claims within the same time periods with the transporting common carrier and with its insurance company. If the shortage is due to failure to ship, Seller's only obligation will be to make good the shortage F.O.B. its plant.
16. **SOFTWARE**—If the equipment purchased by Purchaser includes software, it is acknowledged that such software, together with all documentation provided by Seller in connection therewith, are proprietary to Seller, and that the license to use such software is personal to the Purchaser. Therefore, Purchaser agrees (a) not to reproduce, distribute or disclose to others such software and to maintain same in confidence, (b) to use same only in connection with Purchaser's business and not to allow third parties to use it without Seller's prior written consent and (c) not to make any modifications to the software for any reason whatsoever.
17. **GOVERNING LAW**—This Agreement shall be construed in accordance with the laws of the State of Wisconsin. The courts of such state shall have exclusive jurisdiction over all controversies arising out of or in connection with this Agreement. The parties hereto consent to personal jurisdiction in the courts of such state and agree that process may be served upon them in any such action by registered mail at the address stated at the head of this Agreement personally within or without such state. If service is made in any manner other than personal within such state, the defendant shall be entitled to a period of twenty additional days to answer over and above the time limited by law.
18. **SEVERABILITY**—Each paragraph and provision of this Agreement is severable from the entire Agreement and if any provisions of this Agreement are held to be invalid, the remainder of this Agreement shall nevertheless remain in full force and effect.
19. **RIGHTS**—The parties hereto covenant and agree that if either acquires any right or rights to bring any action, suit or proceeding against the other for or as a result of any breach of this Agreement, except for non-payment of the purchase price, the party acquiring such right or rights shall be conclusively deemed to have waived and relinquished the same unless such action, suit or proceeding is commenced within one year after such right or rights arose.
20. **BACK CHARGES**—In no event shall any installation, erection, modification or corrective work be done by Purchaser for the account of Seller until after full particulars (including an estimate of material cost, amount and rate of labor required) have been submitted in writing to and approved in writing by Seller. Return items will not be accepted unless Seller has previously agreed to such return in writing and supplied written shipping instructions.
21. **EQUAL OPPORTUNITY**—Seller hereby certifies that it does not and will not maintain or provide for its employees any segregated facilities at any of its establishments and it is in compliance with the requirements of executive order 11246, dated September 24, 1965, as amended and the rules, regulations and relevant orders issued thereunder.

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ADDITIONAL LIMITS OF LIABILITY

22. **In no event shall either party be liable to the other for any indirect, special, incidental or consequential damages arising out of the performance or non-performance by such party of its obligations under this Agreement, including without limitation, loss of profits.**

23. **Except for claims for personal injury, the total liability of Subcontractor to Contractor arising under this Agreement, whether arising by causes of action in contract, tort, warranty (expressed or implied), performance guarantee, strict liability, delay or otherwise shall not exceed 10% of the contract price in the aggregate.**

VPSI

PILOT-SCALE REPORT

CONFIDENTIAL ON-SITE TESTING REPORT

DEMONSTRATION OF ORGANIC CONTAMINANT DESTRUCTION IN GROUNDWATER WITH THE perox-pure™ PROCESS

prepared for

Roy F. Weston
West Chester, Pennsylvania
Purchase Order No. P-0569-F1
VPSI Project No. 424

by

Vulcan Peroxidation Systems Inc.
5151 E. Broadway, Suite 600
Tucson, AZ 85711

April 17, 1995

The information contained in this report includes descriptions and procedures which are confidential to Vulcan Peroxidation Systems Inc. The report shall not be copied nor released to third parties without prior approval from Vulcan Peroxidation Systems Inc.

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1.0 EXECUTIVE SUMMARY

A bench-scale **perox-pure™** treatability study was conducted by Vulcan Peroxidation Systems Inc. (VPSI) on a sample of the Savanna Army Depot Activity (SADA) site groundwater in Savanna, Illinois. This study indicated that rapid destruction of the organic contaminants occurred with the **perox-pure™** Process. Approximately 1,900 μg/l of volatile and semi-volatile organic compounds were destroyed to the specified treatment objective with 3 minutes of oxidation.

The bench test results were confirmed during an on-site **perox-pure™** technology demonstration. A **perox-pure™** Model SX-30 with support equipment was provided for the demonstration in an enclosed container. The **perox-pure™** equipment was operated for a period of three weeks during which time fourteen (14) tests were conducted to determine the best treatment conditions for destruction of the groundwater contaminants.

Successful full-scale treatment of the groundwater at the specified flow rate of 50 gpm is projected to occur with a power requirement of 570 kW. Including electricity, sodium hydroxide (NaOH), hydrogen peroxide (H_2O_2), acid, catalyst and maintenance (parts & labor), the treatment cost is estimated to be $14.45 per 1,000 gallons.

The **perox-pure™** Process offers the advantages of a proven, cost-effective treatment system that creates no air emissions, or generation of secondary waste products and is backed by the security of more than 85 successful full-scale installations world-wide.

2.0 INTRODUCTION

The **perox-pure™** Process destroys dissolved organic contaminants in water by means of chemical oxidation. Ultraviolet (UV) light catalyzes the chemical oxidation of organic contaminants in water by its combined effect upon the organic contaminants and its reaction with hydrogen peroxide (H_2O_2). Many organic contaminants absorb UV light and may undergo a change in their chemical structure or may become more reactive with chemical oxidants. More importantly, UV light at less than 400 nm wavelength reacts with H_2O_2 molecules to form hydroxyl radicals. These powerful chemical oxidants then react with the organic contaminants in the water. If carried to completion, the reaction products of hydrocarbon oxidation with the **perox-pure™** Process are carbon dioxide and water. Any halogens present are converted to the corresponding halide.

After the successful completion of the bench-scale treatability study in August of 1994, VPSI was again contracted by Roy F. Weston (Weston) to perform on-site pilot-scale **perox-pure™** testing at the Savanna Army Depot Activity (SADA) site in Illinois. The objectives of this pilot study were (1) to confirm the feasibility of treating the groundwater contaminants with the **perox-pure™** Process (2) to determine the best **perox-pure™** operating conditions in order to provide full-scale equipment design and cost projections and (3) compare the bench-scale testing to the pilot-scale testing to determine the credibility of each method for projecting full-scale equipment costs.

The three week long pilot-scale study was performed in September and October of 1994 using a Model SX-30 **perox-pure™** System. The following report details the testing protocol, test results, a discussion of the best full-scale treatment conditions, and the associated full-scale treatment cost projections.

3.0 PILOT-SCALE perox-pure™ TREATMENT

3.1 Testing Protocol

A VPSI **perox-pure™** System and container with ancillary equipment was used to perform the pilot-scale testing at the SADA site. The VPSI equipment was positioned on a level concrete pad with shelter. A schematic diagram of the VPSI equipment provided for this demonstration is shown in Figure 1. The VPSI container was equipped with a **perox-pure™** Model SX-30 treatment unit, a H_2O_2 feed system, an acid feed system, a feed pump module, dual cartridge filters, a supply of chemicals, and necessary controls, meters, and interconnecting piping. In addition, the container was stocked with various safety equipment including an eye wash and safety shower, a fire extinguisher, a first aid kit, and Level C personal protective equipment.

Groundwater from one well were pumped into a 20,000 gallon tank provided by Weston. Water from the feed tank was then pumped through the cartridge filters and into the oxidation chamber of the SX-30 where the organic contaminants were oxidized. Sodium Hydroxide (NaOH) and H_2O_2 were injected into the groundwater as a pretreatment step prior to the cartridge filters. After passing through the 3 micron cartridge filers, concentrated sulfuric acid and/or a proprietary catalyst was injected at the influent to the oxidation chamber. A H_2O_2 splitter was available on the SX-30 to also inject the H_2O_2 into several access points along the flow path in the oxidation chamber. The treated water was directed to a second 20,000 gallon tank, through granular activated carbon, then discharged as directed by Weston.

Samples were collected each day by Weston personnel for analysis by EPA Methods 8330. Select samples were also collected by VPSI personnel and shipped to Hercules Environmental Testing Laboratory for analysis by EPA Method 8330. Samples collected daily by both Weston and VPSI personnel were analyzed on-site for TNT using a DTECH test kit.

3.1.1 Description of Groundwater

Characterization of the water sample was performed by VPSI to determine parameters of importance for **perox-pure™** treatment. Characterization of selected parameters was also performed by Weston. The results are shown in Table 1.

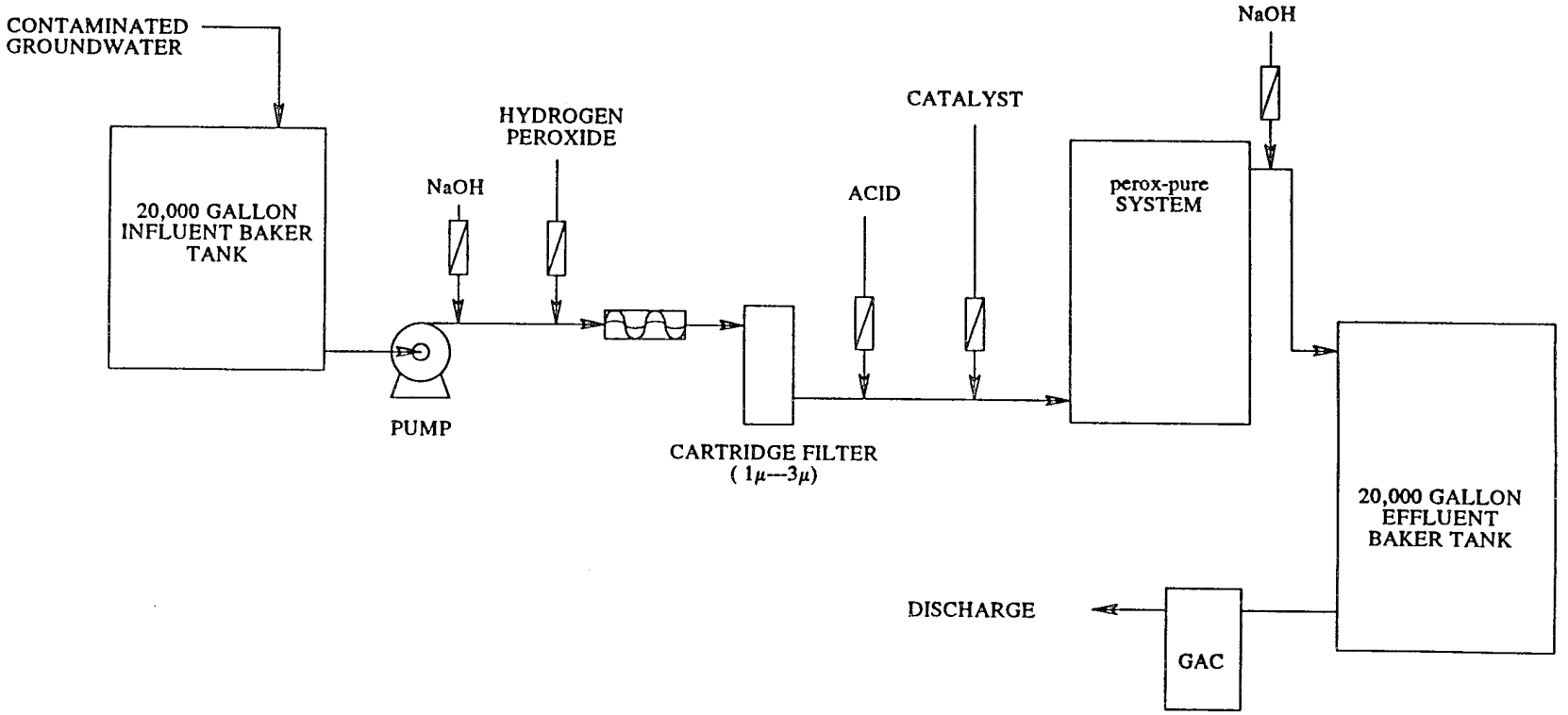


FIGURE 1

DOCUMENT NO.:	Vulcan Peroxidation Systems, Inc. Tucson, Arizona	PROCESS FLOW DIAGRAM

Table 1

Sample Characterization Results for non-target parameters
for the SADA Groundwater

	VPSI Raw Water 9-23-94	Weston Raw Water 10-94
Visual Color:	light yellow	NA
Visual Appearance:	clear	NA
pH:	7.5	NA
Iron (mg/l):	0.67	0.55
Chloride (mg/l):	6.5	NA
Chemical Oxygen Demand (mg/l):	9	NA
Total Organic Carbon (mg/l):	NA	NA
Total Dissolved Solids (mg/l):	360	NA
Total Suspended Solids (mg/l):	<5	NA
Alkalinity (mg/l):	106	170
Hardness (mg/l):	3,100	340
Turbidity (NTU):	4.93	NA
NO_3 (mg/l):	286	NA
Manganese (mg/l)	NA	1.8

NA = Not analyzed

Pretreatment

To remove solids and turbidity, the raw water was treated with NaOH and H_2O_2, then filtered through a 1 or 3 micron cartridge filter. A red-orange floc formed when the pH was raised to 11. H_2O_2 addition accelerated this precipitation process. The resulting water after filtration was clear and relatively free from solids with a slight yellow appearance.

3.2 Treatment Results

The pilot-scale testing /sampling period ran for fourteen days during which time fourteen (14) pilot-scale **perox-pure™** tests were performed with the SADA groundwater. The test conditions are shown in Table 3. The treatment variables investigated include, H_2O_2 dose, pH adjustment, catalyst addition, pretreatment and flow rate.

Table 2

Pilot-Scale perox-pure™ Treatment Conditions
for the SADA Groundwater

Date	Sample No.	pH	Flow (gpm)	H_2O_2 Dose (mg/l)	Catalyst (Type; mg/l)	Pretreatment*
9-27	1	3.5	5	200	I; 8	Filtration only
	2	3.4	5	200	I; 8	Filtration only
	3	4.5	5	200	I; 8	Filtration only
9-28	1	3.4	5	300	I; 8	pH 11.5, H_2O_2, filtration
	2	3.5	5	300	I; 8	pH 11.5, H_2O_2, filtration
	3	3.0	5	300	I; 8	pH 12, H_2O_2, filtration
9-29	1	3	5	500	I; 8	pH 11.6, H_2O_2, filtration
	2	3	5	300	I; 12(1)	pH 11.8, H_2O_2, filtration
	3	3.4	5	300	I; 12	pH 11.8, H_2O_2, filtration
9-30	1	3.3	5	300	I; 12	pH 11.6, H_2O_2, filtration
	2	4.7	2	0(2)	I; 12	pH 11.8, H_2O_2, filtration
	3	12	5	300	None	pH 12, H_2O_2, filtration
10-3	1	4.3	2	300	I; 12	pH 11, H_2O_2, filtration
	2	3.3	2	300	I; 12	pH 11, H_2O_2, filtration
	3	3	2	550**	I; 12	pH 11.8, H_2O_2(2), filtration

Table 2 (cont'd.)

Pilot-Scale **perox-pure™** Treatment Conditions
for the SADA Groundwater

Date	Sample No.	pH	Flow (gpm)	H_2O_2 Dose (mg/l)	Catalyst (Type; mg/l)	Pretreatment*
10-4	1	2.7	2	600**	I; 12	pH 11.2, H_2O_2[2], filtration
10-4	2	2.6	2	600**	I; 12	pH 11, H_2O_2[2], filtration
	3	2.3	2	600**	I; 12[1]	pH 11, H_2O_2[2], filtration
10-5	1	3.0	2	650**	I; 12	pH 11, H_2O_2[3], filtration
	2	2.7	3	550**	I; 12	pH 11, H_2O_2[2], filtration
	3	2.7	3	300	I; 12	No Caustic[4], H_2O_2 Filtration
10-6	1	7.2	3	200	I; 12	pH 11, H_2O_2, filtration
	2	2.7	3	300	I; 12	pH 11, H_2O_2 filtration
	3	3.0	3	750**	I; 12	pH 11, H_2O_2[2], filtration
10-7	1	2.7	3	300	I; 12	pH 11.5, H_2O_2 filtration[5]
	2	2.5	3	300	I; 12	pH 11.6, H_2O_2 filtration[5]
	3	2.6	3	300	I; 12	pH 11.7, H_2O_2 filtration[5]
10-10	1	3.0	3	400	I; 12	pH 11.6, H_2O_2 filtration[5]
	2	2.7	3	500**	I; 12	pH 11.6, H_2O_2[2], filtration[5]

Table 2 (cont'd.)

Pilot-Scale **perox-pure**™ Treatment Conditions
for the SADA Groundwater

Date	Sample No.	pH	Flow (gpm)	H_2O_2 Dose (mg/l)	Catalyst (Type; mg/l)	Pretreatment*
	3	2.7	3	400	I; 12	pH 11.6, H_2O_2 filtration[5]
10-11	1	2.7	3	500	I; 12	pH 11.5, H_2O_2 filtration
	2	3.0	3	500**	I; 12	pH 11.7, H_2O_2[2], filtration
	3	2	3	500**	I; 12	pH 11.5, H_2O_2[2], filtration
10-12	1	2.9	5	300	I; 12	pH 11.8, H_2O_2 filtration
	2	2.8	2	500**	I; 12	pH 11.8, H_2O_2[2], filtration
	3	2.8	2	500**	I; 12	pH 11.9, H_2O_2[2], filtration
10-13	1	4.5	5	300	I; 12	pH 11.7, H_2O_2 filtration
	2	2.8	2	500**	I; 12	pH 11.7, H_2O_2[2], filtration
	3	2.8	2	500**	I; 12	pH 11.7, H_2O_2[2], filtration
10-14[6]	1	2.8	2	300	None	pH 11.6, H_2O_2 filtration
	2	2.8	2	300	None	pH 11.6, H_2O_2 filtration

Table 2 (cont'd.)

Pilot-Scale **perox-pure**™ Treatment Conditions
for the SADA Groundwater

Date	Sample No.	pH	Flow (gpm)	H_2O_2 Dose (mg/l)	Catalyst (Type; mg/l)	Pretreatment*
	3	2.8	2	300	None	pH 11.6, H_2O_2 filtration

* 3 micron cartridge filters used for filtration unless specified otherwise.
(1) Actual concentration uncertain.
(2) 300 mg/l H_2O_2 of total H_2O_2 dose used in pretreatment.
(3) 400 mg/l of total H_2O_2 used in for pretreatment.
(4) Changing NaOH drum - No caustic feed at time of sampling.
(5) 1 micron cartridge filters used.
(6) Only two of the three UV lamps were used during testing.
** Additional H_2O_2 injected after pretreatment.

The analytical results for the pilot tests are shown in Table 3. The influent water contained average TNT an TNB concentrations of approximately 740 μg/l and 620 μg/l, respectively. These concentrations were comparable to the concentrations detected during bench-scale testing. TNB was again determined to be the rate limiting compound. As expected, TNB was generated initially and then destroyed after approximately 2 minutes of oxidation time. The other ordnance compounds (2-amino DNT, 2,6-DNT and 2,4-DNT) were destroyed to below the treatment objective with 2 minutes of oxidation time or less. The best destruction rates were obtained in Test 10-4-1 performed with pretreatment, an initial pH of approximately 3, H_2O_2 dosage of 600 mg/l and 12 mg/l catalyst Formula I.

Table 3
On-Site **perox-pure**™ Treatment Results
for the SADA Groundwater

Test No.	kWH/1000 gal	1,3,5-TNB (µg/l)	1,3-DNB (µg/l)	2-Amino DNTs (µg/l)	2,4,6-TNT (µg/l)	2,6-DNT (µg/l)	2,4-DNT (µg/l)
0927-1	0	550	25	29	750	9.8	64
	100	760	17	ND	70	ND	3.7
0927-2	0	NA	NA	NA	NA	NA	NA
	1.5	57	0.52U	1.0U	0.52U	0.54U	0.52U
0927-3	0	760	25	12U	970	6.1U	68
	1.5	17	1.4	1.6U	55	0.84U	2.1
0928-1	0	730	10	16U	940	8.1U	28
	1.5	11U	28	9.0	1.1U	1.1U	18
0928-2	0	1100	16	70	1500	1.6U	120
	1.5	130	1.6U	3.3U	2.1	1.7U	1.6U
0928-3	0	640	24	3.8U	830	2.0U	49
	1.5	240	0.56	1.7U	3.9	0.89U	0.89U
0929-1	0	650	25	21	840	7.9	54J
	1.5	250	1.8U	3.5U	1.8U	1.8U	1.8U
0929-2	0	750	6.6	22	920	2.7	17
	1.5	230	0.72	2.5U	2.1	1.3U	1.2U
0929-3	0	740	18	60J	910	7.4	84
	1.5	150	1.0U	2.0U	2.9	1.1U	1.0U
0930-1	0	730	17	54	890	8.0	72
	1.5	160	1.5U	3.1U	2.1	1.6U	1.5U
0930-2	0	730	8.8	31	900	3.3	21
	3.75	520	100	2.6U	1.3U	1.4U	1.3U
0930-3	0	730	8.9	29	870	3.0	19
	1.5	420	42	1.6	1.6	0.78U	1.6

U = Analyte not detected. Value presented is the lower detection limit.
J = Analyte presented below the lower detection limit.

Table 3 (cont'd.)
On-Site **perox-pure™** Treatment Results
for the SADA Groundwater

Test No.	Oxidation Time (min)	1,3,5-TNB (µg/l)	1,3-DNB (µg/l)	2-Amino DNTs (µg/l)	2,4,6-TNT (µg/l)	2,6-DNT (µg/l)	2,4-DNT (µg/l)
1003-1	0	610	40	35	750	12	25
	3.75	7.7	1.7U	3.4U	1.7U	1.8U	1.7U
1003-2	0	460	9.4	8.9	560	2.9	8.8
	3.75	15	1.3U	2.5U	1.3U	1.3U	1.3U
1003-3	0	500	18J	52	600	9.0	33
	3.75	63	0.83U	1.7U	2.0	0.86U	0.83U
1004-1	0	610	9.3	75	750	3.8	8.1
	3.75	1.7	1.6U	3.3U	1.6U	1.7U	1.6U
1004-2	0	620	14	42	770	7.0	5.3
	3.75	2.9	1.7U	3.4U	1.7U	1.8U	1.7U
1004-3	0	610	19	34	760	8.6	5.1
	3.75	16	2.3U	4.7U	2.3U	2.4U	2.3U
1005-1	0	610	11	32	740	5.5	3.9
	3.75	57	2.6U	5.2U	2.6U	2.7U	2.6U
1005-2	0	660	16	52	820	8.3	2.3
	2.5	120	1.6U	3.1U	2.1	1.6U	1.6U
1005-3	0	670	18	76	810	8.3	2.6
	2.5	100	1.6U	3.1U	2.2	1.6U	1.6U
1006-1	0	650	17	53	800	8.6	2.5
	2.5	21	1.6U	3.1U	1.6U	1.6U	1.6U
1006-2	0	650	19	82	790	6.5	1.3
	2.5	35	1.6U	3.1U	1.6U	1.6U	1.6U
1006-3	0	650	21	84	790	6.3	1.2
	2.5	37	1.6U	3.1U	1.6U	1.6U	1.6U

J = Analyte not detected. Value presented is the lower detection limit.
= Analyte presented below the lower detection limit.

Table 3 (cont'd.)
On-Site **perox-pure™** Treatment Results
for the SADA Groundwater

Test No.	Oxidation Time (min)	1,3,5-TNB (µg/l)	1,3-DNB (µg/l)	2-Amino DNTs (µg/l)	2,4,6-TNT (µg/l)	2,6-DNT (µg/l)	2,4-DNT (µg/l)
1007-1	0	590	12	45	690	4.4	0.67
	2.5	57	1.7U	3.4U	1.7U	1.8U	1.7U
1007-2	0	590	4.6	34	700	3.3	<1
	2.5	63	1.6U	3.1U	1.6U	1.6U	1.6U
1007-3	0	590	14	55	680	5.2	1.4
	2.5	30	1.6U	3.1U	1.6U	1.6U	1.6U
1010-1	0	610	15	84	720	4.8	1.2
	2.5	98	1.6U	3.1U	1.6U	1.6U	1.6U
1010-2	0	520	13	54	690	1.6U	1.6U
	2.5	130	0.83	3.1U	1.6U	1.6U	1.6U
1010-3	0	560	16	60	700	1.6U	1.6U
	2.5	150	1.0	3.1U	1.6U	1.6U	1.6U
1011-1	0	560	15	56	690	5.2	1.6U
	2.5	210	1.6U	3.1U	5.1	1.6U	1.6U
1011-2	0	550	10	44	670	4.4	1.6U
	2.5	120	1.64	3.1U	1.5	1.6U	1.6U
1011-3	0	600	14	52	700	4.6	1.6U
	2.5	230	1.6U	3.9U	8.4	1.6U	1.6U
1012-1	0	430	16	54	530	5.2	2.0U
	1.5	330	1.6	3.1U	24	2.0U	2.0U
1012-2	0	590	16	62	690	5.6	1.6U
	3.75	28	1.6U	3.1U	1.6U	1.6U	1.6U
1012-3	0	560	16	63	670	6.1	1.6U
	3.75	33	1.6U	3.1U	1.6U	1.6U	1.6U

U = Analyte not detected. Value presented is the lower detection limit.
NA = Not analyzed

Table 3 (cont'd.)
On-Site **perox-pure™** Treatment Results
for the SADA Groundwater

Test No.	Oxidation Time (min)	1,3,5-TNB (µg/l)	1,3-DNB (µg/l)	2-Amino DNTs (µg/l)	2,4,6-TNT (µg/l)	2,6-DNT (µg/l)	2,4-DNT (µg/l)
1013-1	0	570	1.6U	48	680	6.0	1.6U
	1.5	65	1.6U	3.1U	1.6U	1.6U	1.6U
1013-2	0	560	1.6U	3.1U	690	4.2	1.6U
	3.75	120	1.6U	3.1U	1.4	1.6U	1.6U
1013-3	0	560	1.6U	52	670	4.0	1.6U
	3.75	150	1.6U	3.1U	2.3	1.6U	1.6U
1014-1	0	560	1.6U	54	670	4.9	1.6U
	2.5	31	2U	3U	2U	2U	2U
1014-2	0	550	12	53	680	6.2	1.4
	2.5	1.8U	1.8U	3.7U	1.8U	1.9U	1.8U
1014-3	0	540	1.6U	60	660	6.4	1.4
	2.5	4.2	1.6U	3.1U	1.6U	1.6U	1.6U

U = Analyte not detected. Value presented is the lower detection limit.
NA = Not analyzed

4.0 DISCUSSION OF RESULTS

The primary objective of the on-site plot study discussed herein was to determine the best perox-pure treatment conditions for rapid destruction of ordnance compounds in the groundwater. The effect of each parameter is discussed below, with the focus being on the rate limiting compound trinitrobenzene (TNB).

4.1 Pretreatment

Pretreatment for solids and turbidity removal was necessary to improve the treatment efficiency of the **perox-pure™** Process and to prevent fouling of the quartz tubes over long periods of continuous operation. Significant tube coating was noted after an eight hour period of operation with filtration as the only pretreatment. When the pH of the influent water was raised to approximately 11 with 50% NaOH, a red-orange precipitate formed. The formation of this precipitate was accelerated by the addition of H_2O_2. The resulting floc was then filtered through a 1 or 3 micron cartridge filter. No tube coating was observed after eight hours of continuous operation with this pretreatment step.

The NaOH dosage appears to have a significant effect on the reduction of tube coating. The pH of 11 to 11.5 was optimal for quickly forming a floc. Visible floc was remaining in the water after filtration and pH adjustment to 3, in tests with pretreatment at a pH of 11.5 where the NaOH dosage was significantly greater (10 ml/min) as compared to 5 ml/min). The excess NaOH is believed to have contributed to the remaining floc to have had an effect on the tube coating observed in several tests.

4.2 pH Adjustment

Based on results of bench-scale testing and characterization of the groundwater, pH adjustment was shown to be beneficial in obtaining the best contaminant destruction rates. The pH was adjusted downward after filtration. It was difficult to stabilize the pH between the ranges of 4 to 5, therefore, the pH was maintained at approximately 3 prior to treatment in the **perox-pure™** system. The results of Test 1006-1 do not substantiate this finding of improved treatment with lower pH. However, just prior to the collection of the sample by Weston, it was noted that the pH had increased to 7.2 prior to entering the **perox-pure™** system. The acid pump was subsequently changed to adjust the pH back to approximately 3. The time it takes for the effects of the pump readjustment to reach the effluent of the treatment system is less than three minutes, about the time it took Weston personnel to collect a sample for pH and temperature readings. Therefore, the actual pH of the water sample at the time of collection is unknown.

4.3 Catalyst Addition

Catalyst Formula I was selected based on the results of the bench-scale testing. The catalyst concentration was varied from 8 mg/l to 12 mg/l. Optimization was difficult due to the time required for analytical turnaround. Therefore, the dosage of 12 mg/l was selected based on

previous laboratory testing. Tests 9-28-3 and 9-29-3 were selected for comparison based on the closest comparison of the other treatment parameters especially the pretreatment conditions. A 63% increase in the TNB destruction rate was observed in Test 929-3 performed with 12 mg/l of catalyst as compared to Test 928-3 performed with 8 mg/l catalyst. Figure 2 shows the effects of catalyst dosage.

4.4 H_2O_2 Dosage

The effect of H_2O_2 dosage on the TNB destruction rate is shown in Figure 3. The H_2O_2 dosage was varied from 200 mg/l to 750 mg/l. H_2O_2 was injected into the influent as a pretreatment and also within the oxidation chambers of the SX-30 in some tests. The data is unclear as to whether or not injection of additional H_2O_2 is beneficial in increasing the contaminant destruction rate. Comparing Tests 1006-2 (300 mg/l H_2O_2) and Test 1006-3 (750 mg/l H_2O_2) performed with the similar test conditions produced the same TNB destruction rate both with and without additional H_2O_2 injection, respectively. Similar destruction rates were also observed in Tests 1003-1 (300 mg/l H_2O_2) and 1004-2 (600 mg/l H_2O_2) performed with similar test conditions. Therefore, for economical reasons, additional H_2O_2 is not recommended.

4.5 Flow Rate

Typically with higher flow rates, the increased turbulence and chemical better mixing results in more efficient hydroxyl radical formation and increased contaminant destruction rates. This appears to be the case with the SADA Groundwater. The best TNB destruction rates were observed in Tests 927-3, 928-1 and 1013-1 performed at a flow rate of 5 gpm. However, Tests 1004-1, 1004-2 and 1006-1, performed at 2 gpm, produced comparable TNB destruction rates to the tests performed at 5 gpm. Variation in treatment parameters makes a direct comparison of the effects of flow rate on the contaminant destruction rates difficult. Therefore, given the known advantages of increased flow rates, it is assumed that the same benefits of increased flow rate will apply to the contaminant oxidation rates in the SADA groundwater operating at the recommended optimal treatment conditions.

The oxidation time (amount of contact time within the reaction vessel) is directly related to the flow rate. The slower the flow rate, the longer the oxidation time to carry out the reaction. A higher flow rate would equate to less reaction time, but a greater destruction rate is expected because of turbulence.

4.6 Recommendations

Based on a comparison of treatment results, the optimum treatment conditions for destruction of ordnance compound in the SADA groundwater include pretreatment for the removal of solids and turbidity with pH adjustment to 11, a total H_2O_2 addition 300 mg/l, pH adjustment to approximately 4 prior to treatment in the **perox-pure™** system, and a Catalyst Formula I dosage of 12 mg/l.

4.7 Electrical Usage

The SX-30 **perox-pure™** pilot system requires 60 amps of 3 phase, 60 cycle, 480 volt electrical power. The actual operating amps is approximately 30-40 amps. The exact electrical usage was measured by Weston during the testing, however, that information was not provided to VPSI.

FIGURE 2

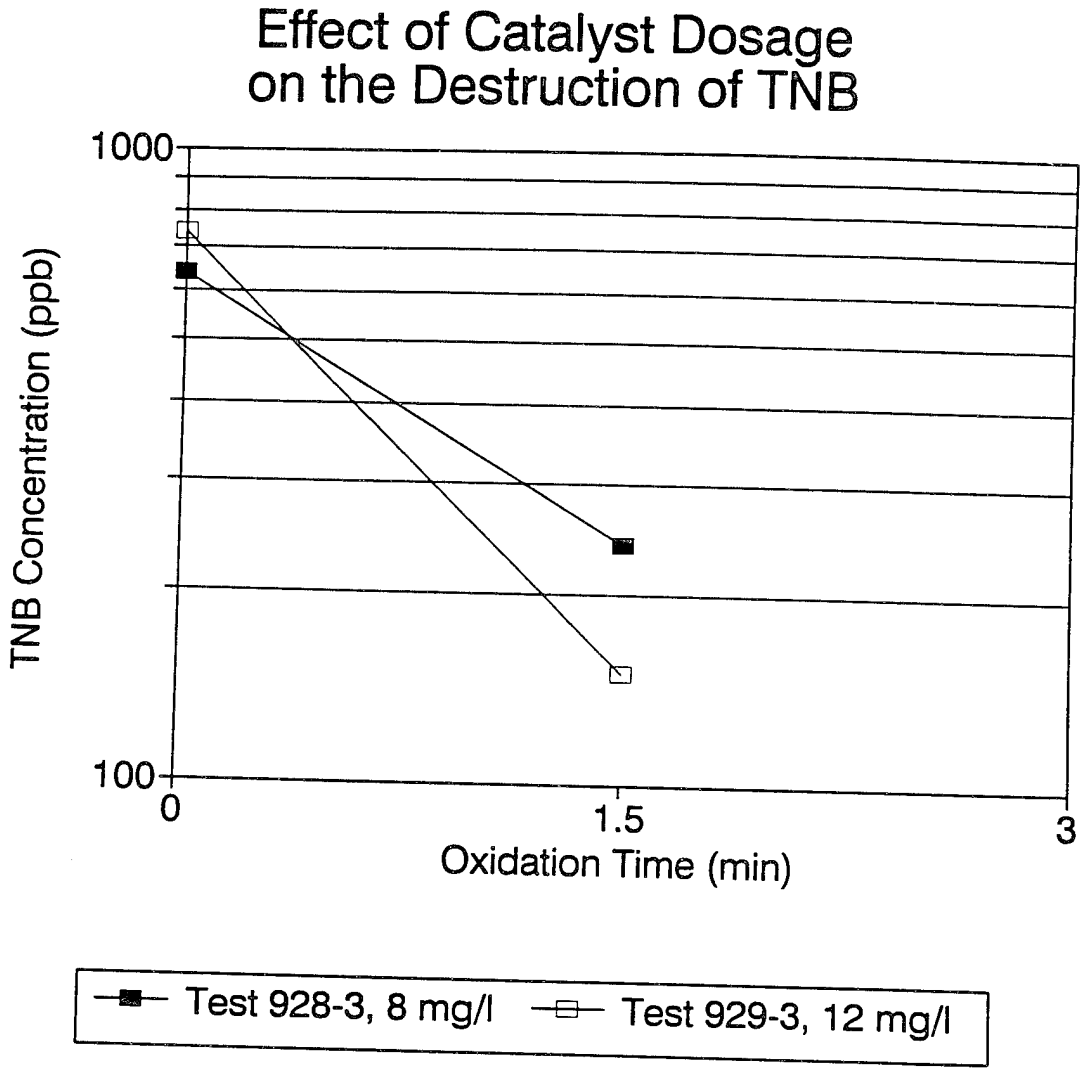
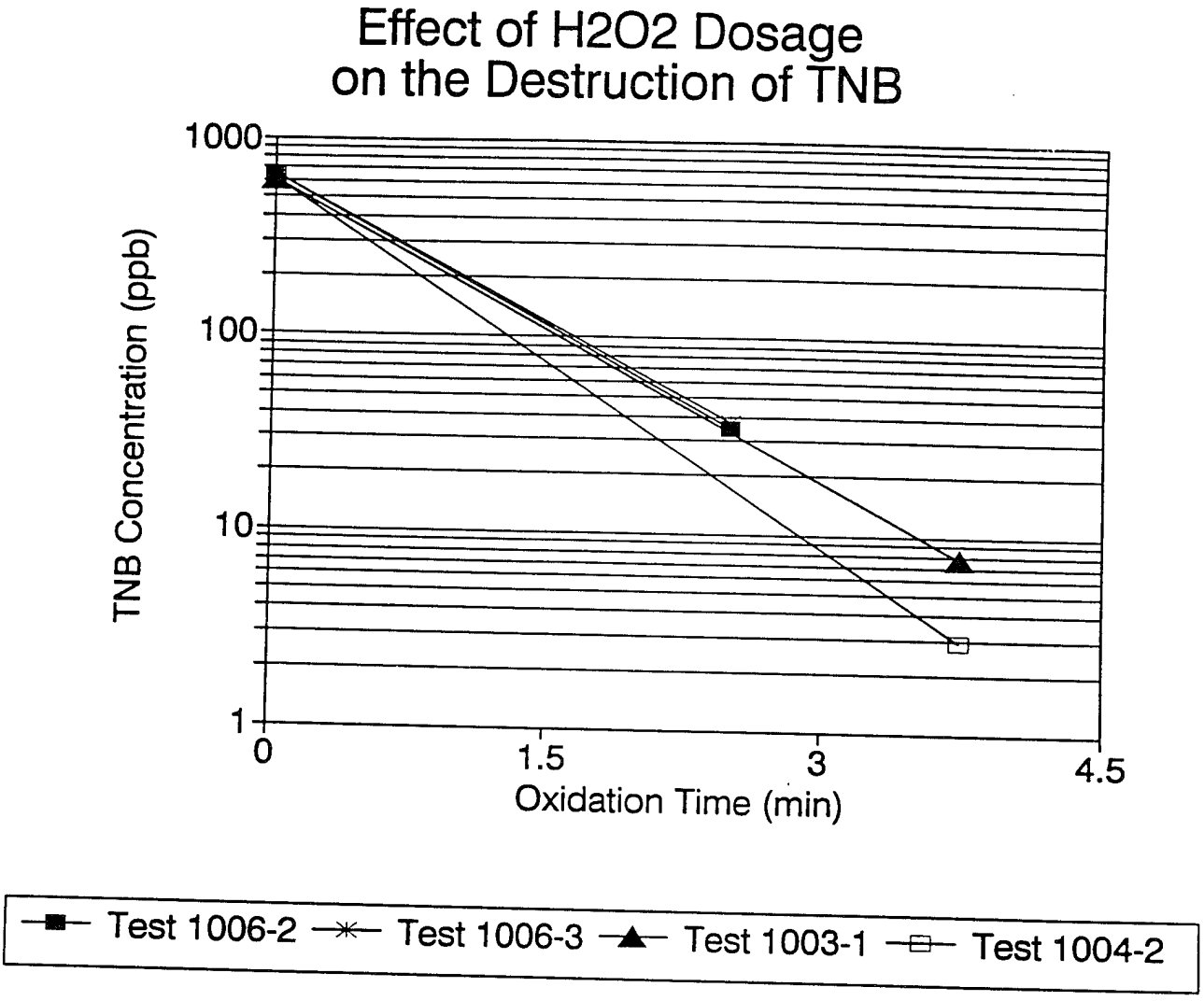

Effect of Catalyst Dosage
on the Destruction of TNB
1000
100
TNB Concentration (ppb)
0
1.5
3
Oxidation Time (min)
Test 928-3, 8 mg/l
Test 929-3, 12 mg/l

FIGURE 3


Effect of H2O2 Dosage
on the Destruction of TNB
TNB Concentration (ppb)
1000
100
10
1
0
1.5
3
4.5
Oxidation Time (min)
Test 1006-2
Test 1006-3
Test 1003-1
Test 1004-2

5.0 FULL-SCALE TREATMENT CONDITIONS

5.1 Treatment Criteria

The criteria used to project full-scale **perox-pure**™ treatment conditions for the SADA groundwater are summarized in Table 4. The flow rates, influent contaminant concentrations and effluent treatment objectives were specified by Weston. Only those contaminants with specified treatment objectives are listed in Table 4.

Table 4

Criteria for Full-Scale Treatment
of the SADA Groundwater

Design Flow Rate (gpm)	50
Influent Contaminants (μg/l)	
2,4,6-Trinitrotoluene	1200
1,3,5-Trinitrobenzene	590
1,3-Dinitrobenzene	47
2-Amino-4,6-Dinitrotoluene	26
Effluent Objectives (μg/l)	
2,4,6-Trinitrotoluene	7
1,3,5-Trinitrobenzene	7
1,3-Dinitrotoluene	9
2-Amino-4,6-Dinitrotoluene	36

5.2 Recommended Process Conditions

Full-scale **perox-pure**™ Process conditions for treatment of the SADA groundwater are projected in Table 5. The pilot-scale oxidation time was calculated from the treatment criteria in Table 4 using the full-scale rate data from Test 1004-1. The full-scale oxidation time was used along with the design flow rate from Table 4 to determine the power demand and the appropriate **perox-pure**™ model. The H_2O_2 dosage of 300 mg/l (See Section 4.4) was used to calculate the full-scale dosage in Table 5.

Table 5
Full-Scale **perox-pure™** Process Conditions
for Treatment of the SADA Groundwater

Oxidation Time (min.)	2.8
perox-pure™ Model	600
Power Demand (kW)	570
50% H_2O_2 Dosage (lb/1,000 gal)	5.0
Concentrated Acid (lb/1,000 gal)	2.7
Catalyst (lb/1,000 gal)	0.1
50% Sodium Hydroxide (lb/1,000 gal-Pretreatment)	3.35
50% Sodium Hydroxide (lb/1,000 gal-Post-treatment)	1.1

5.3 Discussion of Equipment

The on-site testing indicates that the target contaminants in the groundwater are oxidized to below the effluent levels specified by Weston with 2.8 minutes of oxidation in an SX reactor using 570 kW of power to the UV lamps at the specified flow rate of 50 gpm.

A 50% H_2O_2 dosage of 5 pounds per 1,000 gallons is projected from the on-site testing for treatment and pretreatment requirements. This results in a 50% H_2O_2 usage of 1,080 gallons per month. VPSI therefore recommends that a 5,000 gallon H_2O_2 storage and feed module be used to support the **perox-pure™** system.

The only utilities required include potable water for the safety shower, and 1,200 amps of 3 phase, 60 cycle, 480 volt electrical.

VPSI's **perox-pure™** system is a complete skid mounted system with all required controls enclosed. Only a minimal foundation with containment dike, and electrical and plumbing connections are necessary. The equipment can operate with infrequent attention from the operator. It does require occasional servicing which VPSI can provide under several service agreement options.

Equipment other than the **perox-pure™** unit and H_2O_2 storage and feed module are provided upon request, at an additional cost. Pretreatment and posttreatment equipment is generally provided by the client unless specifically requested to be supplied by VPSI.

6.0 INVESTMENT OPTIONS

6.1 Discussion of Investment Options

VPSI offers the **perox-pure™** system under either a Full Service Agreement with no capital investment or through direct purchase.

Option I - Full Service Agreement

VPSI will provide the **perox-pure™** system under a Full Service Agreement program, which includes the **perox-pure™** unit and H_2O_2 feed module, regular equipment maintenance, replacement parts, 24-hour emergency service, and regular service visits. VPSI will provide a written guarantee that the performance of the system will meet the agreed upon effluent specifications.

VPSI's qualified technical personnel will visit the site on a regular basis to monitor the operation, perform necessary maintenance and provide a monthly report on the system. Other operator attention is not normally required.

All of these services are included in one monthly service fee. In addition, if the process conditions change, such as an increase in flow rate or organic contaminant levels, the customer can request equipment replacement. In this way, the facility is always provided with an optimally sized unit, providing minimum operating costs for current site conditions.

If desired, the Full Service Subscriber may purchase the equipment with a credit for a portion of the fees paid.

Option II - Equipment Purchase

Alternatively, VPSI can supply the **perox-pure™** treatment system through equipment purchase with a separate Technical Services Agreement. The Technical Services Agreement provides a program which includes the H_2O_2 storage and feed module, equipment maintenance, replacement parts, 24-hour emergency service and regular service visits. VPSI will provide a written guarantee that the performance of the system will meet the agreed upon effluent specifications.

VPSI's qualified technical personnel will visit the site on a regular basis to monitor the operation, perform necessary maintenance and provide a monthly report on the system. Other operator attention is not normally required.

The VPSI Service Agreements would include service all equipment provided by VPSI. This includes equipment supplied for pre and posttreatment. The monthly service fee would be adjusted accordingly.

7.0 TESTING SUMMARY AND COST ESTIMATES

7.1 Electrical Power Consumption

The **perox-pure™** system was operated for approximately 8 hours per day for 14 days. The power consumption was as follows:

- 30 kW/h X 8 hrs/day X 14 days = 3,360 kW

Daily consumption values were not provided. Actual electrical consumption was reported to be 3054 kilowatt hours over the 14 day operating period. Therefore, the costs provided herein are conservative.

7.2 Chemical Additions

As per section 5.2. The chemical additions represent the usage of these materials over the duration of the pilot-testing.

- Pretreatment:
  1. 50% Sodium Hydroxide
     (3.35 lb/1,000 gal) Total use of approximately 13 gallons.
  2. 50% Hydrogen Peroxide
     (5 lb/1,000 gal) Total use of approximately 15 gallons.

- Process:
  1. Concentrated sulfuric acid (98%)
     (2.7 lb/1,000 gal) Total use of approximately 5 gallons.
  2. Catalyst Formula 1
     (0.1 lb/1,000 gal) Total use of approximately 25 gallons.

- Post-treatment:
  1. 50% Sodium Hydroxide
     (1.1 lb/1,000 gal) Total use of approximately 3 gallons.
     Post-treatment was not employed during the entire 14 days of operation.

7.3 System Components Requiring Repair or Replacement

- During Optimization and at intervals throughout the test period, the system was drained daily to observe chamber and tube conditions.
- Tube coating was observed at intervals throughout the test period. Implementation of NaOH and H_2O_2 for pretreatment reduced the incidence of coating. Several tube wiper configurations were also evaluated to provide optimal system operation. A combination of optimal pretreatment chemicals and tube wiper configuration resulted in no tube coating.

7.4 System Optimization Procedures

The treatment parameters evaluated during the optimization testing included pretreatment chemicals/filtration, H_2O_2 dosage and point of injection, catalyst dosage and a flow rate.

7.5 Routine Adjustments to System Controls

The **perox-pure™** system ran continuously for the 8 to 9 hour period each day. The chemical feed pumps were monitored by calibration throughout the day. Minor adjustments were made to the chemical feed pumps to maintain desired treatment conditions.

7.6 Cleaning Requirements for the UV Lamps

A deep red-brown coating was observed on the quartz tubes during the first few days of operation. The tube coating was significantly reduced or eliminated with the pretreatment step with the addition of NaOH to raise the pH to 11. The resulting floc was filtered through a 1 or 3 micron cartridge filter. When operated under these conditions in addition to employing an aggressive tube coating mechanism no tube coating or maintenance was required.

7.7 System Upsets and Restarts after Shutdown

System shut down occurred infrequently. Low water flow and high water temperature because of the low water flow were the only alarm shut downs experienced. The **perox-pure™** system was easily restarted by acknowledging the alarm and resetting through the touch screen PLC. The flow rate was increased to avoid additional shutdowns.

7.8 Volume of Groundwater Treated

Approximately 19,748 gallons.

7.9 Estimated Treatment Costs

	Full-Scale	Pilot Scale
7.9.1 Estimated Pretreatment and Posttreatment Requirements		
• 50% NaOH (6,910 lb/year @ $0.10/lb)	$ 6.91	$ 6.12
• H_2O_2 (see below)		
• Filtration (see capital costs)		
• 50% NaOH (2063 lb/year @ $0.10/lb) (Estimated pre and post-treatment)	$ 2.06	$1.41
7.9.2 Estimated Chemical Usage		
• H_2O_2 (129,600 lb/yr @ $0.50/lb)	$64,800	$75.00
• Acid (69,984 lb/yr @ $0.08/lb)	$ 5,599	$6.00

- Catalyst (2,603 lb/yr @ $5.00/lb) $13,015 $12.15

7.9.3 Estimated Power Requirements

- Electricity $244,404 $226.80
  Based on total electrical consumption and gallons treated as report by Weston.
  (0.155 kWh/gal @ $0.06/kWh)

7.9.4 Estimated Annual Repair/Replacement Costs
(Includes lamps, quartz tubes, gaskets, etc.)

$51,000 NA

7.9.5 Estimated Total Treatment Cost
($/1,000 gallons) $14.45 $16.58

7.9.6 Estimated Full-Scale System Capital Costs $650,000

7.9.7 Estimated Pilot-Scale System Capital Costs

$77,000

(Does not include capital costs for filtration since this is dependent upon type of filtration selected for pre-treatment.)

8.0 Other

1. Estimated Annual Maintenance Labor Hours 96
   (Includes pre and post-treatment system maintenance in addition to the H_2O_2 system maintenance, tube cleaning and lamp replacement. Estimated one 8 hours service visit per month.
2. System availability
   Typically, 12 weeks are required for drawing approval and manufacturing.

9.0 CONCLUSION

The **perox-pure**™ Process can provide effective treatment of the contaminated groundwater to the effluent limits specified by Weston as shown by the on-site testing results presented herein. The **perox-pure**™ Process offers the advantages of a proven, cost-effective treatment system that creates no air emissions, or generation of secondary waste products and is available under purchase or lease arrangements.

ATTACHMENT A

SPECIFICATIONS FOR **perox-pure**™ EQUIPMENT

SPECIFICATION

Ultraviolet Light/Hydrogen Peroxide Oxidation System

1. General

This specification describes the **perox-pure™** ultraviolet light (UV) - hydrogen peroxide (H_2O_2) oxidation system capable of destroying soluble toxic organic contaminants in water. These specifications are subject to change without notice.

Unloading, handling, installation, excavation, concrete work, finish painting, connecting piping, and electrical hookup are the responsibility of others.

2. Principle of Operation

System utilizes the chemistry of UV/H_2O_2 reactions, which involves generation of hydroxyl radicals, and other reactive species, by the photochemical action of ultraviolet light on hydrogen peroxide. The hydroxyl radicals attack organic species.

The final products of the noted reaction are carbon dioxide, water, and inorganic ions.

3. Applicable Codes - (Latest Editions)

Uniform Building Code	National Electric Code
Uniform Plumbing Code	NFPA
Uniform Mechanical Code	OSHA

Note: Operating pressure is not to exceed 15 psig, ASME Code does not apply.

4. Equipment Description

UV/H_2O_2 Oxidation Module -

Maximum Inlet Pressure: 15 psig
Power Requirement: 3ph/60Hz/480V

Materials of Construction -

UV/H_2O_2 oxidation chamber, fluorocarbon lined 6063-T6 aluminum or ASTM A-36 steel.
Chemical piping - type 316 stainless steel.
Process Piping - CPVC.
Structural Steel Skids and Supports - carbon steel.
ASTM A-36 with chemical and weather resistant paint.
Electrical Enclosures - Enamelled carbon steel.
Wetted non-metallic components - Quartz, fluoroelastomers, or polymers resistant to UV, H_2O_2 and all chemicals present.

Design Features -

The oxidation chamber shall not leak due to chamber penetrations from design of the automatic quartz tube cleaner. Oxidation chamber, control enclosures, instrumentation, controls, and piping shall be shop assembled on a skid and disassembled only as necessary for shipment. Lamps and supports to be shipped separately.

Electrical enclosures shall have hinged and lockable doors.

Electrical enclosure cabinets shall be weatherproof. Lamp drive enclosures will be provided with intake air cooling fans to control the inside temperature. The fans shall operate continuously when the unit is running.

Access doors shall have limit switches to shut the power off should the doors be opened.

All wiring and electrical connections shall be protected against moisture to prevent electrical short or failure. Pressure indicators and temperature switches shall be in weatherproof housings.

All wiring and electrical components within the system shall be designed, constructed and installed in accordance with the latest edition of the National Electrical Code and all applicable State and local electrical codes.

Circuitry within the lamp drive enclosure shall be protected and disconnected by pre-wired circuit breaker rated at 30,000 amp minimum AIC with external ground fault sensor and shunt trip.

Controls will be provided to shut down UV system, and provide alarm contact closure on:

1) high temperature in Lamp Drive Enclosure
2) low flow (adjustable)
3) high water temperature
4) moisture in lamp end enclosure
5) access door opening
6) remote contact closure (10 amp, 120 VAC)
7) low peroxide pressure
8) low peroxide splitter flow (if splitter is provided)
9) overpressure relief flow
10) low oxidation chamber water level
11) tube cleaning system failure
12) lamp low current detection (shut-down optional)
13) lamp contactor failure

Control shall be provided to allow on/off operation of individual UV lamps.

Additional controls shall be provided for on/off operation of (1) chemical pump.

Lamp drives shall be of the high-power factor type.

Flow indicator calibrated in gpm, with totalizer, shall be provided.

A system to indicate the operating status of each lamp shall be provided.

An elapsed timer meter shall be provided to indicate the number of hours of module operation. Timer shall be resettable with access codes.

Lamps shall be horizontally mounted and removable without draining the oxidation chamber.

The lamp end enclosures shall be provided with hinged and gasketed doors.

All UV sensitive materials shall be shielded from the UV rays by material reflective of, or resistant to, UV.

The UV lamps shall be protected against contact with the fluid in the event of a leak.

Water shall be separated from contact with the UV lamps by quartz tubes.

The UV oxidation chamber shall be designed to efficiently distribute and collect the process water throughout the entire oxidation chamber in order to eliminate an uneven flow pattern or short-circuiting. Piping connections shall be designed so that the UV oxidation chamber will remain full of fluid after shutdown.

Connections for injection of H_2O_2 in quantities suitable for the process shall be provided. If required by the process, means for complete mixing of the H_2O_2 and process water, and for variable, staged injection shall be provided. Provide visual indication of relative division of peroxide flow between injection points.

Automatic Tube Cleaning -

An automatic tube cleaning device shall be provided. Cleaner shall be self-propelled, and shall not require any chamber wall penetrations nor moving shaft seals. Cleaner operation cycle shall be adjustable. Cleaner shall be constructed of stainless steel and/or UV resistant materials and shall be replaceable through chamber handholes.

5. Installation, Start-up, and Operator Training

Supplier will supervise initial placement of all equipment provided in this specification.

The mechanical and electrical hookups by others shall be completed per schedule mutually agreed upon by all parties.

Upon completion of installation the equipment supplier shall hydrostatically test all pressure systems provided by this specification. If leaks occur, necessary corrections shall

be made and retested until completed without any evidence of leakage. All electrical circuits and equipment shall be tested for continuity and functional performance.

All surfaces to be contacted by H_2O_2 shall be properly passivated by the equipment supplier.

In addition to the above, during a scheduled start-up period of five (5) calendar days, the equipment supplier shall provide start-up operation of the systems furnished by this specification. The Field Service Engineer shall operate the equipment, make all adjustments and calibrations necessary to allow operation at full load for a 24-hour period. Representative samples will be taken as required to determine performance. During this period, the owner's operating personnel are to be trained in the operation and maintenance of this equipment. Any materials deemed defective during this period are to be replaced.

6. Certified Dimension Drawings

Two (2) sets of certified dimension drawings will be furnished.

7. Operation and Maintenance Instructions

Three (3) complete Operation and Maintenance Instruction Manuals will be furnished.

SPECIFICATION

Hydrogen Peroxide Storage/Feed Module

Materials of Construction:

Structural Steel Skids & Supports - carbon steel ASTM A-36 or Aluminum
Chemical Storage Vessels - HDPE
Chemical Piping - 316 stainless steel
Wetted non-metallic components - fluoroelastomers

Design Features:

Chemical feed pumps, controls, and piping will be shop assembled on skid and disassembled only as necessary for shipment.

Electrical enclosures will be weatherproof. All controls and indicator lights will be housed in electrical enclosures with hinged and lockable doors.

All wiring and electrical connections will be protected against moisture to prevent electrical short or failure. All electrical components and installation within the system will be designed, constructed and installed in accordance with the latest edition of the National Electrical Code and all applicable State and local electrical codes.

Terminals will be provided for connection of control wiring and interlocks with each UV/H_2O_2 Oxidation Module control panel.

Terminals will be provided for connection of control wiring and interlocks with each UV/H_2O_2 Oxidation Module control panel.

Operating and spare H_2O_2 pumps will be provided. Each pump will be of the positive displacement type, infinitely adjustable from 0 to 100% flow, electric motor driven for 1 ph/60 Hz/120 V power, 10 amp max. Wetted pump materials will be suitable for continuous contact with 50% H_2O_2. Piping and valves will be provided to allow use of pump for continuous injection of H_2O_2 to each UV/H_2O_2 module and to ease pump flow calibration. A pump calibration system is to be included on the skid.

Optional: Chemical storage tank will be provided with access man-way and connections for drain, H_2O_2 fill, outlet to feed pumps, and vent. Safety shower will be provided, mounted on the skid.

APPENDIX E

COST ESTIMATING SPREADSHEET

CLIENT :UNITED STATES ARMY ENVIRONMENTAL CENTER
LOCATION:ABERDEEN PROVING GROUND, MARYLAND
W. O. NO:02281-012-006-0270-00

ESTIMATE OF LIFE CYCLE COSTS
ESTIMATOR: NGA

DATE: 05-Jun-95
TIME: 08:39 AM

STUDY TITLE: WASTEWATER TREATMENT ALTERNATIVES USING ULTRA-VIOLET/OXIDATION PROCESS

DISCOUNT RATE: 5.25% | ECONOMIC LIFE: 30 YEARS

		ALTERNATIVE 1 Describe: VENDOR: PURIFICS ESTIMATED COSTS	ALTERNATIVE 1 PRESENT WORTH	ALTERNATIVE Describe: VENDOR: SOLARC ESTIMATED COSTS
	INITIAL COSTS -			
I	A. VENDOR QUOTED COST	687,500		480,000
N	B.			
I	C.			
T	D.			
I	E.			
A	F.			
L	G.			
	H.			
	I.			
C	J.			
O	K.			
S	CONTINGENCIES 0.00%			
T	ESCALATION 3.50%			
	TOTAL INITIAL COST	<><><><><><>	687,500	<><><><><><>
	OPERATIONS (ANNUAL) Differential Escalation Rate / PWA W/Escl			
	A. ELECTRICAL 0.035 23.37856286	55,714	1,302,513	130,349
	B. ACID COST 0.035 23.37856286	6,228	145,602	22,601
	C. BASE/CAUSTIC COST 0.035 23.37856286	1,918	44,840	49,932
	D. HYDROGEN PEROXIDE COST 0.035 23.37856286	0	0	0
O	E. TITANIUM DIOXIDE 0.035 23.37856286	210	4,909	0
W	F. OTHER ADDITIVES 0.035 23.37856286	4,914	114,882	0
N	G. 0.035 23.37856286		0	
I	H. 0.035 23.37856286		0	
N	I. 0.035 23.37856286		0	
G	J. TECH @ 14.88 & MGMT @ 30.00/HR 0.035 23.37856286	3,285	76,799	7,884
	TOTAL ANNUAL OPERATIONS COSTS	<><><><><><>	1,689,545	<><><><><><>
C				
O				
S	MAINTENANCE (ANNUAL) Differential Escalation Rate / PWA W/Escl			
T	A. SITE 0.035 23.37856286		0	
S	B. STRUCTURAL 0.035 23.37856286		0	
	C. MECHANICAL (@ 3% OF CAPITAL) 0.035 23.37856286		0	
	D. ELECTRICAL 0.035 23.37856286		0	
	E. INSTRUMENTATION AND CONTROLS 0.035 23.37856286		0	
	F. OTHER - LAMPS AND QUARTZ SLEEVE 0.035 23.37856286	39,946	933,880	29,171
	G. CONTINGENCY @ 0.00% 0.035 23.37856286		0	
	TOTAL ANNUAL MAINTENANCE COSTS	<><><><><><>	933,880	<><><><><><>

2

ROY F. WESTON, INC.
WEST CHESTER, PENNSYLVANIA

FE CYCLE COSTS

E 1 ICS	ALTERNATIVE 2 Describe: VENDOR: SOLARCHEM		ALTERNATIVE 3 Describe: VENDOR: ULTROX		ALTERNATIVE 4 Describe: VENDOR: VPSI	
PRESENT WORTH	ESTIMATED COSTS	PRESENT WORTH	ESTIMATED COSTS	PRESENT WORTH	ESTIMATED COSTS	PRE WC
	480,000		393,000		650,000	
687,500	<><><><><><>	480,000	<><><><><><>	393,000	<><><><><><>	6
1,302,513	130,349	3,047,372	64,333	1,504,013	299,592	7,0
145,602	22,601	528,379	5,424	126,805	4,967	1
44,840	49,932	1,167,338	442	10,333	11,695	2
0	0	0	0	0	65,700	1,5
4,909	0	0	0	0	0	
114,882	0	0	0	0	13,140	3
0		0		0		
0		0		0		
0		0		0		
76,799	7,884	184,317	1,201	28,078	1,419	
1,689,545	<><><><><><>	4,927,406	<><><><><><>	1,669,229	<><><><><><>	9,2
0		0		0		
0		0		0		
0		0		0		
0		0		0		
0		0		0		
933,880	29,171	681,976	25,413	594,119	50,983	1,1
0		0		0		
933,880	<><><><><><>	681,976	<><><><><><>	594,119	<><><><><><>	1,1

N, I N C.
YLVANIA

FILENAME: USACEUVY.WK1
PAGE 1 OF 3

NATIVE 3 : ULTROX		ALTERNATIVE 4 Describe: VENDOR: VPSI		ALTERNATIVE Describe:		ALTERNATIVE Describe:	
ED	PRESENT WORTH	ESTIMATED COSTS	PRESENT WORTH	ESTIMATED COSTS	PRESENT WORTH	ESTIMATED COSTS	PRESENT WORTH
000		650,000					
<><>	393,000	<><><><><><>	650,000	<><><><><><>	0	<><><><><><>	0
333	1,504,013	299,592	7,004,030		0		0
424	126,805	4,967	116,121		0		0
442	10,333	11,695	273,412		0		0
0	0	65,700	1,535,972		0		0
0	0	0	0		0		0
0	0	13,140	307,194		0		0
	0		0		0		0
	0		0		0		0
	0		0		0		0
201	28,078	1,419	33,174		0		0
<><>	1,669,229	<><><><><><>	9,269,904	<><><><><><>	0	<><><><><><>	0
	0		0		0		0
	0		0		0		0
	0		0		0		0
	0		0		0		0
	0		0		0		0
13	594,119	50,983	1,191,909		0		0
	0		0		0		0
<><>	594,119	<><><><><><>	1,191,909	<><><><><><>	0	<><><><><><>	0

CLIENT :UNITED STATES ARMY ENVIRONMENTAL CENTER
LOCATION:ABERDEEN PROVING GROUND, MARYLAND
W. O. NO:02281-012-006-0270-00

R O Y
WE

STUDY TITLE: WASTEWATER TREATMENT ALTERNATIVES USING ULTRA-VIOLET/OXIDATION PROCESS

DISCOUNT RATE: 5.25% | ECONOMIC LIFE: 30 YEARS

				ALTERNATIVE 1 Describe: VENDOR: PURIFICS 0 0		ALTERNATIVE 2 Describe: VENDOR: SOLARCHEM 0 0	
		YEAR	PW Factor	ESTIMATED COSTS	PRESENT WORTH	ESTIMATED COSTS	PR W
	ALTERATIONS (SINGLE EXPENDITURE) ITEM(S) ALTERED						
	A.	0	1		0		
	B.	0	1		0		
	C.	0	1		0		
O	TOTAL ALTERATION COSTS			<><><><><><>	0	<><><><><><>	
W	REPLACEMENTS (SINGLE EXPENDITURE)	YEAR	PW Factor				
	A.	0	1		0		
N	B.	0	1		0		
	C.	0	1		0		
I	D.	0	1		0		
	E.	0	1		0		
N	F.	0	1		0		
	G.	0	1		0		
G	H.	0	1		0		
	I.	0	1		0		
	J.	0	1		0		
	K.	0	1		0		
C	L.	0	1		0		
O	TOTAL REPLACEMENT COSTS			<><><><><><>	0	<><><><><><>	
S	F I N A N C I N-G C O S T S						
T							
S	F U N C T I O N A L U S E C O S T S						
	D E N I A L O F U S E C O S T S						

ASSOCIATED (ANNUAL)	Differential Escalation Rate	PWA W/Escl				
A.	0.035	23.37856286		0		
B.	0.035	23.37856286		0		
C.	0.035	23.37856286		0		
D.	0.035	23.37856286		0		
E.	0.035	23.37856286		0		
F.	0.035	23.37856286		0		
G. CONTINGENCY @ 0.00%	0.035	23.37856286		0		
TOTAL ANNUAL ASSOCIATED COSTS			<><><><><><>	0	<><><><><><>	

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ROY F. WESTON, INC.
WEST CHESTER, PENNSYLVANIA

SENT WORTH	ALTERNATIVE 2 Describe: VENDOR: SOLARCHEM 0 0 ESTIMATED COSTS	PRESENT WORTH	ALTERNATIVE 3 Describe: VENDOR: ULTROX 0 0 ESTIMATED COSTS	PRESENT WORTH	ALTERNATIVE 4 Describe: VENDOR: VPSI 0 0 ESTIMATED COSTS	PRE WC
0		0		0		
0		0		0		
0		0		0		
0	<><><><><><><>	0	<><><><><><><>	0	<><><><><><><>	
0		0		0		
0		0		0		
0		0		0		
0		0		0		
0		0		0		
0		0		0		
0		0		0		
0		0		0		
0		0		0		
0		0		0		
0	<><><><><><><>	0	<><><><><><><>	0	<><><><><><><>	
0		0		0		
0		0		0		
0		0		0		
0		0		0		
0		0		0		
0		0		0		
0		0		0		
0	<><><><><><><>	0	<><><><><><><>	0	<><><><><><><>	

ALTERNATIVE 4 cribe: DOR: VPSI 0 0		ALTERNATIVE Describe: 0 0 0		ALTERNATIVE Describe: 0 0 0	
TIMATED COSTS	PRESENT WORTH	ESTIMATED COSTS	PRESENT WORTH	ESTIMATED COSTS	PRESENT WORTH
	0		0		0
	0		0		0
	0		0		0
><><><><>	0	<><><><><><>	0	<><><><><><>	0
	0		0		0
	0		0		0
	0		0		0
	0		0		0
	0		0		0
	0		0		0
	0		0		0
	0		0		0
	0		0		0
	0		0		0
	0		0		0
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	0		0		0
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	0		0		0
	0		0		0
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	0		0		0
	0		0		0
<><><><>	0	<><><><><><>	0	<><><><><><>	0

R O Y
WES

CLIENT :UNITED STATES ARMY ENVIRONMENTAL CENTER
LOCATION:ABERDEEN PROVING GROUND, MARYLAND
W. O. NO:02281-012-006-0270-00

STUDY TITLE: WASTEWATER TREATMENT ALTERNATIVES USING ULTRA-VIOLET/OXIDATION PROCESS

DISCOUNT RATE: 5.25% | ECONOMIC LIFE: 30 YEARS

		YEAR	PW Factor	ALTERNATIVE 1 Describe: VENDOR: PURIFICS 0 0 ESTIMATED COSTS	ALTERNATIVE 1 PRESENT WORTH	ALTERNATIVE 2 Describe: VENDOR: SOLARCHEM 0 0 ESTIMATED COSTS	ALTERNATIVE 2 PRE WO
SALVAGE	SALVAGE AT END OF ECONOMIC LIFE						
	A. STRUCTURE/ARCHITECTURAL	30	0.215445220		0		
	B. EQUIPMENT	30	0.215445220	(46,750)	(10,072)	(32,640)	
	C. MECHANICAL	30	0.215445220	0	0	0	
	D. ELECTRICAL	30	0.215445220	0	0	0	
	E. OTHER	30	0.215445220	0	0	0	
	F.	30	0.215445220		0		
	G.	30	0.215445220		0		
	TOTAL SALVAGE			<><><><><><>	(10,072)	<><><><><><>	
LIFE CYCLE COSTS	TOTAL PRESENT WORTH LIFE CYCLE COSTS			<><><><><><>	3,300,853	<><><><><><>	6,0
	LIFE CYCLE PRESENT WORTH DOLLAR SAVINGS			<><><><><><>		<><><><><><>	

NOTES:

<><><><><><>

2

ROY F. WESTON, INC.
WEST CHESTER, PENNSYLVANIA

1 :S	ALTERNATIVE 2 Describe: VENDOR: SOLARCHEM 0 0		ALTERNATIVE 3 Describe: VENDOR: ULTROX 0 0		ALTERNATIVE 4 Describe: VENDOR: VPSI 0 0	
PRESENT WORTH	ESTIMATED COSTS	PRESENT WORTH	ESTIMATED COSTS	PRESENT WORTH	ESTIMATED COSTS	PRES WOR
0		0		0		
(10,072)	(32,640)	(7,032)	(26,724)	(5,758)	(44,200)	(
0	0	0	0	0	0	
0	0	0	0	0	0	
0	0	0	0	0	0	
0		0		0		
0		0		0		
(10,072)	<><><><><><>	(7,032)	<><><><><><>	(5,758)	<><><><><><>	(
	<><><><><><>		<><><><><><>		<><><><><><>	
	<><><><><><>		<><><><><><>		<><><><><><>	
3,300,853	<><><><><><>	6,082,350	<><><><><><>	2,650,591	<><><><><><>	11,10
	<><><><><><>		<><><><><><>		<><><><><><>	
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FILENAME: USACEUVY.WK1
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	ALTERNATIVE 4 Describe: VENDOR: VPSI 0 0		ALTERNATIVE Describe: 0 0 0		ALTERNATIVE Describe: 0 0 0	
	ESTIMATED COSTS	PRESENT WORTH	ESTIMATED COSTS	PRESENT WORTH	ESTIMATED COSTS	PRESENT WORTH
0		0		0		0
8)	(44,200)	(9,523)	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0		0		0		0
0		0		0		0
8)	<><><><><><>	(9,523)	<><><><><><>	0	<><><><><><>	0
	<><><><><><>		<><><><><><>		<><><><><><>	
	<><><><><><>		<><><><><><>		<><><><><><>	
1	<><><><><><>	11,102,291	<><><><><><>	0	<><><><><><>	0
	<><><><><><>		<><><><><><>		<><><><><><>	
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