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J.R SIMPLOT
EX-SITU BIOREMEDIATION TECHNOLOGY FOR TREATMENT OF TNT-CONTAMINATED SOILS

INNOVATIVE TECHNOLOGY EVALUATION REPORT

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NOTICE

The information in this document has been prepared for the U.S. Environmental Protection Agency's (EPA's) Superfund Innovative Technology Evaluation (SITE) Program under Contract No. 68-CO-0048. This document has been subjected to EPA's peer and administrative reviews and has been approved for publication as an EPA document. Mention of trade names of commercial products does not constitute an endorsement or recommendation for use.

FOREWORD

The U.S. Enviromnental Protection Agency is charged by Congress with protecting the Nation's land air, and water resources. Under a mandate of national enviromnental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and ground water, and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

This report was prepared under the direction of Dr. Wendy Davis-Hoover, the EPA Technical Project Manager for this SITE Demonstration at the National Risk Management Research Laboratory (formerly the Risk Reduction Engineering Laboratory) in Cincinnati, Ohio. This report was prepared by the Process Technology Division of Science Applications International Corporation (SAIC). Contributors and reviewers for this report were Dr. Ron Lewis and Mr. Robert Stenbcrg of the EPA-NRMRL, Dr. Russ Kaake of the J.R. Simplot Company, and Mr. Craig Nowell formerly of Envirogen, Inc.

EXECUTIVE SUMMARY

This report summarizes the findings *of* the second evaluation of the J.R. Simplot Ex-situ Bioremediation Technology also known as the Simplot Anaerobic **Bioremediation (SABRE™)** process. This technology was developed by the J.R. Simplot Company to biologically degrade nitroaromatic and energetic compounds. The first evaluation was performed using soil contaminated with dinoseb, an agricultural herbicide. The second evaluation, and subject of thii report, demonstrated the effectiveness of the process on the biodegradation of soil contaminated with 2,4,6-Trinitrotoluene (TNT). These evaluations were conducted under *the* U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Program.

Conclusions from this SITE Demonstration

Based on this SITE Demonstration, the following conclusions may be drawn concerning the applicability of the J.R. Simplot Ex-Situ Bioremediation Technology:

- The J.R. Simplot Bioremediation Technology can reduce the levels of TNT in the clayey gravel with sand soil by 99.4% based on an average pre-treatment slurry concentration of 1,500 mg/kg (on a dry basis) and a final average post-treatment slurry concentration of 8.7 mg/kg. This Reduction Efficiency has a 95% confidence interval of 98.3% to 99.9%. The treatment time associated with this Reduction Efficiency is approximately 9 months. QC data indicate that the post-treatment slurry concentration may be slightly biased thereby potentially lowering the overall Reduction Efficiency of the process. The Reduction Efficiency reported above is an overall "best" estimate based upon a statistically significant number of analytical results with no correction for spike recoveries.

- A 95% Reduction Efficiency, the critical objective of this demonstration, was achieved after approximately 5 months of remediation.

- Intermediate by-products resulting from the biological degradation of TNT were found to increase during the course of treatment and then decrease to below the analytical detection limit at the completion of the demonstration.

- Relative toxicity studies (early seedling growth, root elongation, and earthworm reproduction tests) from the commencement of the treatment process to a point approximateIy 5 months into the test showed that the technoIogy bad successfully reduced the toxicity of the contaminated soil.

- It is possible that remediation of the TNT contaminated soil is not uniform throughout the bioreactor. A large variability in the TNT concentrations existed in the post-treatment data. It is believed that one of the primary reasons for this variability in the post-treatment soil is because of an inability to completely wet the soil at the start of treatment due to the failure of the mixers while loading the soil and water into the bioreactor. The soil at this site consisted of a large clay content and therefore had a tendency to form soil clumps which were not easily broken apart prior to treatment. In addition, because of the rain that occurred on site once the soil was excavated soil clumps became more prevalent. While previous treatability tests (see below) have shown that mixing is not critical for the treatment to progress it is important that the soil is thoroughly wetted at the beginning of the treatment process. Because the soil was not easily broken apart during the pm-treatment processing phase and therefore the soil was not thoroughly wetted, it is possible that uniform treatment did not occur throughout the process. The consequence of this conclusion is that for similar soil types a comprehensive post-treatment sampling and analysis program may be required to determine if all TNT has been degraded.

- The negative process control showed that the degradation of TNT was a result of the J.R. Simplot Technology.

- The cost associated with this technology for treatment of 3,524 m3 (5,000 yd^3) of TNT-contaminated soil in four Iined pits is approximately $147/m3 ($112/yd^3) for a treatment time of 6 months. This does not include costs for excavating the TNT-contaminated soil. Depending on site characteristics, an additional cost of up to $131/$m^3$ ($100/$yd^3$) may be assessed to the client by the developer for additional technical assistance, soil nutrients, a carbon source, and other process enhancements.

Conclusions that may be drawn regarding this technology, based on treatabiIity studies and other pertinent information, include:

- The treatment time was found to be approximately 9 months, much longer than expected. This was due, in part, to. the freezing conditions encountered which necessitated the inclusion of heaters to the system. Another time-limiting step was the diffusion of the TNT from the solid phase to the liquid phase within the bioreactor. The TNT degrading microorganisms thrive in the Iiquid phase of the bioreactor, therefore, the contaminants must be soluble, to some extent, in the liquid phase.

- Agitation of the bioreactor is required to ensure that diffusion of TNT into the liquid phase of the bioreactor. Although constant agitation of the bioreactor is not rquired, some form of "turning over" the soil in the bioreactor to create sufficient contact with the liquid phase is required.

- The presence of heavy metals in the soil does not adversely affect the process. As this technology is a sulfate reducing process, the toxic metals in the feed soil (e.g.: cadmium, lead, etc.,) are reduced to their sulfide forms thus. making the metals less toxic than in their original form (I). Simplot claims that this technology is less susceptible to the effects of toxic metals than other bioremcdiation systems.

If the feed soil contains greater than 1,000 mg/kg by weight total recoverable petroleum hydrocarbons (TRPH) then these hydrocarbons are thought to be toxic to the microorganisms (I) However, if these hydrocarbons can be separated from the TNT-contaminated soil, the process is still applicable to the waste.

The Simplot process can remediate most types of soil. However, pre-processing of the soil is required prior to placement into the bioreactor. This pre-processing may take longer for soils with a high clay content than for sandy type soils, thus increasing the cost of remediation. The low diffusivity of contaminants from clay soils to the water phase can also increase the treatment period. If the soil to be treated contains large rocks or debris, then this larger fraction must either be passed through a rock washing system with the washwater and tines being added to the bioreactor or crushed to the required size before being placed in the bioreactor.

The J.R. Simpiot Ex-Situ Bioremediation Technology was evaluated based on the nine criteria used for decision-making in the Superfund Feasibility Study (FS) process. Table ES-I presents this evaluation.

Table ES-1. Evaluation Criteria for the J.R. Simplot Ex-Situ Bioremediation Technology

Overall Protection of Human Health and the Environment	Compliance with Federal ARARs	Long-Term Effectiveness and Performance	Short-Term Effectiveness	Reduction of Toxicity, Mobility, or Volume through Treatment
Provides both short- and long-term protection by destroying contaminants in soil. Prevents groundwater contamination and off-site migration. Requires measures to protect workers and perhaps nearby communities during excavation, handling, and treatment.	Requires compliance with RCRA treatment, storage, and land disposal regulations (for a hazardous waste). Excavation, construction, and operation of on-site treatment unit may require compliance with location-specific ARARs. Emission controls may be needed to ensure compliance with air quality standards if volatile compounds are present. Wastewater discharges to POTW or surface bodies requires compliance with Clean Water Act regulations.	Permanently destroys contamination and intermediate compounds. Provides reduction in contamination levels; duration of treatment determines final contaminant levels. Overall toxicity reduced between pre- and post-treatment.	Presents potential short-term risks to workers and nearby community, including exposure to noise and contaminants released to air during excavation and handling. These can be minimized with correct handling procedures and borders.	Eliminates toxicity of soil contaminants through treatment. Does not leave intermediate compounds if conducted properly. Could result in intermediate compounds if terminated prematurely. If not fully dried, increases volume of treatment material by addition of water to create slurry.

Table ES-1. (Continued)

Implementability	Cost	Community Acceptance	State Acceptance
Major equipment is limited to bioreactor and agitation/suspension devices. Support equipment includes earthmoving equipment (for excavation, screening, and loading of bioreactor) and monitoring equipment (for tracking of pH, redox potential, and temperature). Once on-site, the small portable bioreactor can be assembled and ready to load within two days. The larger modular bioreactor requires approximately four days. After excavation, bioreactor loading activities (soil and water) are a function of the treatment volume. After treatment is complete, the small bioreactor can be emptied and demobilized in three days. If allowed by enforcement personnel treated soil can be placed in the excavated area and used as fill material. For erected bioreactors, the integrity of the liner can be intentionally breached when	Estimated cost is $147/m^3$ ($112/yd^3) for treatment in four lined pits, remediating a total of 3,824 m^3 (5,000 yd^3) of soil. Actual cost is site-specific and dependent upon: the volume of soil, soil characteristics, contaminants present, and original and target cleanup levels. Cost data presented in this table are for treating TNT-contaminated soil similar to the SITE Demonstration treatment soil. Costs presented are based on a 6 month batch treatment time, and exclude treatment soil excavation costs. Depending on site characteristics, an additional cost of up to $131/m^3$ ($100/yd^3) may be assessed to the client by the developer for additional technical assistance, soil nutrients, a carbon source, and other process enhancements.	Minimal short-term risks presented to the community makes this technology favorable to the public. Public knowledge of common bioremediation applications (e.g., wastewater treatment) eases community acceptance for hazardous waste treatment using this technology. Use of naturally-selected microorganisms makes treatment by this technology a favorable option to the community. Low levels of noise exposure may impact community in the immediate vicinity.	If remediation is conducted as part of a RCRA corrective action, state regulatory agencies may require permits to be obtained before implementing the system. These may include a permit to operate the treatment system, an air emissions permit (if volatile compounds are present), a permit to store contaminated soil for more than 90 days, and a wastewater discharge permit.

SECTION 1

INTRODUCTION

This section provides background information about the Superfund Innovative Technology Evaluation (SITE) Program, discusses the purpose of this Innovative Technology Evaluation Report (ITER). and describes the J.R. Simplot Ex-Situ Bioremediation Technology. For additional information about the SITE Program, this technology, and the demonstration site, key contacts are listed at the end of this section.

1.1 Background

In 1987, the J.R. Simplot Company began working with researchers at the University of Idaho to develop a process to anaerobically degrade nitroaromatic compounds. In September 1990. the process was accepted into the SITE Emerging Technologies Program. A treatability study funded by the Emerging Technologies Program was performed by the University of Idaho on 9,000 kg (9.9 tons) of soil contaminated with the nitroaromatic herbicide, dinoseb. The results of this treatability study showed that the process could degrade dinoseb from approximately 20 mg/kg to below the analytical detection limit in 15 days. A transient unidentified intermediate compound was formed by the process, but the concentration of this intermediate compound was reduced to near the analytical detection limit within 45 days (2). In April 1992, the J.R. Simplot Company applied, and was accepted into the SITE Demonstration Program. A full-scale demonstration of the technology was performed at an airport where the soil was contaminated with dinoseb. An evaluation of the J.R. Simplot Ex-Situ Bioremediation Technology using this listed RCRA waste as the contaminant of interest was performed in the summer of 1993. The results of this SITE Demonstration conducted at the afore-mentioned airport with supporting information from the bench-scale treatability studies conducted by the University of Idaho is described in a separate ITER. The results and conclusions of the SITE Demonstration with TNT as the contaminant of interest is the focus of this ITER.

The J.R. Simplot Ex-Situ Bioremediation Technology is a simple bioenhancement process that treats soils contaminated with nitroaromatic compounds by the addition of naturally selected anaerobic soil microorganisms. The process is initiated under aerobic conditions, but anaerobic conditions are quickly achieved under designed parameters, thus enabling the microbes to degrade the nitroaromatic contaminants completely. As claimed by the developer, anaerobic degradation of nitroaromatics by the J.R. Simplot process takes place without the presence of any known toxic degradation products at the completion of treatment.

1.2 Brief Description of Program and Reports

The SITE Program is a formal program established by the EPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) in response to the Superfund Amendments and Reauthorization Act of 1986 (SARA). The SITE Program promotes the development, demonstration, and use. of new or innovative technologies to clean up Superfund sites across the country.

The SITE Program's primary purpose is to maximize the use of alternatives in cleaning hazardous waste sites by encouraging the development and demonstration of new, innovative treatment and monitoring technologies. It consists of four major elements:

- the Demonstration Program,
- the Emerging Technology Program,
- the Measurement and Monitoring Technologies Program, and
- the Technology Transfer Program.

The objective of the Demonstration Program is to develop reliable performance and cost data on innovative technologies so that potential users may assess the technology's site-specific applicability. Technologies evaluated are either currently available or close to being available for remediation of Superfund sites. SITE Demonstrations are conducted on hazardous waste sites under conditions that closely simulate full-scale remediation conditions, thus assuring the usefulness and reliability of information collected. Data collected are used to assess: (1) the performance of the technology, (2) the potential need for pre- and post-treatment processing of wastes, (3) potential operating problems, and (4) the approximate costs. The demonstrations also allow for evaluation of long-term risks.

The Emerging Technology Program focuses on conceptually proven bench-scale technologies that are in an early stage of development involving pilot or laboratory testing. Successful technologies are encouraged to advance to the Demonstration Program.

Existing technologies that improve field monitoring and site characterization are identified in the Measurement and Monitoring Technologies Program. New technologies that provide faster, more cost-effective contamination and site assessment data are supported by this program. The Measurement and Monitoring Technologies Program also formulates the protocols and standard operating procedures for demonstration methods and equipment.

The Technology Transfer Program disseminates technical information on innovative technologies in the Demonstmtion, Emerging Technology, and Measurement and Monitoring Technologies Programs thmugh various activities. These activities increase the awareness and promote the use of innovative technologies for assessment and remediation at Superfund sites. The goal of technology transfer activities is to develop interactive communication among individuals requiring up-to-date technical information.

1.3 The SITE Demonstration Program

Technologies are selected for the SITE Demonstration Program thmugh annual requests for proposals. ORD staff reviews the proposals to determine which technologies show the most promise of use at Superfund sites. Technologies chosen must be at the pilot- or full-scale stage, must be innovative, and must have some advantage over existing technologies. Mobile technologies are of particular interest.

Once the EPA has accepted a proposal, cooperative agreements between the EPA and the developer establish responsibilities for conducting the demonstration and evaluating the technology. The developer is responsible for demonstrating the technology at the selected site and is expected to pay any costs for transport, operations, and removal of the equipment. The EPA is responsible for project planning, sampling and analysis, quality assurance and quality control, preparing reports, disseminating information, and transporting and disposing of treated waste materials.

The results of this evaluation of the J.R. Simplot Ex-Situ Bioremediation Technology for treatment of TNT-contaminated soil are presented in three documents: the SITE Technology Capsule, the Technical Evaluation Report (TER), and this Innovative Technology Evaluation Report. The SITE Technology Capsule provides relevant information on the technology, emphasizing key features of the results of the SITE field demonstration. The TER presents all data gathered during the SITE Demonstration and is a companion document to the ITER. The TER also presents all relevant QC information (3). Both the

SITE Technology Capsule and the 1TER are intended for use by remedial managers making a detailed evaluation of the technology for a specific site and waste.

1.4 Purpose of the Innovative Technology Evaluation Report (ITER)

This ITER is the second to be published regarding the J.R. Simplot Ex-Situ Bioremediation Technology. This ITER provides information on the treatment of TNT-contaminated soils using this approach and includes a comprehensive description of this demonstration and its results. The first ITER gives the results and conclusions regarding the efficacy of the technology for the treatment of the RCRA listed herbicide, dinoseb. The ITER is intended for use by EPA remedial project managers, EPA on-scene coordinators, contractors, and other decision-makers carrying out specific remedial actions. The ITER is designed to aid decision-makers in further evaluating specific technologies for further consideration as applicable options in a particular cleanup operation. This report represents a critical step in the development and commercialization of a treatment technology.

To encourage the general use of demonstrated technologies, the EPA provides information regarding the applicability of each technology to specific sites and wastes. The ITER includes information on cost and site-specific characteristics. It also discusses advantages, disadvantages, and limitations of the technology.

Each SITE Demonstration evaluates the performance of a technology in treating a specific waste. The waste characteristics of other sites may differ from the characteristics of the treated waste. Therefore, a successful field demonstration of a technology at one site does not necessarily ensure that it will be applicable at other sites. Data from the field demonstration may require extrapolation for estimating the operating ranges in which the technology will perform satisfactorily. Only limited conclusions can be drawn from a single field demonstration.

1.5 Technology Description

The J.R. Simplot Bx-Situ Bioremediation Technology is designed to destroy nitroaromatic and energetic compounds without the presence of any toxic intermediate compounds at the completion of remediation. The theory of operation behind the Simplot technology is that soils contaminated with these compounds may be treated using an anaerobic consortium. A consortium may be defined as a group of different populations of microorganisms in close association that form a community structure with a certain symbiosis or interrelationship. Each population contributes to the general welfare of the group. An anaerobic consortium is a group of different populations of microorganisms that exist symbiotically without oxygen. Studies have found that anaerobiosis with redox potential less than -200 mV promotes the establishment of an anaerobic microbial consortium that degrades nitroaromatic compounds completely (2). Under ***aerobic or*** microaerophilic conditions, degradation of nitroaromatic compounds may form degradation products that are potentially toxic. ***Anaerobic*** degradation of nitroaromatics using the J.R. Simplot technology takes place with the formation and then destruction of these degradation products.

Execution of the Simplot bioremediation technology is carried out by mixing a carbon source (a J.R. Simplot Company potato-processing starch by-product) with contaminated soil and then adding water and buffers to create a slurry. This prompts aerobic microorganisms to consume oxygen, thus creating anaerobic conditions in the treatment slurry. These conditions subsequently stimulate anaerobic microorganisms to consume toxins present in the slurry. The appropriate microorganisms are often indigenous to the treatment soil. Treatment soils may also be inoculated with the necessary consortium to initiate or enhance degradation rates. Treatment may take place in a small, mobile bioreactor or, when larger treatment soil volumes exist, in shallow, lined in-ground pits, or in large modular bioreactors.

Section 4.2 provides the specific details of the process design used during the Demonstration Test. Section 4.3 discusses the methodology behind the treatment and testing performed.

1.6 Key Contacts

Additional information on the J.R. Simplot Ex-Situ Bioremediation Technology and the SITE Program can bc obtained from the following sources:

The J.R. Simplot Ex-Situ Bioremediation Technology

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The J.R. Simplot Company
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Information on the SITE Program is available through the following on-line information clearinghouses:

The Alternative Treatment Technology Information Center (ATTIC) System [operator: (301) 670-6294] is a comprehensive, automated information retrieval system that integrates data on hazardous waste treatment technologies into a centralized. searchable source. This data base provides summarized information on innovative treatment technologies.

The Vendor Information System for Innovative Treatment Technologies (VISITT) [hotline: (800) 245-4505)] data base currently contains information on approximately 231 technologies offered by 141 developers.

The OSWER CLU-In electronic bulletin board contains information on the status of SITE technology demonstrations. The system operator can be reached at (301) 585-8368.

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

SECTION 2

TECHNOLOGY APPLICATIONS ANALYSIS

This section of the report addresses the general applicability of the J.R. Simplot Ex-Situ Bioremediation Technology to contaminated waste sites. The analysis is based primarily on this SITE Demonstration, and conclusions are based exclusively on these data since only limited information is available on other applications of the technology. Supporting data from treatability studies performed by the University of Idaho are included. Thii SITE Demonstration was conducted on soil contaminated with TNT (2,4,6-trinitrotoluene).

2.1 Key Features of the J.R. Simplot Ex-Situ Bioremediation Technology

The J.R. Simplot Ex-Situ Bioremediation Technology has several unique features that distinguish it from most bioremediation technologies. Bioremediation using this technology is anaerobic. The anaerobic consortium used for degradation of nitroaromatic compounds is a consortium that has been naturally selected, and not genetically engineered. For the Demonstration Test, the necessary microorganisms were not indigenous to the local soil. Therefore, the test soil was inoculated with specific microorganisms to degrade the TNT.

Initially, consumption of oxygen by aerobic microorganisms is promoted by the addition of a carbon source. This carbon source is a J.R. Simplot Company potato-processing starch by-product. The potato starch mixture is made up of 42% solids; 215 mg of starch per gram; 6.7 mg of total nitrogen per gram; 2.6 x 10^4 culturable heterotrophic bacteria per gram; and 8 x 10^3 culturable amolytic bacteria per gram. The starch by-product is a stream that is normally discarded by the potato-processing industry (J.R. Simplot Co. uses it as a supplement to cattle feed), but in this case is beneficially utilized by the bioremediation system. In this manner, the process also acts as a reduction measure for the potato-processing industry.

The degradation of TNT using this bioremediation technology is not as temperature dependent as other biological systems. However, the degradation rate can be restricted if freezing conditions exist. This problem can be overcome by adding heaters to the system (as was the case during the Demonstration Test), but at an additional cost to the remediation.

This Demonstration Test has shown that treatment by the J.R. Simplot Ex-Situ Bioremediation Technology can attain a 99.4% Removal Efficiency of TNT. This Removal Efficiency was based upon the levels of TNT in the pre-and post-treatment slurries on a dry basis. Treatment by bioremediation may be more time-consuming than other treatment methods since the amount of contamination that is biologically degraded is a function of time. However, any technology that is technically and economically suitable for contaminated sites is of interest to remedial managers.

The J.R. Simplot Ex-Situ Bioremediation Technology is a cost-effective treatment method. The cost associated with this technology for biodegradation of TNT is approximately $147/m^3$ ($112/yd³) for 3,824 m^3 (5,000 yd^3) of soil treated in four lined pits. The J.R. Simplot Company may also impose a cost of up to $131/$m^3$ ($100/$yd^3$) to these estimated costs. This additional cost is dependent on site characteristics and is used for additional technical assistance, soil nutrients, and other process enhancements provided by the developer. The Economic Analysis associated with this technology is described in detail in Section 4 of this report.

2.2 Technology Performance versus ARARs during the Demonstration

Federal and state applicable or relevant and appropriate regulations (ARARs) for the J.R. Simplot Ex-Situ Bioremediation Technology are presented in Table 2-l. The performance of the technology during the Demonstration Test with respect to ARARs is discussed below.

Prior to treatment, the waste was characterized by performing chemical and physical analyses. The treatment soil was analyzed for TNT, pesticides, chlorinated herbicides, and metals. Tests were also performed to characterize the soil type; particle size distribution and Atrerberg limits of the soil were determined. The waste was found to contain TNT and background levels of pesticides, herbicides, and toxic metals. The soil was classified as a clayey gravel with sand

Because the pre-treatment waste carried hazardous characteristics as defined by RCRA, it was subject to RCRA regulations. (Only Wastes that are defined as hazardous by bearing a RCRA characteristic or RCRA listing are subject to RCRA regulations.) After treatment, the waste no longer possessed any hazardous characteristics, so it was not handled as a hazardous waste.

Table 2-1. Federal and State ARARs for the J.R. Simplot Ex-Situ Bioremediation Technology

Process Activity	ARAR	Description	Basis	Response
Waste characterization (untreated waste)	RCRA 40 CFR Part 261 or state equivalent	Standards that apply to identification and characterization of waste to be treated	A requirement of RCRA prior to managing and handling the waste	Chemical and physical analyses must be performed.
	TSCA 40 CFR Part 761 or state equivalent	Standards that apply to the treatment and disposal of wastes containing PCBs	During waste characterization, PCBs may be identified in contaminated soil, and are therefore subject to TSCA regulations	Chemical and physical analyses must be performed. If PCBs are identified, soils will be managed according to TSCA regulations.
Soil excavation	Clean Air Act 40 CFR 50.6, and 40 CFR 52 Subpart K or state equivalent	Regulations governing the management of toxic pollutants and particulate matter in the air	Fugitive air emissions may occur during excavation and material handling and transport	If necessary, the waste material should be watered down or covered to eliminate or minimize dust generation.
	RCRA 40 CFR Part 262 or state equivalent	Standards that apply to generators of hazardous waste	Soils are excavated for treatment	If possible, soils should be fed directly into the bioreactor for treatment.
Storage prior to processing	RCRA 40 CFR Part 264 or state equivalent	Standards applicable to the storage of hazardous waste	Excavation and pre-treatment screening may generate hazardous wastes that must be stored in waste piles	If stored in a waste pile, the material should be placed on and covered with plastic, and tied down to minimize fugitive air emissions and volatilization. The time between excavation and treatment (or disposal if material is unsuitable for treatment) should be minimized.
Waste processing	RCRA 40 CFR Part 254 or state equivalent	Standards applicable to the treatment of hazardous waste at permitted and interim status facilities	Treatment of hazardous waste must be conducted in a manner that meets the operating and monitoring requirements; the treatment process may occur in a small, portable bioreactor or in a large, constructed bioreactor.	Equipment must be maintained daily. Integrity of bioreactor must be monitored and maintained to prevent leakage or failure. If treatment standards are not met, the bioreactor must be decontaminated when processing is complete.

Table 2-1. (Continued)

Process Activity	ARAR	Description	Basis	Response
Storage after processing	RCRA 40 CFR Part 264 or state equivalent	Standards that apply to the storage of hazardous waste	The treated material will remain in the bioreactor until it has been characterized and a decision on final disposition has been made. Oversize material unsuitable for processing may be stored in a waste pile.	Bioreactors must continue to be well-maintained. If stored in a waste pile, oversize material should be placed on and covered with plastic, and tied down to minimize fugitive emissions and volatilization. The material should be disposed of or otherwise treated as soon as possible.
Waste characterization (treated waste)	RCRA 40 CFR Part 261 or state equivalent	Standards that apply to waste characteristics	A requirement of RCRA prior to managing and handling the waste; it must be determined if treated material is RCRA hazardous waste.	Chemical and physical analyses must be performed on treated wastes and on oversize material prior to disposal.
	TSCA 40 CFR Part 761 or state equivalent	Standards that apply to the treatment and disposal of wastes containing PCBs	Treated wastes may still contain PCBs	Chemical and physical analyses must be performed on treated wastes and on oversize material prior to disposal. A proper disposal method must be selected if PCBs are found.
On-site/off-site disposal	RCRA 40 CFR Part 264 or state equivalent	Standards that apply to landfilling hazardous waste	Treated wastes and/or oversize material may still contain contaminants in levels above required cleanup action levels and therefore be subject to LDRs	Treated wastes and/or oversize material still defined as hazardous must be disposed of at a permitted hazardous waste facility, or approval must be obtained from the lead regulatory agency to dispose of the wastes on-site.
	TSCA 40 CFR Part 761 or state equivalent	Standards that restrict the placement of PCBs in or on the ground	Treated wastes and/or oversize material containing less than 500 ppm PCBs may be landfilled or incinerated	If untreated wastes contained PCBs, then treated wastes and oversize material should be analyzed for PCB concentration. Approved PCB landfills or incinerators must be used for disposal.

Table 2-1. (Continued)

Process Activity	ARAR	Description	Basis	Response
On-site/off-site disposal (continued)	RCRA 40 CFR Part 268 or state equivalent	Standards that restrict the placement of certain wastes in or on the ground	The nature of the waste may be subject to the LDRs	The waste must be characterized to determine if the LDRs apply. If so, waste must be handled in accordance with LDRs.
	SARA Section 121(d)(3)	Requirements for the off-site disposal of wastes from a Superfund site	The waste is being generated from a response action authorized under SARA	Wastes must be disposed of at a RCRA-permitted hazardous waste facility.
Transportation for off-site disposal	RCRA 40 CFR Part 262 or state equivalent	Manifest requirements and packaging and labelling requirements prior to transporting	The treated waste and/or oversize material may need to be manifested and managed as a hazardous waste	An identification (ID) number must be obtained from EPA.
	RCRA 40 CFR Part 263 or state equivalent	Transportation standards	Treated wastes and/or oversize material may need to be transported as hazardous wastes	A transporter licensed by EPA must be used to transport the hazardous waste according to EPA regulations.
Wastewater discharge	Clean Water Act 40 CFR Parts 301, 304, 306, 307, 308, 402, and 403	Standards that apply to discharge of wastewater into POTWs or surface water bodies	The wastewater may be a hazardous waste	Determine if wastewater could be directly discharged into a POTW or surface water body. If not, the wastewater may need to be further treated to meet discharge requirements by conventional processes. An NPDES permit may be required for discharge to surface waters

The waste did not contain PCBs, and therefore the ARARs pertaining to materials contaminated with PCBs were not applicable to this situation. It is unlikely that waste with PCB contamination would be treated by the J.R. Simplot Ex-Situ Bioremediation Technology because PCBs are not amenable to remediation by this technique.

During excavation, the wet nature of the waste material negated the need for dust suppression. No volatile contaminants were present in the treatment soil, therefore, volatile air emissions were not a concern during excavation. Although it was not possible to feed the soils directly into the bioreactor because of the logistical considerations associated with sampling during the Demonstration Test, the stockpiled excavated soil was kept covered with plastic and fed to the bioreactor as soon as it was sampled. During normal operation of the J.R. Simplot Ex-Situ Bioremediation Technology, it is anticipated that excavated soils may be screened, then homogenized with the carbon source and fed directly into the bioreactor. The J.R. Simplot Co. has stated that in future operations, the carbon source will be mixed with the water prior to the addition of the soil.

Before it was fed into the bioreactor, the Demonstration Test soil was screened to remove rocks and other debris greater than 15.9 mm (0.625 in) in diameter. Treatment of this oversize fraction may be performed by a soil or rock washing device at a later date. Alternatively, the oversize fraction may be crushed and fed into the biorcactor during subsequent treatment. It should be noted that, although soil or rock washing reduces the volume of contaminated material, waste requiring further treatment or disposal (e.g., contaminated wash water) will remain. In most cases, the waste resulting from soil or rock washing may be treated by the J.R. Simplot Ex-Situ Biorcmediation Technology. If stored in a waste pile prior to treatment, the oversize material must be kept covered. If treated by a separate technology, the length of time that the oversize material is stored before treatment must be minimized.

Treatment of the Demonstration Test soil took place in a bioreactor that was maintained on a regular basis. The integrity of the biorcactor was monitored and maintained to prevent leakage or failure. Once treatment was complete, the post-treatment slurry was sampled and analyzed for TNT and known biodegradation by-products. The Missouri Department of Natural Resources (MDNR) specified a cleanup objective of 57 mg/kg for TNT and a total of 2.5 mg/kg for the sum of known byproducts of biological degradation for each sampling location. The results of the analyses of discrete samples indicated that

TNT in the post-treatment slurry was below the cleanup objective specified by the MDNR at all but one location within the bioreactor.

The treated material remained in the bioreactor until the results of post-treatment analyses were obtained and verified. The integrity of the bioreactor continued to be monitored and maintained. Based on analytical results, the treatment slurry was later pumped from the bioreactor into prepared lined pits for evaporation and filtering of the liquid phase without the need for decontamination. The liquid phase met the treatment standards set by the MDNR. In cases where the cleanup objective is not met, the bioreactor must be decontaminated when processing is complete and the slurry must be disposed of in an appropriate manner. Oversize material that was excavated during the Demonstration Test was stored in a waste pile on top of plastic liners. The pile was also covered with plastic and tied down. This material will be incinerated during full site remediation of the WSOW.

Using a conservative approach, personal protective equipment, debris contaminated during the Demonstration Test, and the spent on-site TNT test kits were handled as hazardous waste. All hazardous waste that was generated during the Demonstration Test was handled by WSOW personnel. The oversize fraction, if not treated on-site, must be transported off-site for treatment or disposal at a RCRA-permitted facility. Waste water generated by the remediation process was run through a sand filter and then passed through a carbon adsorber before discharged on-site. The carbon drum was handled as hazardous waste.

2.3 Operability of the Technology

The J.R. Simplot Ex-Situ Bioremediation Technology is a simple system. The system consists solely of the bioreactor equipped with agitation/suspension devices and monitoring equipment. Support equipment is only required to excavate, screen, and homogenize the soil and to load the bioreactor prior to treatment. During treatment, support equipment is not required. Small, portable bioreactors are mobile and operated by trained personnel. Large, excavated pits for use as bioreactors may be constructed with minimal effort as with modular tanks. The system may operate unattended for several days at a time, if necessary. The bioreactor appeared to be relatively free of operational problems during the demonstration in Weldon Spring, Missouri.

Several operating parameters influence the performance of the J.R. Simplot Ex-Situ Bioremediation Technology. These parameters are continually monitored. The technology is dependent on pH. redox potential. and temperature. The pH must be regulated by the addition of acids and/or phosphate buffers. Based on a limited parametric study, it appears that the preferred pH range for TNT degradation is between 6 and 7 (2) Small variations in the pH of the slurry during the demonstration did not seem to adversely affect the behavior of the consortium. Anaerobic conditions suitable for the microorganisms that are capable of degrading TNT exist when the redox potential is less than -200 mV (2). These anaerobic conditions are achieved when aerobic microorganisms consume oxygen from the soil and lower the redox potential. Although the treatment slurry should be mildly agitated to keep the solid fraction in suspension during treatment and to allow diffusion of the TNT from the solid phase to the liquid phase, rigorous mixing should not be performed to avoid aerating the slurry and recreating aerobic conditions. Treatability studies have shown that continuous mixing is not required (4). A static system in sand type soils is known to achieve acceptable results when the soil, water, and carbon source are well-mixed during loading of the bioreactor. Temperature is a third parameter that may influence the performance of the J.R. Simplot Ex-Situ Bioremediation Technology. During the parametric study mentioned above, it was also found that a suitable operating temperature is between 35 and 37°C (2).

During the demonstration, excavated soil was screened to separate rocks and debris greater than 15.9 mm (0.625 in) in diameter. The screening process was laborious, due in part to the inappropriately sized screening equipment and the wet nature of the clay type soil. Important knowledge and experience about full-scale operations were gained during the Demonstration Test.

To determine the amount of soil treated, the volume of the excavated soil may be measured geometrically, or the volume of soil fed into the bioreactor may be determined by counting the number of loads deposited onto the conveyor. Both techniques were employed during the SITE Demonstration. To determine the amount of water added, the volume of water in the bioreactor may be measured geometrically before the addition of any soil, or the volume of water fed into the bioreactor may be determined by using a totalizing flowmeter. Because a totalizing flowmeter was unavailable during the demonstration, a tank of known volume was used to transport water from the source to the test site. The water was then pumped from this tank into the bioreactor and the volume was recorded. The volume of water added to the bioreactor was verified using geometric calculations. This information is required to ensure that a correct ratio of soil to water is established and maintained in the treatment slurry. Accurate measurements of these quantities were also required during the Demonstration Test to facilitate calculations for the TNT concentration in the treatment slurry.

2.4 Applicable Wastes

The J.R. Simplot Ex-Situ Bioremediation Technology is suitable for soils and liquids contaminated with nitroaromatic and energetic compounds. The medium to be treated must not contain high levels of toxic metals or any other compounds that may be detrimental to the appropriate microorganisms (e.g., hydrocarbons). Although high levels of hydrocarbons may inhibit the performance of the microorganisms, the hydrocarbons can be removed from the soil prior to bioremediation by using a cloud-point separation technique. This technique incorporates the addition of a surfactant/water solution to the waste. Heat aids the separation of the organic phase from the aqueous phase, and gravity aids the separation of the solid phase. The hydrocarbon waste stream generated by this technique must be treated using an alternate technology or disposed of at a permitted facility. The J.R. Simplot Ex-Situ Bioremediation Technology has been demonstrated on dinoseb (2-sec-butyl-4,6-dinitrophenol) in a separate SITE Demonstration.

Simplot claims that any soil type can be treated, provided that the soil is thoroughly mixed with the carbon source (J.R. Simplot Company potato-processing starch by-product). The soil itself need not contain the microorganisms necessary to degrade the contaminants since the bioreactor can be inoculated with the appropriate microorganisms. These microorganisms can be obtained from previous site remediations or treatability studies. If the soil to be treated contains large rocks or debris, then this larger fraction can be passed through a soil washing system to remove surface contamination and separate the fine material. The washwater and the fines may subsequently be treated in the bioreactor. Alternatively. the larger fraction may be crushed to an appropriate size and then fed into the bioreactor. During the Demonstration Test, the soil was screened at 15.9 mm (0.625 in) diameter. However, Simplot claims that rocks and debris up to 38.1 mm (1.5 in) diameter can be remediated. Soil washing of the oversize fraction was not attempted by Simplot during the Demonstration Test because of inadequate equipment. For future operations, it is anticipated that, if required, the oversized fraction will be cleaned by an independent rock or soil washing vendor using an already proven process.

2.5 Availability and Transportability of Equipment

Currently, the J.R. Simplot Company does not own any bioreactors, but rents and modifies mobile tanks to accommodate small-scale treatment. The small, portable tanks are wheel-mounted and can be transported by licensed haulers. For large-scale treatment where the treatment volume exceeds approximately 31 m^3 (40 yd^3), lined, excavated pits, or modular, fabricated tanks are likely to be used. Excavated pits can be constructed to accommodate any volume of treatment soil. The large modular tanks can be bolted together on-site and rented on a case-by-case basis. Each large tank can treat up to 956 m^3 (I.250 yd^3) of soil. If the treatment volume exceeds 956 m^3, multiple tanks can be used simultaneously. Agitation/suspension devices (mixers) and monitoring equipment can easily be transported by freight. Support equipment may be obtained locally and transported to the site by freight. Once all the equipment is on-site, the small portable system can be assembled in approximately two days. For the larger erect tanks or lined pits, the time required for loading of the system is a function of the soil volume.

Demobilization activities include emptying the bioreactor, decontaminating on-site equipment (if necessary), disconnecting utilities, disassembling equipment. and transporting equipment off-site. Demobilization requires approximately three days for the small portable bioreactor and approximately five weeks for the larger erected tanks.

2.6 Materials Handling Requirements

Before treatment can commence, the soil must be excavated, staged, screened, and loaded into the bioreactor. Soils should be kept moist if fugitive emissions or airborne particulates are expected. If present in the soil, most VOCs will volatilize into the atmosphere unless strict preventative measures are undertaken. These measures may include covering the excavated material and/or operating in an enclosed environment. At sites where VOCs are the primary contaminants, treatment by the J.R. Simplot Ex-Situ Bioremediation Technology is not recommended.

When the treatment soil contains large rocks or other debris, it must be passed through a vibrating screen (or other size-separating device) to remove the oversize material. This oversize material must be removed to facilitate adequate mixing of the treatment soil with the water to form a slurry. Large clumps of soil which pass through the screen must also be broken apart to increase the surface area and thereby increase the number of sites available for attack by the microorganisms. The oversize fraction may be crushed or washed on-site using a separate rock or soil washing technology. The washwater generated by soil washing may be treated in the bioreactor. If not treated by an alternate technology on-site, the oversize material must be transported off-site for treatment or proper disposal at a permitted facility.

At some sites, water may be available from the facility or from a local water source. At remote locations, water may need to be transported to the site in water trucks. For treatment of 23 m^3 (30 yd^3) in a 75,700-L (20,000-gal) portable bioreactor, approximately 24,000 L (6,400 gal) of water are required. For large-scale treatment, the volume of water required will vary and is based on the amount of soil treated and the composition of the soil. In either case, approximately one liter (0.26 gal) of water is required for each kilogram (2.2 lb) of soil treated.

The J.R. Simplot Company potato-processing starch by-product that is mixed with the treatment soil as a carbon source for the microorganisms is generally transported to the site in 208-L (55-gal) drums or, alternatively, in a tanker truck. When stored for extended periods of time or when exposed to heat, the J.R. Simplot Company potato-processing starch by-product begins to naturally ferment, causing an increase in pressure inside the drums. When handling this material, particularly when opening the drums, strict precautions must be followed to avoid ruptures of the J.R. Simplot potato-processing starch by-product drums. Drum lids may be pierced to provide an escape route for gases that build up during fermentation. The size of the hole should be minimized to control the release of foul odors associated with fermentation.

The treated slurry is pumped from the bioreactor at the conclusion of treatment. Wastewater with few suspended solids may be discharged into a publicly owned treatment works (POTW) or a surface water body if treatment standards have been met. The remaining sludge can be pumped into lined pits for evaporation of the liquid phase with the dried product being disposed of in the appropriate manner.

2.7 Range of Suitable Site Characteristics

Locations suitable for on-site treatment using the J.R. Simplot Ex-Situ Bioremediation Technology must be able to accommodate lined pits or modular tanks (if used), utilities, support facilities, and support equipment. These requirements are discussed below.

Simplot proposes to excavate treatment pits for the remediation of contaminated soil. It is anticipated to place water to a depth of 0.61 m (2 ft.), add 0.61 m of contaminated soil to form the slurry, and leave 0.305 m (1 ft.) of freeboard at the surface to account for rainfall.

Utilities required for the Simplot bioremediation system are limited to water and electricity. Water is needed to create a treatment slurry in the bioreactor. As mentioned above, approximately one liter (0.26 gal) of water was required for each kilogram (2.2 lb) of soil added to the reactor during the Demonstration. Water is also required for cleanup and decontamination activities, if necessary. The J.R. Simplot Ex-Situ Bioremediation Technology requires an on-site electrical circuit to power the agitators, and screening and homogenization equipment. The electrical current needed is a function of the size of the equipment. Additional power is required for on-site office trailers, if present.

Support facilities include a contaminated soil staging area, a treated slurry storage area, a drum storage area, and an office area. The treated slurry that is generated must be stored in soil piles or in cleared areas and allowed to dry before it is suitable for ultimate disposal. Drums containing nutrients (J.R. Simplot Company potato-processing starch by-product) and waste personal protective equipment (PPE) must be stored in a drum storage area. In addition, a tank storage area to store water and wastewater may be required at some sites. These support facilities must be contained to control run-on and run-off. Mobile trailers may be used as office space on-site. These office trailers must be located outside the treatment area.

Support equipment for the J.R. Simplot bioremediation system includes earth-moving equipment, conveyor belts, a vibrating screen (or other size-separating device), and homogenization equipment (Hydrolance). Earth-moving equipment (including backhoes, front-end loaders, and bobcats) is needed to excavate and move soils. Earth-moving equipment is also needed to load soils onto the vibrating screen and the conveyor belts. Conveyor belts are required to move the screened soil into the homogenization equipment and the bioreactor. The vibrating screen is used to remove large rocks and other debris, and the homogenization equipment is utilized to blend the soil and water together in the bioreactor to allow diffusion of the contaminant. A container for wastewater (if not discharged into the sewer) may also be necessary.

2.8 Limitations of the Technology

According to the developer, the scope of contaminants suitable for treatment using the J.R. Simplot Ex-Situ Bioremediation Technology is limited to nitroaromatic and other energetic compounds. This SITE Demonstration was conducted to evaluate the performance of the technology with respect to TNT only. The behavior of another nitroaromatic compound, dinoseb, was evaluated during an earlier demonstration. The results and conclusions regarding this demonstration are presented in a separate Innovative Technology Evaluation Report.

It has been established that high levels of hydrocarbons (approximately > 1,000 ppm TRPH) may be toxic to the microorganisms necessary for biodegradation of nitroaromatic compounds. However, by using a cloud-point separation technique prior to bioremediation, hydrocarbons can be removed from the soil. The technology cannot reduce levels of inorganic compounds in contaminated soil. In fact, the presence of high levels of toxic metals may preclude the use of this technology.

Because the performance of the technology is temperature-sensitive, cold climates may adversely affect the rate of biodegradation. This was obvious during treatment in Weldon Spring, Missouri when temperatures were significantly below that considered optimal by the parametric study (4). Heaters were added to the bioreactor (at an additional cost) to bring the temperature up to an acceptable level. Other tests have indicated that treatment can be performed with operating temperatures substantially below the optimum range of 35 to 37°C but the rate of degradation is slower, as expected. During the first SITE Demonstration on the biodegradation of dinoseb, the levels of dinoseb were reduced from 27.3 mg/kg to non-detect levels in 23 days with slurry temperatures that averaged 18°C.

For large-scale treatment, space requirements for the construction of lined pits may also restrict the use of this technology.

2.9 ARARS for the J.R. Simplot Ex-Situ Bioremediation Technology

This subsection discusses specific federal environmental regulations pertinent to the operation of the J.R. Simplot Ex-Situ Bioremediation Technology including the transport, treatment, storage, and disposal of wastes and treatment residuals. These regulations are reviewed with respect to the demonstration results. State and local regulatory requirements, which may be more stringent, must also be addressed by remedial managers. Applicable or relevant and appropriate requirements (ARARs) include the following: (1) the Comprehensive Environmental Response, Compensation, and Liability Act; (2) the Resource Conservation and Recovery Act; (3) the Clean Air Act; (4) the Safe Drinking Water Act; (5) the Toxic Substances Control Act; and (6) the Occupational Safety and Health Administration regulations. These six general ARARs are discussed below; specific ARARs that may be applicable to the J.R. Simplot EX-Situ Bioremediation Technology are identified in Table 2-1.

2.9.1 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

The CERCLA of 1980 as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986 provides for federal funding to respond to releases or potential releases of any hazardous substance into the environment, as well as to releases of pollutants or contaminants that may present an imminent or significant danger to public health and welfare or to the environment.

As part of the requirements of CERCLA, the EPA has prepared the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) for hazardous substance response. The NCP is codified in Title 40 Code of Federal Regulations (CFR) Part 300, and delineates the methods and criteria used to determine the appropriate extent of removal and cleanup for hazardous waste contamination.

SARA states a strong statutory preference for innovative technologies that provide long-term protection and directs EPA to do the following:

- use remedial alternatives that permanently and significantly reduce the volume, toxicity, or mobility of hazardous substances, pollutants, or contaminants;
- select remedial actions that protect human health and the environment, are cost-effective, and involve permanent solutions and alternative treatment or resource recovery technologies to the maximum extent possible; and

- avoid off-site transport and disposal of untreated hazardous substances or contaminated materials when practicable treatment technologies exist [Section 121(b)].

In general, two types of responses are possible under CERCLA: removal and remedial action. The J.R. Simplot Ex-Situ Bioremediation Technology is likely to be part of a CERCLA remedial action. Between 1986 and 1992, ex-situ bioremediation technologies were selected with increasing frequency as source control remedies at 33 Superfund sites (6).

Remedial actions are governed by the SARA amendments to CERCLA. As stated above, these amendments promote remedies that permanently reduce the volume, toxicity, and mobility of hazardous substances, pollutants, or contaminants. When using the J.R. Simplot Ex-Situ Bioremediation Technology, the total volume of material undergoing treatment is increased because water is added to the contaminated soil to provide a treatment slurry. Even so. the volume of identified contaminants in the soil is reduced by biological degradation of these compounds. Some biodegradation processes form toxic intermediate compounds which were not previously present in the contaminated media. The J.R. Simplot Ex-Situ Bioremediation Technology anaerobically degrades nitroaromatic contaminants without the presence of known toxic intermediate compounds at the completion of treatment, and thus reduces the volume, toxicity, and mobility of the contaminants.

On-site remedial actions must comply with federal and more stringent state ARARs. ARARs are determined on a site-by-site basis and may be waived under six conditions: (I) the action is an interim measure, and the ARAR will be met at completion; (2) compliance with the ARAR would pose a greater risk to health and the environment than noncompliance; (3) it is technically impracticable to meet the ARAR; (4) the standard of performance of an ARAR can be met by an equivalent method; (5) a state ARAR has not been consistently applied elsewhere; and (6) ARAR compliance would not provide a balance between the protection achieved at a particular site and demands on the Superfund for other sites. These waiver options apply only to Superfund actions taken on-site, and justification for the waiver must be clearly demonstrated.

2.9.2 Resource Conservation and Recovery Act (RCRA)

RCRA, an amendment to the Solid Waste Disposal Act (SWDA), is the primary federal legislation governing hazardous waste activities and was passed in 1976 to address the problem of how to safely dispose of the enormous volume of municipal and industrial solid waste generated annually. Subtitle C of RCRA contains requirements for generation, transport, treatment, storage, and disposal of hazardous waste, most of which are also applicable to CERCLA activities. The Hazardous and Solid Waste Amendments (HSWA) of 1984 greatly expanded the scope and requirements of RCRA.

RCRA regulations define hazardous wastes and regulate their transport, treatment, storage, and disposal. These regulations are only applicable to the J.R. Simplot Ex-Situ Bioremediation Technology if RCRA-defined hazardous wastes are present. If soils are determined to be hazardous according to RCRA (either because of a characteristic or a listing carried by the waste), all RCRA requirements regarding the management and disposal of hazardous waste must be addressed by the remedial managers. Criteria for identifying characteristic hazardous wastes are included in 40 CFR Part 261 Subpart C. Listed wastes from specific and nonspecific industrial sources, off-specification products, spill cleanups, and other industrial sources are itemized in 40 CFR Part 261 Subpart D. For the Demonstration Test, the technology was subject to RCRA regulations because TNT carries hazardous waste characteristics. RCRA regulations do not apply to sites where RCRA-defined hazardous wastes are not present.

For cases like the Demonstration Test at WSOW where the pre-treatment waste is defined as hazardous because it carries a RCRA characteristic (not a RCRA listing), it is anticipated that, once the contaminated material is treated by the J.R. Simplot Ex-Situ BioremediationTechnology, it will no longer be considered a hazardous waste, During the Demonstration Test, the J.R. Simplot Company met the cleanup objectives specified by MDNR except at one location within the bioreactor and altered the composition of the waste through treatment such that the treated waste did not possess any hazardous characteristics. Therefore, the treated material was not considered a hazardous waste.

Listed hazardous wastes (40 CFR Part 261 Subpart D) remain listed wastes regardless of the treatment they may undergo and regardless of the final contamination levels in the resulting effluent streams and residues. This implies that, even after remediation, treated wastes are still classified as hazardous if the pre-treatment material was a listed waste

For generation of any hazardous waste, the site responsible party must obtain an EPA identification number. Other applicable RCRA requirements may include a Uniform Hazardous Waste Manifest (if the waste is transported), restrictions on placing the waste in land disposal units, time limits on accumulating waste, and permits for storing the waste.

Requirements for corrective action at RCRA-regulated facilities are provided in 40 CFR Part 264. Subpart F (promulgated) and Subpart S (partially promulgated). These subparts also generally apply to remediation at Superfund sites. Subparts F and S include requirernents for initiating and conducting RCRA corrective action, remediating groundwater, and ensuring that corrective actions comply with other environmental regulations. Subpart S also details conditions under which particular RCRA requirements may be waived for temporary treatment units operating at corrective action sites and provides information regarding requirements for modifying permits to adequately describe the subject treatment unit.

2.9.3 Clean Air Act (CAA)

The CAA requires that treatment, storage, and disposal facilities comply with primary and secondary ambient air quality standards. During the excavation, transportation, and treatment of soils, fugitive emissions are possible. Fugitive emissions include (1) volatile organic compounds and (2) dust which may cause semivolatiles and other contaminants to become airborne. Soils must be watered down or covered with industrial strength plastic prior to treatment to prevent or minimize the impact from fugitive emissions. State air quality standards may require additional measures to prevent fugitive emissions. The J.R. Simplot Ex-Situ Bioremediation Technology is not designed to treat soils contaminated with volatile compounds. However, if volatile compounds are present, the system may be modified to include a cover, an exhaust fan, and carbon adsorbers or biofilters to treat volatile emissions generated by excavation of the soil.

2.9.4 Safe Drinking Water Act (SDWA)

The SDWA of 1974, as most recently amended by the Safe Drinking Water Amendments of 1986. requires the EPA to establish regulations to protect human health from contaminants in drinking water. The legislation authorized national drinking water standards and a joint federal-state system for ensuring compliance with these standards.

The National Primary Drinking Water Standards are found in 40 CFR Parts 141 through 149. Wastewater generated by the J.R. Simplot Ex-Situ Bioremediation Technology during the degradation of TNT is anticipated to be acceptable for discharge into a POTW. Analyses of the wastewater and approval by the local authorities will confirm this assumption.

2.9.5 Toxic Substances Control Act (TSCA)

The TSCA of 1976 grants the EPA authority to prohibit or control the manufacturing, importing, processing, use, and disposal of any chemical substance that presents an unreasonable risk of injury to human health or the environment. These regulations may be found in 40 CFR Part 761; Section 6(e) deals specifically with PCBs. Materials with less than 50 ppm PCB are classified as non-PCB; those containing between 50 and 500 ppm are classified as PCB-contaminated; and those with 500 ppm PCB or greater are classified as PCB. PCB-contaminated materials may be disposed of in TSCA-permitted landfills or destroyed by incineration at a TSCA-approved incinerator; PCBs must be incinerated. Sites where spills of PCB-contaminated material or PCBs have occurred after May 4, 1987 must be addressed under the PCB Spill Cleanup Policy in 40 CFR Part 761. Subpart G. The policy establishes cleanup protocols for addressing such releases based upon the volume and concentration of the spilled material. The J.R. Simplot Ex-Situ Bioremediation Technology is not suitable for PCB-contaminated wastes; alternative treatment must be undertaken to treat this type of contamination.

2.9.6 Occupational Safety and Health Administration (OSHA) Requirements

CERCLA remedial actions and RCRA corrective actions must be performed in accordance with the OSHA requirements detailed in 20 CFR Parts 1900 through 1926, especially Part 1910.120 which provides for the health and safety of workers at hazardous waste sites. On-site construction activities at Superfund or RCRA corrective action sites must be performed in accordance with Part 1926 of OSHA, which describes safety and health regulations for construction sites. State OSHA requirements, which may be significantly stricter than federal standards, must also be met.

All technicians operating the J.R. Simplot bioremediation system and all workers performing on-site construction are required to have completed an OSHA training course and must be familiar with all OSHA requirements relevant to hazardous waste sites. For most sites, minimum PPE for workers will include gloves, hard hats, steel-toe boots, and Tyvek® suits. Depending on contaminant types and concentrations, additional PPE may be required. Noise levels are not expected to be high, with the possible exception of noise caused by pre-treatment excavation and soil handling activities. During this time, noise lcvels should be monitored to ensure that workers are not exposed to noise levels above a time-weighted average of 85 decibels over an eight-hour day. If noise levels increase above this limit, then workers will be required to wear ear protection. The levels of noise anticipated are not expected to adversely affect the community.

SECTION 3

ECONOMIC ANALYSIS

3.1 Introduction

The primary purpose of this economic analysis is to provide a cost estimate (not including profit) for commercial remediation of TNT-contaminated sites utilizing the J.R. Simplot Ex-Situ Bioremediation Technology. This analysis is based on the results of a SITE Demonstration Test that utilized a small-scale bioreactor with a soil batch capacity of 31 m^3, and also information provided by Simplot on future plans to remediate 3,824 m^3 (5,000 yd^3) sites. This economic analysis estimates expenditures for remediating a total volume of 3,824 m^3 of treatment soil in four lined pits utilizing the J.R. Simplot Ex-Situ Bioremediation Technology.

Remediation is anticipated to be performed in four lined pits, Each of the four lined pits are assumed to be 50 feet wide, 340 feet long, four feet deep, and have a one-foot berm. They are each capable of treating 956 m^3 (1,250 yd^3) of soil using the J.R. Simplot BioremediationTechnology. Thus, throughout this cost estimate they will be referred to as "956-m'" lined pits. Each pit is double lined with 30-mil HDPE and has an E-ounce geotextile underlayment beneath the liners. Approximately two inches of sand is placed between the two liners. A hydro-mixer is used to agitate the treatment slurry. This is a device that Simplot has developed to mix the soil with the water.

The actual Demonstration Test treated approximately 23 m^3 (30 yd^3) of soil with an average 2,4.6-trinitrotoluene (TNT) contamination level of 1,500 mg/kg (dry basis). The soil was classified as a clayey gravel with sand. During the Demonstration Test the critical objective of 95% TNT reduction was achieved within 156 days. Within 283 days a TNT reduction efficiency of 99.4% was achieved under far from optiminum conditions. For conditions considered to be more suitable for the bioremediation of TNT, with the same contamination levels as those encountered during the Demonstration Test, batch treatment times for this economic analysis are assumed to be six months. Treatment costs will be reduced for shorter treatment periods, and increase for longer treatment times. The total treatment period for treating 3,824 m^3 of soil in four lined pits is approximately seven months. This total treatment time includes: excavation of the pits, soil processing, and remediation. It does not include excavation of the treatment soil and demobilization.

3.2 Conclusions

Estimated costs for four 956-m^3 lined pits remaiiating a total volume of 3,824 m^3 of TNT-contaminated soil are approximately **\$147/m^3 (\$112/yd^3).** Table 3-1 breaks down these costs into categories and lists each category's cost as a percent of the total cost. Costs that are assumed to be the obligation of the responsible party or site owner have been omitted from this cost estimate and are indicated by a line (-) in Table 3-l. These total costs do not include additional charges that may be imposed by the J.R. Simplot Company. These additional costs may total up to **\$131/m^3 (\$100/yd^3),** depending on site-specific information.

Costs presented in this report are order-of-magnitude estimates as defined by the American Association of Cost Engineers, with an expected accuracy within +50% and -30%; however, because this is an innovative technology, the range may actually be wider.

3.3 Issues and Assumptions

The cost estimates presented in this analysis are representative of charges typically assessed to the client by the vendor, but do not **include** profit. As mentioned above, the total costs do not include an additional expense that may be charged by the J.R. Simplot Company. Depending on site characteristics, this additional expense may include supplementary technical assistance, soil nutrients and enhancements, and a carbon source. This could total up to **\$131/m^3 (\$100/yd^3)** to the cost of remediation.

Many actual or potential costs that exist were not included as part of this estimate. They were omitted because site-specific engineering designs that are beyond the scope of this SITE project would be required. Also, certain functions were assumed to be the obligation of the responsible party or site owner and were not included in the estimates.

Costs that were considered to be the responsible party's (or site owner's) obligation include: preliminary site preparation, excavation of the TNT-contaminated soil, permits and regulatory requirements, initiation of monitoring and sampling programs, effluent treatment and disposal, environmental monitoring, and site cleanup and restoration. These costs are site-specific. Thus, calculations are left to the reader so that relevant information may be obtained for specific cases, Whenever possible, applicable information

Table 3-1. Estimated Costs for Treatment Using The J.R. Simplot Ex-Situ Bioremediation Technology

Bioremediation Lined Pit Size Number of Lined Pits Total Treatmeor Volume Batch Treatment Time Approximated Total Project Period	986 m^3 (1,250 yd^3) 4 3,824 m^3 (5,000 yd^3) 6 Months 7 Months		
	$/$m^3$	**$/$yd^3$**	% of Total Cost
Sire Facility Preparation Costs†	32.37	24.75	22.0%
Permitting & Regulatory Costs	—	—	---
Annualized Equipment Costs	33.15	25.35	22.6%
Startup & Fixed Costs	6.65	5.09	4.5%
Labor Costs	28.82	22.03	19.6%
Supplies Costs	0.24	0.18	0.2%
Consumables Costs	34.86	26.65	23.7%
Effluent Treatment & Disposal Costs	---	—	
Residuals & Waste Shipping, Handling, & Transport Costs	0.18	0.14	0.1%
Analytical Costs	10.05	7.68	6.8%
Facility Modifications, Repair, & Replacement Costs	0.77	0.59	0.5%
Site Restoration Costs	—	—	—
Total costs	**$147/$m^3$**	**$112/$yd^3$**	

† This does not include costs for excavation of the contaminated soil. It does include excavation cost for constructing the lined pits.

is provided on these topics so that the reader can independently perform the calculations required to acquire relevant economic data. Table 3-2 lists a summary of the expenditures included in the total estimated costs.

Other important assumptions regarding operating conditions and task responsibilities that could significantly impact the cost estimate results are presented below:

- Operating hours during treatment are assumed to be eight hours a day, five days a week for personnel. Site preparation operations are assumed to be 10 hours a day for seven days a week. Site preparation operations will take approximately four weeks.
- The soil being treated is similar to the TNT-contaminated soil treated during the Demonstration Test.
- A sufficient water supply of at least 200 gpm is available on-site. Costs will significantly increase if wells must be constructed and/or if water must be transported to the site.
- Operations take place in suitable weather conditions. If not, provisions for heating the bioreactor tanks will increase the treatment costs.
- The batch treatment time is six months. Costs will be directly effected if the treatment rate increases or decreases.
- Four lined pits are used to treat the TNT-contaminated soil. If Simplot scales their process up differently (such as using modular erected bioreactors, or different size and number of lined pits), then the treatment costs will vary.

3.4 Basis for Economic Annlysis

The cost analysis was prepared by breaking down the overall cost into l2 categories:

- Site and facility preparation costs,
- Permitting and regulatory costs,
- Equipment costs,
- Startup and fixed costs,
- Labor costs,
- Supplies costs,
- Consumables costs,

Table 3-2. Items Included in This Cost Estimate

Cost Item	Included in Cost Estimate?
Site Design and Layout	NO
Survey and Site Investigations	NO
Preparation of Support Facilities	NO
Excavation of Contaminated Material	NO
Excavation of Lined Pits	YES
Construction of the Lined Pits	YES
Screening and Loading the Contaminated Soil into the Lined Pits	YES
Permitting and Regulatory	NO
Equipment Costs Incurred During Treatment	YES
Working Capital	YES
Insurance, Taxes, and Contingency	YES
Initiation of Monitoring Programs	NO
Labor Incurred During Treatment	YES
Labor Incurred During Demobilization and Site Restoration	NO
Travel	YES
Supplies	YES
Consumables (Fuel, Water, and pH Adjustment Chemicals)	YES
J.R. Simplot Potato-Processing By-Product (Starch)	NO
Effluent Treatment and Disposal	NO
Waste Shipping, Handling & Transportation for used PPE	YES
Environmental Monitoring Analytical	NO
Simplot Monitoring Analytical	YES
Design Adjustments, Facility Modifications, & Equipment Replacement	NO
Maintenance Materials	YES
Site Restoration & Demobilization (Including Drying the Slurry)	NO

- Effluent treatment and disposal costs,
- Residuals and waste shipping, handling, and transport costs,
- Analytical costs,
- Facility modification, repair. and replacement costs, and
- Site restoration costs.

These 12 cast categories reflect typical cleanup activities encountered on Superfund sites (6). Each of these cleanup activities is defined and discussed, forming the basis for the detailed estimated costs presented in Table 3-3. The estimated costs are shown graphically in Figure 3-1. The 12 cost factors examined and assumptions made are described in detail below.

3.4.1 Site and Facility Preparation Costs

For the purposes of these cost calculations, "site" refers to the location of the contaminated soil. For these cost estimates, it is assumed that the space available at the site is sufficient for a configuration that would allow the J.R. Simplot Ex-Situ Bioremediation lined pits to be located near the contaminated soil. Thus, costs for transportation of the contaminated soil from the site to a separate facility where the Ex-Situ Bioremediation lined pits are located is not required for this cost estimate.

It is assumed that preliminary site preparation will be performed by the responsible party (or site owner). The amount of preliminary site preparation required will depend on the site. Site preparation responsibilities include site design and layout, surveys and site logistics, legal searches, access rights and roads, preparations for support and decontamination facilities, utility connections, excavation of the TNT-contaminated soil, and fixed auxiliary buildings. Since these costs are site-specific, they are not included as part of the site preparation costs in this cost estimate.

For the purposes of these cost calculations, installation costs are limited to shipping cost for the liners, and construction of the four lined pits. Shipping costs for all of the liners are estimated at a total cost of $2,400. Excavation costs for the lined pits is limited to rental equipment, fuel for the equipment, equipment operators, and labor to install the liners and geotextile underlayment for the liner. Excavation rental equipment includes: five 1-yd^3 excavators (each $2,100/wk), three 10-$yd^3$ box dump trucks (each $600/wk), and one backhoe ($700/wk) each rented for approximately three weeks. Fuel requirements

Table 3-3. Detailed Costs for Treatment Using the J.R Simplot Ex-Situ Bioremediation Technology (page 1 of 2)

Bioremediation Lined Pit Size	986 m^3 (1,250 yd^3)
Number of lined Pits	4
Total Treatment Volume	3,824 m^3 (5,000 yd^3)
Batch Treatment Time	6 Months
Approximated Total Project Period	7 Months

	$/$m^3$	$/$yd^3$
Site and Facility Preparation Costs		
Site design and layout	---	
Survey and site investigations	---	---
Legal searches, access rights & roads	---	---
Preparations for support facilities	---	---
Auxiliary buildings	---	---
Excavation of the contaminated soil	---	
Technology-specific requirements (construction of lined pits)	32.37	24.75
Transportation of wastefeed		
Total Site and Facility Preparation Costs	32.37	24.75
Permitting and Regulatory Costs		
Permits	---	---
System monitoring requirements	---	---
Development of monitoring and protocols	---	---
Total Permitting and Regulatory Costs	---	---
Equipment Costs		
Annualized equipment cost	1.80	1.38
Support equipment cost	24.88	19.02
Equipment rental	6.47	4.95
Total Equipment Costs	33.15	25.35
Startup and Fixed Costs		
Working capital	5.11	3.91
Insurance and taxes	0.77	0.59
Initiation of monitoring programs	---	---
Contingency	0.77	0.59
Total Startup and Fixed Costs	6.65	5.09
Labor Costs		
Supervisors	3.44	2.63
Health & Safety	0.71	0.54
Technicians	11.98	9.16
General	9.42	7.20
Secretary	1.96	1.50
Rental car	0.37	0.28
Travel	0.94	0.72
Total Labor Costs	28.82	22.03

(Continued)

Table 3-3. Detailed Costs for Treatment Using the J.R. Simplot Ex-Situ Bioremediation Technology (page 2 of 2)

Bioremediation Lined Pit Size	986 m^3 (1,250 yd^3)	
Number of Lined Pits	4	
Total Treatment Volume	3,824 m^3 (5,000 yd^3)	
Batch Treatment Time	6 Months	
Approximated Total Project Period	7 Months	
	$/$m^3$	$/$yd^3$
Supplies Costs		
Personal protective equipment	0.24	0.18
Total Supplies Cost	0.24	0.18
Consumables Costs		
Fuel	0.78	0.60
Water	0.07	0.05
pH adjustment chemicals	34.01	26.00
Total Consumables Costs	34.86	26.65
Effluent Treatment and Disposal Costs		
On-site facility costs	---	---
Off-site facility costs	---	---
-wastewater disposal	---	---
-monitoring activities	0	0
Total Effluent Treatment and Disposal Costs	---	---
Residuals & Waste Shipping, Handling & Transport Costs		
Preparation	---	---
Waste disposal	0.18	0.14
Total Residuals & Waste Shipping, Handling & Transport Costs	0.18	0.14
Analytical Costs		
Operations	10.05	7.68
Environmental monitoring	—	---
Total Analytical Costs	10.05	7.68
Facility Modification, Repair, & Replacement Costs		
Design adjustments	0	0
Facility modifications	0	0
Maintenance materials	0.77	0.59
Equipment replacement	0	0
Total Facility Modification, Repair, & Replacement Costs	0.77	0.59
Site Restoration Costs		
Site cleanup and restoration	---	---
Permanent storage	---	---
Total Site Restoration Costs	---	---
TOTAL COSTS	$147/$m^3$	$112/$yd^3$

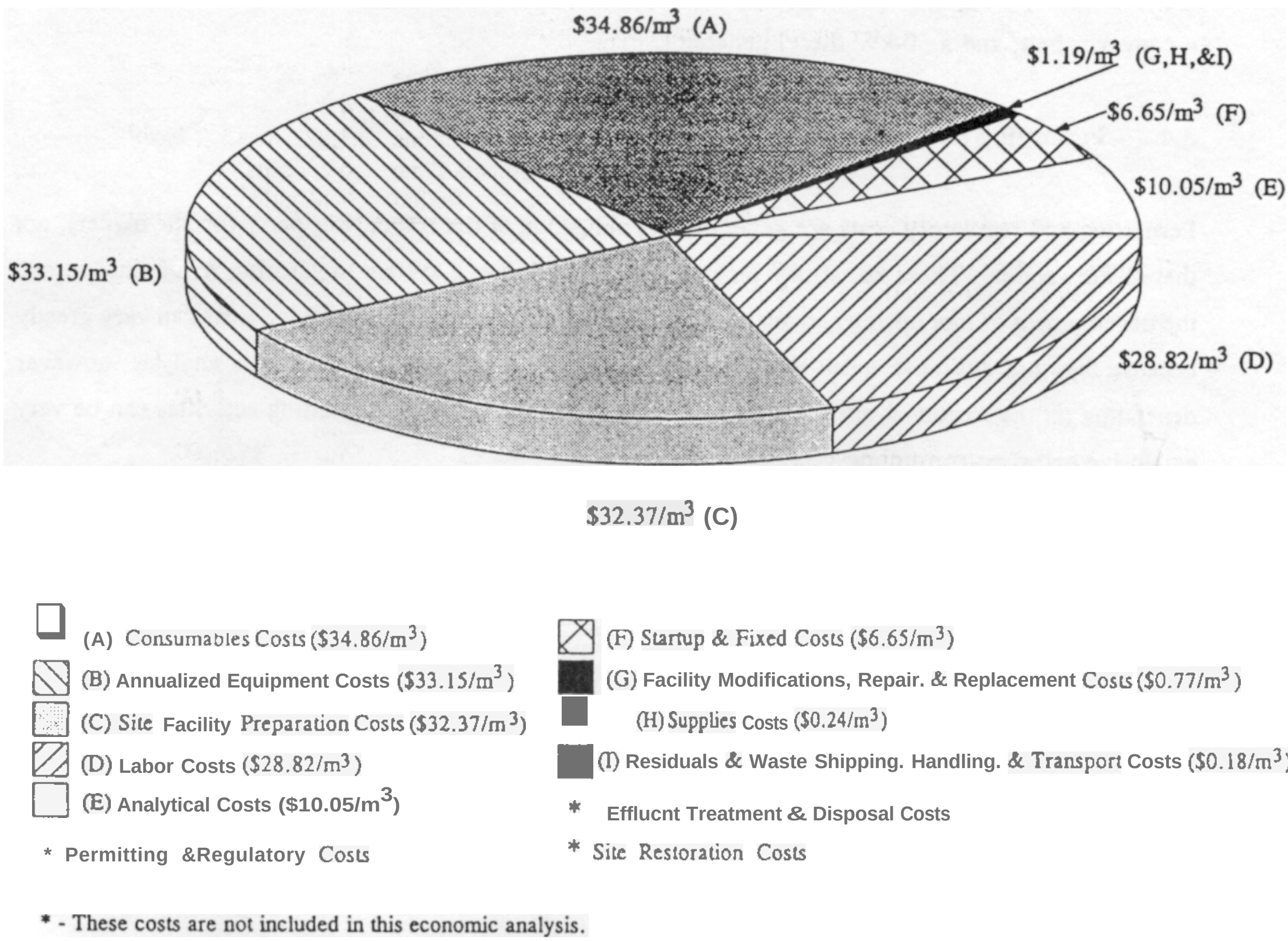

Figure 3-1. Estimated Costs for the J.R. Simplot Ex-Situ Bioremediation Technology

are approximated at 3-gals/hr for each excavator, 2-gals/hr for each dump truck, and 3-gals/hr for the backhoe. Fuel cost are estimated a $1.00 per gallon. Equipment operators include five excavator operators (each $25/hr), three dump truck operators (each $25/hr), one backhoe operator ($25/hr), and one supervisor ($40/hr) for 10 hrs per day for approximately 17 days. Liner installation requires 12 general labors at $20/hour/person for 16 hours per lined pit and liner installation equipment (estimated at a total of $2,700).

Technology-specific site preparation requirements for the Ex-Situ Bioremediation Unit consist of soil screening, and soil and water loading into the bioreactor.

Equipment necessary for technology-specific site preparation for treatment includes: a vibrating screen, a conveyor belt, and a 50-kW diesel generator.

3.4.2 Permitting and Regulatory Costs

Permitting and regulatory costs are generally the obligation of the responsible party (or site owner), not that of the vendor. These costs may include actual permit costs. system monitoring requirements, and the development of monitoring and analytical protocols. Permitting and regulatory costs can vary greatly because they are site- and waste-specific. No permitting costs are included in this analysis; however depending on the treatment site, this may be a significant factor since permitting activities can be very expensive and time-consuming.

3.4.3 Equipment Costs

Equipment costs include purchased equipment, purchased support equipment, and rental equipment. Support equipment refers to pieces of purchased equipment and/or subcontracted items that will only be used for this one remediation.

Purchased Equipment Costs

The purchased equipment costs are presented as annualized equipment costs, prorated based on the amount of time the equipment is used for the project. The annualized equipment cost is calculated using a 5-year equipment life and a 10% annual interest rate. The annualized equipment cost is based upon the writeoff of the total initial capital equipment cost and scrap value (7,8) (assumed to be 10% of the original equipment cost) using the following equation:

$$\text{Capital recovery} = (V - V_s)\,\frac{i(1+i)^n}{(1+i)^n - 1}$$

Where

V is the cost of the original equipment,

V_s is the salvage value of the equipment.

n is the equipment life (5 years), and

i is the annual interest rate (10%) (7,8).

For this cost estimate, purchased equipment includes: four hydro-mixers (used for 7 months) at a total cost of $40,000, and four data loggers (used for 7 months) at a total cost of $10.000. The total cost of the purchased equipment is thus $50,000. This total cost is used to calculate the prorated annualized purchased equipment cost.

Support Equipment Costs

For estimating purposes, support equipment includes: double liners, geotextile underlayment for the liner, and 2 inches of sand between the liners for each pit ($22,700 per pit), a decontamination area ($300), four area lights ($245 each), and 12 probes to measure temperature, pH. and redox potential ($250 each). This support equipment will not be used on subsequent projects, and therefore these costs are not prorated.

Rental Equipment Costs

Rental equipment includes: a bobcat at $1,650/month for seven months, an office trailer at $330/month for seven months, a telephone at $30/month for seven months, portable toilet facilities at $30/month for seven months, and a 50-kW generator at $1,500/month for seven months.

3.4.4 Startup and Fixed Costs

For this cost estimate startup costs are limited to lined pit construction. Lined pit construction costs are included under "Site and Facility Preparation Costs." Working capital is based on the amount of money currently invested in supplies and consumables. The working capital cost of supplies and consumables is based on maintaining a one-month inventory of these items. (See "Supplies Costs" and "Consumables Costs" for the specific amount of supplies and consumables required for the operation of the system. These quantities were used to determine the amount of supplies and consumables required to maintain a one-month inventory of these items.)

Insurance and taxes are usually approximately 1% and 2 to 4% of the total purchased equipment capital costs, respectively. The cost of insurance for a hazardous waste process can be several times more. Insurance and taxes together are assumed for the purposes of this estimate to be 10% of the purchased equipment capital costs (8).

The cost for the initiation of monitoring programs has not been included in this estimate. The monitoring program does not include sampling and analysis of the bioreactor contents to evaluate the bioremediation process. These costs are included under the "Analytical Costs" section. Depending on the site and the location of the system, local authorities may impose specific guidelines for monitoring programs. The stringency and frequency of monitoring (if required) may have significant impact on the project costs. Simplot does plan to monitor pH. redox potential, and temperature within the bioreactor using probes and data loggers. The cost of the data logger is included under purchased equipment, and the cost of the probes are included under support equipment in the "Equipment Costs" section.

A contingency cost of 10% of the equipment capital costs is allowed for any unforeseen or unpredictable cost conditions, such as strikes, storms, floods, and price variations (8,9).

3.4.5 Labor Costs

Labor costs are limited to labor rates, per diem, daily transportation, and travel. Labor rates include overhead and administrative costs. Only supervisors, health and safety engineers, and technicians require per diem, daily transportation to the site, and round trip air travel to the site location. Support secretaries provide assistance from the home office and are not required to be present on-site. Loader operators and general operators are assumed to be local hires that will be trained and supervised by Simplot personnel. Thus, loader operators and general operators do not require per diem or daily transportation to the site. Per diem is estimated at $70/day/person. Daily transportation includes a rental car and fuel at $50/day. Round trip travel costs are assumed to be $600/round trip/person.

For this cost estimate, operating labor time on-site is assumed to be eight hours a day, five days a week. Labor requirements include: one supervisor at $70/hour for four weeks; one health and safety engineer at $55/hour for one week; two technicians at $45/hour/person for ten weeks; two general labors at $15/hour/person for 30 weeks; and one secretary at $25/hour for two hours a day, five days a week for

30 weeks. Travel includes six round trips (one trip for the supervisor, one trip for the health and safety engineer, and four trips total for the two technicians).

3.4.6 Supplies Costs

Supplies cost for this cost estimate is limited to personal protective equipment (PPE). The cost of PPE is estimated at $3 per set of PPE. It is assumed that approximately 300 sets of PPE will be required.

3.4.7 Consumables Costs

Consumables required for the operation of the J.R. Simplot Ex-Situ Bioremediation Technology are limited to buffer, fuel, electricity, and water. For the purposes of this economic analysis it is assumed that the cost of tbe buffer is **$34/m^3 ($26/yd^3)** of treatment soil. The fuel required for the Ex-Situ Bioremediation Unit is estimated at 380 L/week (100 gal/week) for 30 weeks. The water rate is assumed to be $0.05/1,000 L ($0.20/1.000 gal). Approximately 4,660,000 L (1,230,000 gals) of water are required for treatment of 3,824 m^3 of soil using the J.R. Simplot Ex-Situ Bioremediation Technology.

3.4.8 Effluent Treatment and Disposal Costs

One effluent stream is anticipated from the J.R. Simplot Ex-Situ Bioremediation Technology. This is the treated slurry from the Ex-Situ Bioremediation Unit. It is anticipated that the solid phase of the treated slurry can be dried and replaced within the excavated area or used as fill material. In states where cleanup levels have not been established or when cleanup levels are not met, then disposal of the soil at a RCRA-permitted facility may be necessary. The liquid phase of the slurry is anticipated to be non-hazardous and suitable for disposal to a local POTW. In cases where the proper permits have been acquired it may be possible that the integrity of the liner can be intentionally breached when treatment is complete, and the liner abandoned in place. For the purposes of this cost estimate, it was assume that this approach was taken.

3.4.9 Residuals and Waste Shipping, Handling and Transport Costs

Waste disposal costs including storage, transportation and treatment costs are assumed to be the obligation of the responsible party (or site owner). It is assumed that the only residuals or solid wastes generated from this process will be used PPE and decontamination water. The disposal cost for 208-L (55-gal) drums of used PPE and/or decontamination water is estimated at $225/208-L drum. For this cost estimate, it is assumed that three 208-L drums of used PPE and decontamination water will be generated.

3.4.10 Analytical Costs

Only spot chocks executed at Simplot's discretion (to verify correct performance of the equipment and that cleanup criteria are being met) are included in this cost estimate. The client may elect, or may be required by local authorities, to initiate a planned sampling and analytical program at their own expense. The cost for Simplot's spot checks is estimated at $200 per sample. For the purposes of this cost estimate, it is assumed that there will be approximately 190 samples analyzed.

The analytical costs associated with environmental monitoring (not process monitoring) have not been included in this estimate due to the fact that monitoring programs are not typically initiated by Simplot. Local authorities may impose specific sampling criteria whose analytical requirements could contribute to the cost of the project.

3.4.11 Facility Modification, Repair and Replacement Costs

Maintenance costs are assumed to consist of maintenance labor and maintenance materials. Maintenance labor and materials costs vary with the nature of the waste and the performance of the equipment. For estimating purposes, the annual maintenance labor and materials cost is assumed to be IO% of the purchased equipment capital costs. Costs for design adjustments, facility modifications, and equipment replacements are not included in this cost estimate.

3.4.12 Site Restoration Costs

Site restoration requirements will vary depending on the future use of the site and are assumed to be the obligation of the responsible party. Therefore, no site cleanup and restoration costs are included in this cost estimate.

SECTION 4
TREATMENT EFFECTIVENESS DURING THE SITE DEMONSTRATION

This section presents the results of the SITE Demonstration in Weldon Spring, Missouri and discusses the effectiveness of treatment at the Weldon Spring Ordnance Works (WSOW) by the J.R. Simplot EX-Situ Bioremediation Technology.

4.1 Background

The Weldon Spring Ordnance Works (WSOW) is a former army ordnance factory located in rural Weldon Spring, Missouri. State regulatory agencies have detected 2,4,6-trinitrotoluene (TNT) contamination at this site. TNT is a nitroaromatic compound used in the production of munitions. The U.S. Corps of Engineers allowed the J.R. Simplot Company to evaluate their technology for the remediation of TNT-contaminated soils at this facility. The evaluation was initiated in cooperation with the EPA under the SITE Demonstration Program. A partial site characterization was performed in April 1993 by Science Applications International Corporation (SAIC), a contractor to the EPA. The investigation was not intended to fully characterize the site, but to identify the location and level of TNT-contaminated soil for use in the SITE Demonstration Test. The results of the site characterization indicated that the levels of TNT were appropriate and of enough volume to be suitable for the technology evaluation. Neither volatile or semivolatile organic compounds were detected by SW-846 Methods 8240 and 8270. Other pesticides, herbicides, and metals were identified in low concentrations as being present in the soil. However, TNT was the only target analyte selected for the Demonstration Test.

The only critical objective for the Demonstration Test was based on the developer's claim-that TNT contamination in soil could be reduced by at least 95% using their technology. This critical objective was determined based on the TNT concentration in the pre-treatment slurry (dry basis) and the post-treatment slurry (dry basis). Results were to be reported as percent reduction in the slurry (dry basis).

Non-critical objectives for the Demonstration Test were:

- to determine if the reduction of TNT contamination was a result of the J.R. Simplot Ex-Situ Bioremediation Technology;

- to determine if the reduction of TNT contamination was a result of biodegradation;
- to determine the relative toxicity of the test soil before and after treatment;
- to determine the presence of process intermediate compounds, RDX, and HMX in the soil before and after treatment;
- to determine if pesticides and herbicides were present in the test soil and, if so, to establish their levels of contamination;
- to determine the metals contamination in the soil before treatment;
- to determine the type of soil being remediated; and
- to develop operating costs.

The use and manipulation of microorganisms for treatment of waste, particularly wastewater, has been applied for many years. Bioremediation, or enhanced microbial treatment, now has many other applications including soils, sludges, groundwater, process water, and surface waters. Treatment may take place under aerobic or anaerobic conditions. Although bioremediation has met much success, degradation products that are potentially toxic are often formed under aerobic or microaerophilic conditions. The J.R. Simplot Company has developed a simple bioenrichment procedure that achieves anaerobic conditions under which a microbial consortium can degrade nitroaromatic compounds in soil and destroy any known toxic degradation products that are formed by the process.

4.2 Detailed Process Description

The J.R. Simplot Ex-Situ Bioremediation Technology takes place in a bioreactor. Portable tanks with a volume of 75,700-L (20,000-gal) are used to treat up to 31-m^3 (40-yd^3) of soil. For larger soil volumes, lined, In-ground pits can be constructed to act as bioreactors, or alternatively, erected modular tanks with a volume of 2.84 million-L (750,000-gal) are used to treat up to 956-m^3 (1,250 yd^3) of soil. When the treatment volume exceeds 956 m^3, multiple modular bioreactors may be used simultaneously.

Simplot utilized a portable tank as the bioreactor during the Demonstration Test because the volume of test soil was small-only 23 m^3 (30 yd^3). The bioreactor for these tests was 12.2 m long, 2.4 m wide, and 2.6 m tall (40 ft x 8.0 ft x 8.5 ft). To facilitate mixing, water was placed in the bioreactor with the soil in a ratio of approximately 1 L (0.26 gal) water to 1 kg (2.2 lb) soil. Nutrients (J.R. Simplot

Company potato-processing starch by-product) and pH-regulating agents were added to induce the aerobic microorganisms to consume oxygen from the soil. This lowered the redox potential (E_h) and created anaerobic conditions. Tests have shown that anaerobic conditions with E_h less than -200 mV promote the establishment of the anaerobic microorganisms capable of degrading TNT and other nitroaromatic compounds (2).

Figure 4-l shows the flow diagram for the Simplot process as operated during the Demonstration Test. Initially. the excavated test soil was sent through a vibrating screen to remove large rocks and other debris greater than 15.9 mm (0.625 in) in diameter. This larger fraction was not remediated during the Demonstration Test. Simplot claims that this oversize can be reduced in size to the required diameter by crushing equipment or that the contamination on the rocks and debris can be removed by a soil washing system with the wash water being placed in the bioreactor for treatment. After the soil, water, and nutrients were loaded in the bioreactor, the mixture was inoculated with 0.02 m^3 (a 5-gallon pail) of soil previously treated by the Simplot process during treatability studies for this site. This previously-treated soil contained the naturally selected microorganisms necessary for the degradation of TNT using the J.R. Simplot Ex-Situ Bioremediation Technology.

The bioreactor was loosely covered and equipped with two mixers for agitation. The mixers were installed to achieve a well-mixed slurry in the bioreactor. However, during loading of the bioreactor the motors on these mixers failed. Therefore, "dead spots" (i.e. settled sediment that did not receive agitation) occurred in the bioreactor due to insufficient mixing of the slurry by the agitators. Although previous testing indicated that the effect of the dead spots on the J.R. Simplot Ex-Situ Bioremediation Technology is not significant, the bioreactor was lanced to agitate these dead spots. This was accomplished by placing the suction end of a diaphragm pump into the settled sediment and pumping the sediment into a more well-mixed region of the bioreactor. The bioreactor was also equipped with instrumentation to monitor pH. temperature, and redox potential. A limited study has shown that suitable operating conditions are: temperature between 35 and 37°C, pH below 8.0 (ideally between 7.5 and 8.0 for TNT degradation), and redox potential <-200 mV (2).

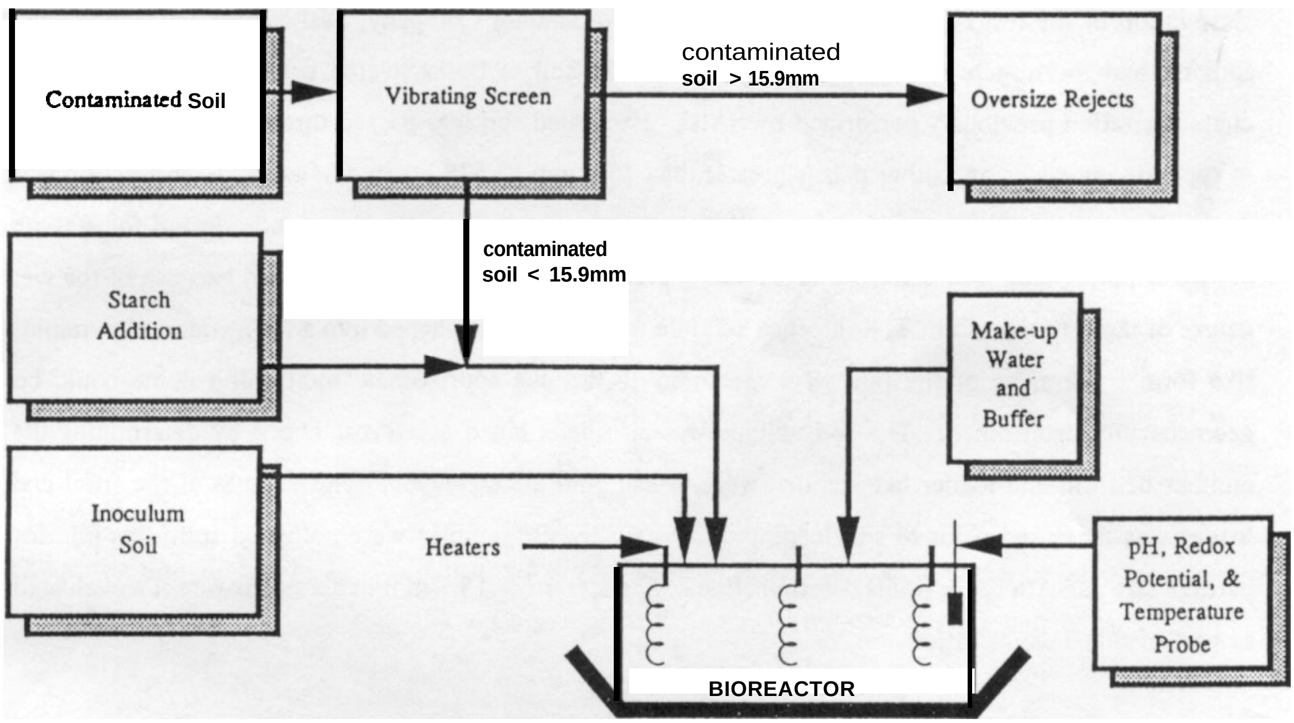

Figure 4-1. J.R. Simplot Process Flow Diagram for the Bioremediation of TNT-Contaminated Soil During the Demonstration Test

4.3 Methodology

Prior to commencement of the Demonstration Test, it was decided that evaluation of the J.R. Simplot Ex-Situ Bioremediation Technology would begin after the excavated soil was screened. Therefore, sampling of the pre-treatment feed soil for all parameters occurred after the soil had been excavated and passed through the screening process. For informational purposes, three composite samples of the pre-screened material were collected for particle size and Atterberg limits determination to evaluate the type of soil that could be processed by the overall system (including screening).

Excavation of the test soil was performed by the J.R. Simplot Company, assisted by Envirogen, Inc. Simplot and Envirogen determined the location of the soil to be excavated based on the limited site characterization previously performed by SAIC. Excavated soil was passed through a vibrating screen to separate out rocks and other debris greater than 15.9 mm (0.625 in) in diameter. Each fraction (the screened test soil and the oversize material) was placed in a separate lined area and covered for storage before sampling and processing. The screening process took longer than anticipated because of the wet nature of the clay type soil. The screened soil pile was leveled and shaped into a flat, truncated pyramid-like form. All sides of the pile were measured so that the approximate total soil volume could be geometrically determined. The soil volume was also determined as a cross check by determining the number of front-end loader batches that were placed onto the conveyor. The volume of the front-end loader was measured prior to soil loading. Three composite samples were collected from this pile for particle size and Atterberg limits determination. All materials > 15.9 mm in diameter were not evaluated as part of this demonstration.

The screened soil was collected in a small front-end loader to facilitate loading of the soil into a hopper before hand mixing with the carbon source. The carbon source consisted of a J.R. Simplot Company potato-processing starch by-product that was added to the soil. This starch was comprised of the materials stated in Section 2.1. Soil samples were collected from each front-end loader batch before the starch by-product was added. Simplot claims that in the future the starch will be mixed directly into the water before the soil addition.

In order to measure the variability of TNT contamination in the treatment soil, a grab sample was collected from every front-end loader batch fed into the hopper as mentioned above. After four grab samples, the soil was homogenized and appropriate aliquots were collected. A total of 41 primary samples were collected for TNT analysis. Four field duplicates were collected for TNT analysis to measure sampling and compositing variability. Four samples were taken to determine if any known biological degradation products of TNT could be found. Samples of soil that were known to be free of TNT contamination were taken so that TNT spiking could be performed to determine if any matrix interferences were present in the treatment soil. Samples of this soil were also taken for use as the reference samples in the toxicity test (see below).

A soil density grab sample was collected in metal sleeves of known mass and volume from every sixth front-end loader batch. A total of 27 soil density grab samples were collected The volume of each metal sleeve was determined on-site using a calibrated Vernier caliper. The mass of each metal sleeve was also determined on-site using a certified calibrated balance. The soil density and total soil volume were used to determine the mass of treatment soil.

Thirteen composite samples each were collected for pesticides, chlorinated herbicides, and metals analysis. These samples were collected in a manner similar to the TNT samples; a grab sample was collected from every front-end loader batch. After every twelve grab samples, the soil was homogenized and appropriate aliquots were collected. One field duplicate each was collected for pesticides, chlorinated herbicides, and metals. MS/MSD analyses were performed on aliquots of one pesticide and one chlorinated herbicide sample. MS and analytical duplicate (AD) analyses were performed on aliquots of one metals sample.

A negative process control was set up prior to the start of the Demonstration Test as a means of comparing naturally occurring TNT degradation to degradation by the Simplot process. Grab samples were collected from each front-end loader batch to comprise a composite sample of the entire feed stream for the negative process control. The sample was homogenized and placed in a covered 19-L (5-gal) container near the bioreactor. This sample then remained in place during the entire demonstration period.

Grab samples were collected from each front-end loader batch to comprise composite samples of the entire feed stream for toxicity tests. These toxicity tests included earthworm reproduction, early seedling growth, and root elongation. Reference samples for the toxicity teats were also collected to compare to the toxicity of uncontaminated soil with TNT-contaminated soil. Except for having no TNT contamination, this soil had the same characteristics and composition as the treatment soil.

Based on the amount of soil to be treated, a total of 24,000 L (6.400 gal) of make-up water was added to the bioreactor. This water was sampled before Introducing the soil into the bioreactor. Three samples were analyzed each for TNT, pesticides, chlorinated herbicides, and metals.

After the soil, water, and nutrients were added, a sterile process control was set up at the start of the Demonstration Test by collecting slurry directly from the bioreactor (day 0). This sample was to be sterilized, using gamma radiation, to destroy any existing microorganisms and then returned to the vicinity of the bioreactor. Degradation of TNT in the bioreactor and lack of degradation in the sterile control under similar conditions would indicate that TNT degradation in the bioreactor was biological. The sterile process control was not evaluated since the level of gamma radiation did not fully sterilize the control based upon biological counts of the slurry.

Monitored parameters during remediation were pH. temperature, and redox potential. Measurements of these parameters were taken every 15 seconds and recorded on a data logger. However, at the completion of remediation, while down loading the data from the data logger considerable periods of data were lost.

During the course of remcdiation, conditions more than sufficient for anaerobic TNT degradation $(E_h < -200\ mV)$ were achieved in 26 days. The biodegradation of TNT by this process requires that the microorganisms break the NO linkage forming amino groups. This causes the slurry to become more alkaline, therefore, requiring the addition of hydrochloric acid to maintain the pH. Due to the unusually cold winter experienced during 1994, the temperature in the bioreactor often neared the freezing mark. This was lower than the preferred bioreactor temperature of 35 to 37^{o}C (2). To overcome this, 3 immersion heaters were added to the bioreactor to avoid freezing conditions.

In order to determine the amount of TNT reduction, daily samples of the treatment slurry were taken at five locations throughout the bioreactor and tested in the field using a simple TNT test method with selected samples being shipped to the laboratory for an abbreviated Method 8330 analysis ***(10).*** Complete sampling and analysis of the contents of the bioreactor were obtained after approximately 5 months of treatment (day 156) Analysis of these samples indicated that the TNT had not been completely degraded in all of the samples. Final post-treatment sampling was initiated 9 months (day 283) after the commencement of the tests

At the mid-point sampling stage (5 months after test initiation-day 156) 50 primary samples were taken from the bioreactor to determine the level at which the TNT had been remcdiatcd. These samples were collected using a stratified approach to determine the required number of samples from the top, middle, and bottom layers of the bioreactor. Sample stratification and slurry concentration calculations were based on the total mass of soil in each layer. Once the number of samples to be collected from each layer was determined, the sample locations within each layer were chosen randomly. Five samples were taken to determine the level of intermediate compounds throughout the reactor. Three samples were also collected from the biorcactor for lead analysis. Slurry samples were obtained for the post-treatment toxicity tests.

All post-treatment slurry samples (day 283) were obtained using the same stratified approach used during the mid-point sampling (day 156) within the biorcactor. A total of 40 post-treatment slurry samples were collected and analyzed for TNT. Four field duplicate samples were collected for TNT to measure sampling variability and MS/MSD analysis was performed on aliquots of four TNT samples.

4.4 Performance Data

This section presents the performance data gathered for this demonstration by the testing methodology described above. Results are presented and interpreted below.

4.4.1 Chemical Analyses

TNT: A total of 41 pre-treatment (day 0), 50 mid-point (day 156). and 40 post-treatment (day 283) were analyzed by the Lockheed Analytical Laboratory for TNT using modified SW-846 8330 ***(10).*** Sampling occurred on a daily basis at five locations within the bioreactor, as shown in Figure 4-2. These samples were analyzed using a field test kit to give approximate levels of TNT within certain areas of the biorcactor. A number of these samples were also analyzed at the laboratory using a shortened run time

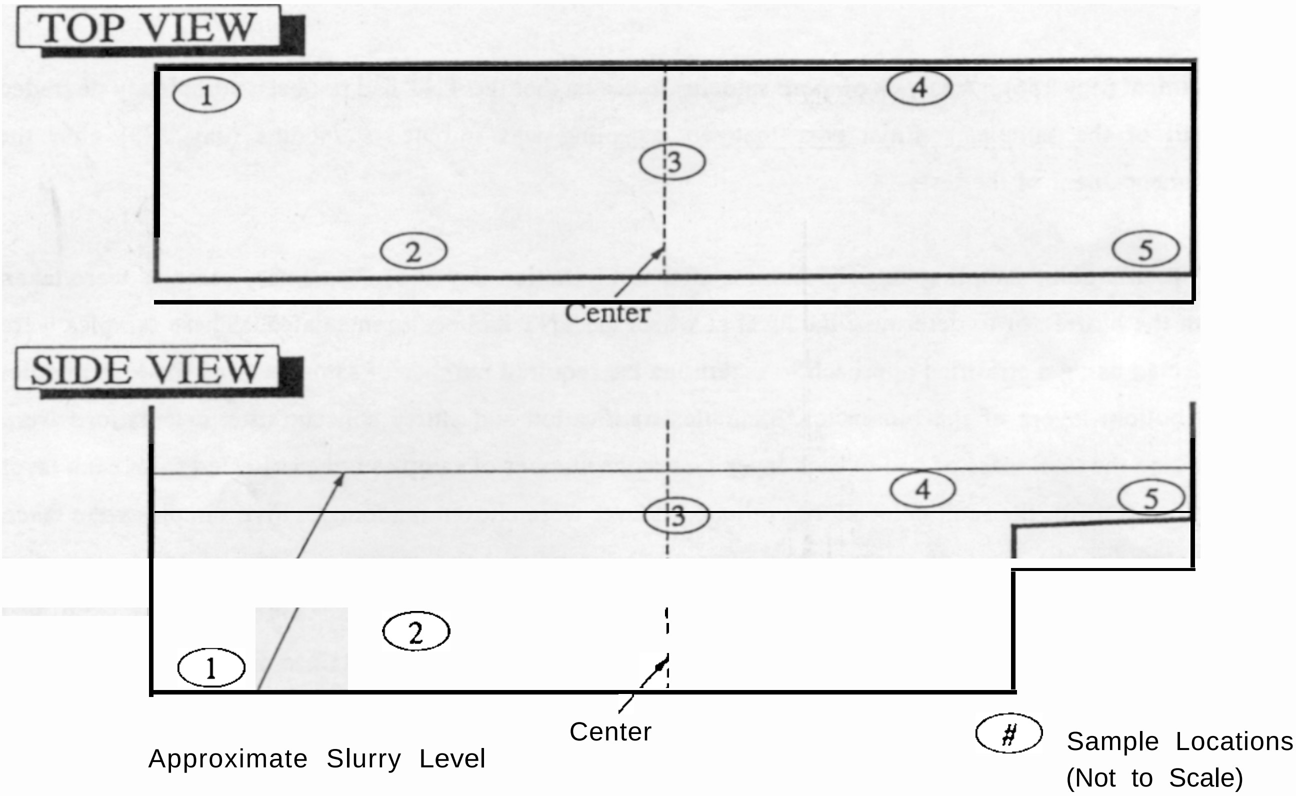

Figure 4-2. Daily Sampling Locations

of modified Method SW 846 8330 *(10)*. The average concentration of TNT in the feed soil, on a dry basis, was 1500 mg/kg with a range of 660 to 6,100 mg/kg. The 95% confidence interval around this average was 1200 to 1800 mg/kg. Upon arrival in the laboratory, the mid-point and the post-treatment slurry samples were phase separated, and the solid and liquid phases were analyzed separately. The mid-point samples showed that although the degradation of TNT was occurring, some locations within the bioreactor were above the State mandated treatment limit of 57 mg/kg with two aliquots from a single sample being much higher than encountered in pre-treatment analysis. It was postulated that “nuggets” of TNT were present in the soil that had not been captured during the pre-treatment sampling and analysis episode. The post-treatment sampling was initiated 9 months after loading of the bioreactor. A plot of the approximate degradation of TNT for the first 5 months of the treatment period at location 1 is given in Figure 4-3. The results from the final stage of sampling showed the average slurry concentration of TNT within the bioreactor was 8.7 mg/kg, on a dry basis, with a range of 0.005 mg/kg to 300 mg/kg.

Location 1
TNT & 4-AM-DNT (Dry Slurry) by HPLC Analysis

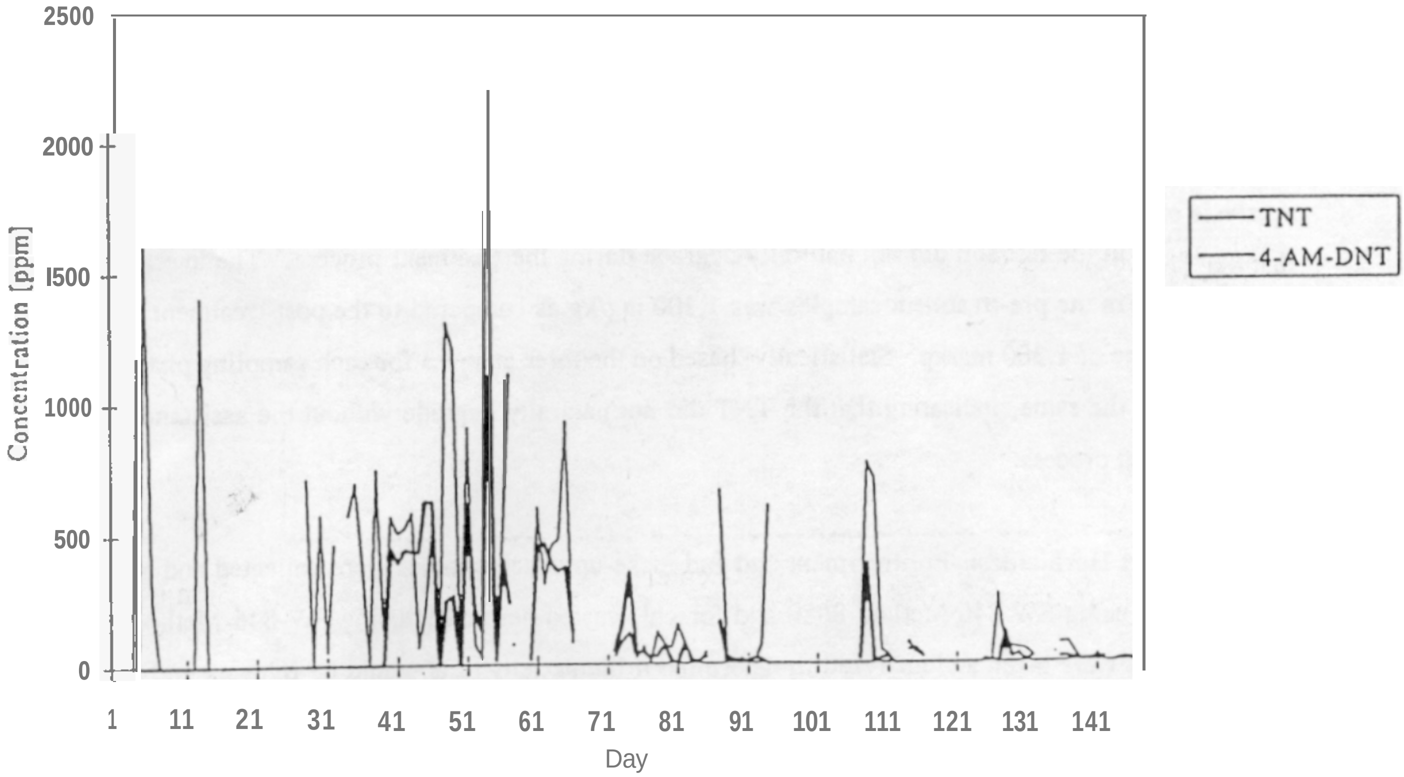

Figure 4-3. Daily Sampling Results for Location 1

This gives a Removal efficiency of 99.4%. The 95% confidence interval for this Removal Efficiency is 98.3% to 99.9%. The 95% confidence interval was determined using a bootstrap-based replication approach. This statistical method determines 10,000 alternate removal efficiencies then selects the 2.5 and 97.5th percentiles as the bounds for the confidence interval. This approach is further explained in the companion Technology Evaluation Report (TER).

Throughout the course of treatment, known intermediate compounds from the degradation of TNT were found during analysis. These known intermediate compounds are amino and diamino derivatives, 2,4,6-trihydroxytoluene, and p-cresol. The levels of these intermediate compounds were found to rise at the beginning of treatment and then decline significantly as remediation progressed. At the completion of treatment, the level of intermediate compounds was below the MDNR requirement that the total sum of intermediate compounds at each location be below 2.5 mg/kg. The method of analysis for the quantification of the intermediate compounds was the same as for the TNT analysis but using a C18 column. A plot of the 4-amino-dinitrotoluene intermediate compound until the approximate mid-point of treatment (day 156) for location 1 is also given in Figure 4-3.

Analysis of 3 samples from the negative process control before, and 3 samples after treatment indicate that the TNT in the test soil did not naturally degrade during the treatment process. The average TNT concentration in the pre-treatment samples was 1,100 mg/kg as compared to the post-treatment negative control average of I,300 mg/kg. Statistically, based on the three samples for each sampling phase, these quantities are the same, indicating that the TNT did not naturally degrade without the assistance of the bioremediation process.

Pesticides and Herbicides: Pre-treatment soil and make-up water samples were collected and analyzed for pesticides using SW-846 Method 8080 and for chlorinated herbicides using SW-846 Method 8150. These samples were taken and analyzed to determine if the toxicity tests would be relevant and that the presence of any pesticide or herbicide could lead to inconclusive results. Based upon the analysis of these samples, no significant quantities of these analytes were detected. It was decided not to analyze the post-treatment samples for these compounds.

Metals: Pre-treatment soil and make-up water samples were analyzed for ICP metals using SW-846 Method 6010. Samples were also analyzed for mercury using SW-846 Method 7470/71. Metals concentrations in the pre-treatment soils and make-up water were at levels generally found in natural soils and potable water, and were not thought to be toxic to the microorganisms. Although the post-treatment slurry samples were collected, they were only analyzed for lead to determine if bioconcentrating of this element had occurred. Other metals concentrations were not expected to change due to remediation. Table 4-1 presents a summary of the pre-treatment metals data for the soil and the make-up water. As can be seen from the Table any bioconcentration of the lead is not immediately apparent.

Toxicity: The toxicity tests were performed simultaneously on the pre- and post-treatment soils (slurry) to determine if the relative toxicity of the soil had changed because of the degradation of TNT. A suite of toxicity tests which included vascular plant root elongation, seedling survival and growth, and earthworm survival and reproduction were used to evaluate the efficiency of the J.R. Simplot

Table 4-1 Summary of Pre-Treatment Metals Data and Mid-Point Lead Data

Compound	Average Soil Concentration on a Dry Basis (mg/kg)	Average Make-up water Concentration (ug/L)	Average Slurry Midpoint Solid Phase Conc. (dry basis) (mg/kg)
Antimony	<11.9	<60	
Arsenic	< 39.7	<200	
Barium	83.1	<200	
Berylium	< 1.0	<5.O	
Cadmium	<I.0	<5.O	
Calcium	48,900	19,700	
chromium	16.0	< 10.0	
Cobalt	<9.9	<5O.0	
Copper	8.5	<25.0	
Iron	14,900	19,700	
Lead	42.1	<100	31.7
Magnesium	2,IOO	16.100	
Manganese	262	424	
Mercury	<.IO	< .20	
Molybdenum	<13.3	<67.0	
Nickel	10.6	<40.0	
Potassium	528	3.750	
Selenium	<59.5	<300	
Silver	<2.0	< 10.0	
Sodium	<400	22,900	
Titanium	<99.2	<500	
Vanadium	24.2	<50.0	
Zinc	49.8	30.6	

bioremediation process in soils contaminated with TNT. This battery of tests was conducted on three treatment phases (reference, pre-, and post-treatment) of the three environmental matrices of primary interest: soil, solid phase of the slurry (slurry), and liquid phase of the slurry (eluate). However, no post-treatment soil (only slurry) was available for testing. To allow for comparisons between pre-treatment and post-treatment, a pre-treatment slurry was constructed. The pre-treatment slurry was prepared by mixing pre-treatment soil, make-up water, and treatment buffers in the same ratios as during the demonstration. The pre-treatment and post-treatment slurries were each allowed to settle into two phases, the eluate decanted into separate containers and the remaining soil dried to approximately the same dryness as the pre-treatment soil. The companion Technology Evaluation Report (TER) refers to these two separate phases as the post-treatment slurry and the post-treatment eluate. The vascular plant toxicity testing utilized alfalfa, red clover, cucumber, lettuce and penewawa wheat. The earthworm toxicity tests utilized the red worm. Each of the test species is routinely used in the evaluation of contaminated soils.

The Simplot bioremediation process successfully reduced the toxicity of the TNT-contaminated soil. The reduction in toxicity was evident from earthworm survival and reproduction. Concentration-response relationships also were generally observed in the toxicity tests during dilution series testing of the soils, solid phase of the slurry, and liquid phase of the slurry. The comparison of the toxicity test results for the soils, solid phase of the slurry, and liquid phase of the slurry supports the contention that the contaminant(s) in the site soil have a greater affinity for the particle phase than for the aqueous phase.

In all of the 100% reference and pre-treatment soils, the endpoints of interest for a particular test species was depressed in the pre-treatment soil relative to the reference soil and the negative controls. For example, survival of the five plant species during early seedling and growth tests was approximately 79% or greater in the negative controls, 46-94% in the reference soil but only 0-54% in the pre-treatment soil. Similarly, for all five plant species, measures of growth (i.e. mean shoot length and weight, total plant weight) were depressed in the pre-treatment soil relative to both negative control and reference soil. This pattern of results was also evident in earthworm survival and reproduction in pre-treatment soil when compared to negative controls and reference soil.

Evaluation of the test results for the 100% reference, pretreatment, and post-treatment solid phase of the slurry indicated that the solid phases were about equally toxic to the five plant species relative to the negative controls. The bioremediation process appeared to slightly reduce the toxicity of the post-treatment solid phase, although plant survival and growth among species was still depressed relative to the negative controls. Wheat was somewhat less affected by the toxicity of the pre-treatment slurry than were the other plant species. Earthworm survival was reduced in the pre-treatment slurry relative to all other treatments and reproduction was completely inhibited in the reference and the pre-treatment slurries. The Simplot bioremediation process decreased the toxicity of the post-treatment slurry to the earthworm both in terms of survival and reproduction although reproduction was still inhibited in the post-treatment slurry relative to the negative control.

In general, no effects were observed on survival or growth of the five plant species during early seedling tests of reference, pre-treatment, and post-treatment liquid phase of the slurry (eluate). Results of these tests were generally comparable to the results obtained with the negative controls. In contrast, root elongation tests of eluates conducted with the five plant species indicated that reference and pre-treatment eluates were toxic relative to both post-treatment eluate and negative controls. The bioremediation process effectively reduced the eluate effects observed on the five plant species in the root elongation test. Neither pre-treatment nor post-treatment eluate appeared to have any obvious effect on the earthworm survival or reproduction. The reference eluate exhibited toxicity to the earthworm, both in terms of survival and reproduction.

Sterile Process Control: Immediately after collection, the sterile process control was shipped to the laboratory for sterilization using gamma radiation. The sterile control was a slurry collected directly from the bioreactor (day 0). The sterile control did not receive sufficient dosage of gamma radiation to fully sterilize the control. This was identified after culture counts performed on the sterile process control detected the presence of the TNT degraders. The sample could not be re-irradiated because of the time lapse encountered and because of problems with the radiation source equipment at the laboratory.

4.4.2 Physical Analyses

Prior to treatment in the bioreactor, the soil was screened to separate out material greater than 15.9 mm (0.625 in) in diameter. Particle size distribution was determined for the soil both before and after the screening process. Atterberg limits were also determined for the soil before and after the screening process. The soil was determined to be a clayey gravel with sand. The density of the screened soil was determined to be 1.4 g/cm^3 (87 lbs/ft^3). Density data were used to determine the total mass of soil treated.

4.5 Process Residuals

Three process waste streams were generated by implementation of the J.R. Simplot Ex-Situ Bioremediation Technology. These streams were the treated soil, the treated liquid, and the rocks and debris with diameters greater than 15.9 mm (0.625 in). The Missouri Department of Natural Resources (MDNR) established a clean-up level for TNT and known intermediate compounds below which the slurry no longer presented a hazard to human health and, therefore, would no longer be considered hazardous. After treatment in the bioreactor at Weldon Spring Ordnance Works (WSOW), the TNT concentrations in the treated soil and liquid were below the required treatment limits with exception of one soil location within the bioreactor. In all cases, the level of total process intermediate compounds was below the MDNR limit, as noted in Section 4.4.I of this report. The treated slurry was then placed within lined pits in the excavated area. The ultimate disposal for TNT contaminated soils at the WSOW is by on-site incineration. In states where clean-up levels have not been established or when the clean-up levels have not been met. disposal of the soil at a RCRA-permitted facility may be necessary. If nitroaromatic compounds other than TNT are remediated, then disposal of the soil at a RCRA-permitted facility is only required if components of the wastes are listed or the material has hazardous waste characteristics.

A water/ethanol mixture may be used to wash the TNT from the separated rocks and debris. This was not performed by the J.R. Simplot Company during the Demonstration Test. When the percentage of oversize material becomes excessive and becomes a logistical problem, a separate soil or rock washing vendor may provide assistance in this task. The rinse water/ethanol mixture can then be added to the bioreactor with the make-up water to be remediated by the process. Another alternative is to crush the oversize debris to the required size and then add it to the bioreactor for remediation. After treatment in the bioreactor at the WSOW, the TNT concentration in the water phase was below the regulatory limit set by MDNR. The slurry was added to the lined pits allowing the liquid phase to flow through a sand filter and a carbon canister into adjacent areas. The spent carbon was treated as hazardous waste in this instance. In instances where ethanol is not used to wash the oversized debris, the wastewater can be disposed through a publicly owned treatment works (POTW), assuming treatment standards have been met and the appropriate permits have been obtained.

The untreated rocks and debris, if not washed or crushed, may present a disposal problem. During the Demonstration Test, no rocks and debris greater than 15.9 mm (0.625 in) in diameter were washed or treated. For full-scale remediation when material greater than 38 mm (1.5 in) in diameter represents a high percentage of the excavated soil and not placed in the treatment process, the material must be transported off-site for disposal at a RCRA-permitted facility.

SECTION 5

OTHER TECHNOLOGY REQUIREMENTS

5.1 Environmental Regulation Requirements

Before implementing the J.R. Simplot Ex-Situ Bioremediation System, state regulatory agencies may require a number of permits to be obtained. A permit maybe required to operate the system. A permit is required for storage of contaminated soil in a waste pile for any length of time and for storage in drums on-site for greater than 90 days. At the conclusion of treatment, permits may be required to discharge the wastewater to a publicly owned treatment works (POTW). A National Pollutant Discharge Elimination System (NPDES) permit may be required to discharge into surface walers. If air emissions are generated, an air emissions permit will be necessary. If off-site disposal of contaminated waste is required, the waste must be taken off-site by a licensed transporter lo a permitted landfill.

Section 2 of this report discusses the environmental regulations that apply to this technology. Table 2-1 presents a summary of the Federal and state ARARs for the J.R. Simplot Ex-Situ Bioremediation Technology.

5.2 Personnel Issue

For pre-treatment operations (excavation, assembly, and loading), the number of workers required is a function of the volume of soil to be remediated. During the Demonstration Test, three workers and one supervisor were required for all operations through loading of the bioreactor. Once the reactor is loaded, a Simplot employee familiar with the system and any contaminant-specific requirements will fine-tune the system to ensure that appropriate operating conditions are established and maintained. During treatment, only one technician is required to operate the J.R. Simplot Ex-Situ Bioremediation System. This technician will be trained by a Simplot supervisor. The training will be specific to the J.R. Simplot Ex-Situ Bioremediation System. Treatment will take place 24 hours a day; however, it is anticipated that the technician will only be present for approximately one hour each day. During this lime, all system parameters will be checked and any required modifications will be made. If necessary, the system may operate unattended for several days at a time. The same conditions apply for the lined. in-ground pits.

For the larger, modular bioreactors, eight workers are required for 16 hours to erect each bioreactor, and 12 workers are required for 16 hours to install the liner for each bioreactor. Two technicians are required for 8 hours a day, 5 days a week during treatment.

The health and safety issues for personnel using the Simplot system for waste treatment are generally the same as those that apply to all hazardous waste treatment facilities. The regulations governing these issues are documented in 40 CFR 264 Subparts B through G, and Subpart X.

Emergency response training for operations of the J.R. Simplot Ex-Situ Bioremediation System is the same as the general training required for operation of a treatment, storage, and disposal (TSD) facility as detailed in 40 CFR 264 Subpart D. Training must address fire-related issues such as extinguisher operation, hoses, sprinklers, hydrants, smoke detectors and alarm systems. Training must also address contaminant-related issues such as hazardous material spill control and decontamination equipment use. Other issues include self-contained breathing apparatus use, evacuation, emergency response planning. and coordination with outside emergency personnel (e.g., fire/ambulance).

For most sites, personal protective quipment (PPE) for workers will include gloves, hard hats, steel-toed boots, and Tyvek® suits. Depending on contaminant types and concentrations, additional PPE may be required. Noise levels should be monitored during excavation and pre-treatment screening, homogenization, and loading activities to ensure that workers are not exposed to noise levels above a time-weighted average of 85 decibels, over an 8-hour day. If operation of the J.R. Simplot Ex-Situ Bioremediation System increases noise levels above this limit, workers will be required to wear additional protection.

5.3 Community Acceptance

Potential hazards related to the community include exposure to volatile pollutants (if present) and other particulate matter released to air during soil excavation and handling. Air emissions can be managed by watering down the soils prior to excavation and handling, and covering the stockpiled soil with plastic. Depending on the scale of the project, the biodegradation process may require contaminated soils to remain stockpiled on-site for extended periods of time. This could expose the community to airborne emissions for several months. Community exposure to stockpiled soils may be minimixed by excavating in stages, limiting the amount of soil excavated to the amount of soil that can be treated at once.

The J.R. Simplot potato-processing starch byproduct used as a carbon source at the onset of treatment may be stored in 208-L (55-gal) drums on-site. Once the drums are opened, the potato-processing starch by-product gives off a foul odor in the immediate vicinity. This odor intensifies over time as the starch by-product ferments in the drums. The odor may be minimized by storing the drums in a shaded area to reduce the rate of fermentation. Keeping the drums sealed when not in use will also reduce the odor that escapes into the ambient air. However, the vapor pressure will build up in the drum and occasional venting will be necessary.

During bioremediation, the treatment slurry may also give off a foul odor caused by the enhanced microbial activity. The odor is not pervasive and only penetrates airspace in the immediate proximity of the treatment area; covering the bioreactor minimizes this odor.

Noise may be a factor to neighborhoods in the immediate vicinity of treatment. Noise levels may be elevated during excavation, screening, and homogenization since heavy equipment is used for these activities. During actual treatment the noise generated by the bioreactor and associated equipment is expected to be minimal.

SECTION 6

TECHNOLOGY STATUS

This section discusses the experience of the developer in performing treatment using the J.R. Simplot Ex-Situ Bioremediation Technology. It also examines the capability of the developer in using this technology at sites with different volumes of contaminated soil.

6.1 Previous Experience

The demonstration performed at the WSOW is the second demonstration to evaluate this technology for the destruction of nitroaromatic compounds. The first demonstration was performed at Bowers Field, near Ellensburg, WA. The contaminant of interest during this successful demonstration was the RCRA listed herbicide, dinoseb (P020). Dinoseb was reduced from 27.3 mg/kg to below the analytical detection limit in less than 23 days. This site is to undergo full-scale remediation using the Simplot process in the Spring of 1995.

The J.R. Simplot Company has no experience in the remediation of contaminated sites. To overcome this hurdle, Simplot intends to form partnerships with respected environmental remediation companies to implement this technology. For the two SITE Demonstrations, Envirogen Inc. has teamed with Simplot to provide the necessary expertise in performing full-scale operations. This company is working with Simplot for the full remediation at the Bowers Field Site.

The University of Idaho, in cooperation with the J.R. Simplot Company, have ongoing research programs to design improvements in the Simplot process and expand the applicability of this technology to specific sites and to additional compounds. Further work is being conducted to develop an in-situ process for subsurface soils and groundwater. Currently, treatability studies are being performed on soil from sites contaminated with TNT and other explosives in addition to sites contaminated with dinoseb. The Idaho Department of Environmental Quality has approved the use of the process at a dinoseb site neat Pocatello, Idaho. Approval from the California Department of Toxic Substances is required before the process can remediate a dinoseb contaminated site in Reedley, California. Field-scale remediation at Reedley has proven effective and it is anticipated that full-scale remediation will begin in the near future.

Additional labomtory treatability studies are being performed using the Simplot process on explosives-contaminated soil from several U.S. Navy bases by the Corps of Engineers Experimental Station in Vicksburg, MS. Laboratory studies are being used to determine the suitability of the process to treat explosive-contaminated soil from a former ordnance works near Mead, NE. Additional in-ground pits are being constructed for testing the process on soil contaminated with explosive compounds at Bangor Submarine base near Seattle, WA.

6.2 Scaling Capabilities

To date, the two SITE Demonstrations represent the largest scale of remediation performed using the J.R. Simplot Ex-Situ Bioremediation Technology. During the demonstrations, a small portable bioreactor was used to degrade 30 m^3 of dinoseb-contaminated soil in Ellensburg, WA and 23 m^3 of TNT-contaminated soil in Weldon Spring, MO.

Simplot (in cooperation with an environmental remediation company) has proposed that the remediation of greater volumes of soil will require the use of in-ground, lined, excavated pits, or large erected modular tanks. A scenario has been proposed by Simplot in which the remediation of up to 7,646 m^3 (10,000 yd^3) could be accomplished. This scenario involves excavating a pit 1.52 m (5 feet) deep, double lining the pit with HDPE liner, and using this as the bioreactor. Alternatively, remediation can be realized involving the rotating use of four 3,800,000-L (750,000-gal) tanks. Each tank would be lined with a 30-mil liner and used to remediate two 956 m^3 (1,250 yd^3) batches of soil. It is assumed that the remediation of each batch of soil would take approximately a similar remediation time as required during the SITE Demonstration. The maximum rock size that could be handled would be 38.1 mm (1.5 in) in diameter; all larger rocks would undergo washing or be crushed to this diameter.

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APPENDIX A

VENDOR'S CLAIMS

This appendix was generated and written solely by the J.R. Simplot Company. The statements presented herein represent the vendor's point of view and summarize the claims made by the vendor, the J.R. Simplot Company, regarding their Ex-Situ Bioremediation Technology. Publication herein does not represent the EPA's approval or endorsement of the statements made in this section; the EPA's point of view is discussed in the body of this report.

A.1 Introduction

The Simplot Bioremediation Process offers a bioremediation alternative to cleaning soils and water contaminated with nitroaromatics. Nitroaromatics have become serious environmental contaminants at both private and military locations nationwide. Examples of nitroaromatic contaminants include nitortoluene explosives, as well as many pesticides, including dinoseb, a herbicide banned because of health concerns.

The Simplot Process was demonstrated to degrade TNT (2,4,6-trinitrotoluene) and its degradation intermediate compound to acceptable cleanup levels specified by the Federal government. The Simplot process is an anaerobic bioslurry process for the degradation of nitroaromatic compounds in soil or aqueous phases. In the demonstration, the Simplot Process was used to clean soil contaminated with the explosive TNT, a National Prioritics List contaminant.

The Simplot Process was demonstrated by the J.R. Simplot Company at the Weldon Spring Ordnance Works in Weldon Spring, Missouri. TNT contamination had persisted at this site since the 1940's. TNT wad degraded to a slurry concentration of 8.7 ppm from a beginning slurry concentration of 1500 ppm, resulting in overall reduction greater than 99.4%

Optimal temperatures for The Simplot Process have been determined to be between **35°C** to **37°C.** Because the treatment was not begun until late Fall, the average ambient temperature was **below** this.

The Simplot Process was entirely effective, even with sub-optimal temperatures resulting in degradation of TNT within 5 months.

The Simplot Process, developed by the University of Idaho and the J.R. Simplot Company, with patents pending, is licensed exclusively to the J.R. Simplot Company.

A.2 Process

The Simplot process begins when contaminated soil is placed in a bioreactor with specially prepared water in an one-to-one ratio by weight. Water is prepared by adding nutrients, pH buffers, and a special carbon source (a Simplot potato processing byproduct). Addition of the excess carbon source to the reactors results in the consumption of dissolved oxygen by aerobic bacteria, rapidly establishing anaerobic conditions. The process is illustrated on the next page.

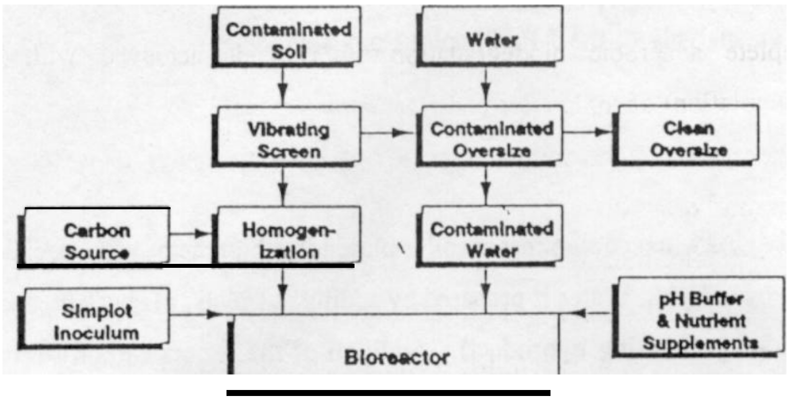
Before soil is added to the bioreactor, a consortium of enhanced nitroaromatic-degrading anaerobic bacteria is introduced to the conditioned water, to increase the rate of nitroaromatic degradation. The enhanced anaerobic bacteria are stimulated to grow and degrade dinoseb to short chain organic acids, without formation of potentially toxic polymerization products. After the treatment is complete and the soil is returned to site, aerobic bacteria can degrade the short-chain organic acids to CO_2 and water.

The Simplot Process has been demonstrated successfully on a variety of soil types, from sandy soils to tight clays. Rates of degradation are slightly delayed in heavier soil textures. The Simplot Process makes use of feasibility testing to optimize the rate of degradation for each site by altering inputs on a site-by-site basis.

A.3 Cost

Cost of the Simplot process is less than half the cost of thermal processes including incineration. Savings of transportation and related costs result because soil remains on site. Cost for a typical site can be as low as $250 per cubic yard. Costs are dependent on site characteristics and cost per cubic yard of soil will be lower with greater quantities.

The Simplot Process



A.4 Technical Information

This technology is designed to treat soils contaminated with nitroaromatic contaminants. Anaerobic microbial mixtures have been developed for the TNT and other explosives. These contaminants can be reduced to meet or exceed regulatory treatment levels in most soils. The proprietary inoculum used by the Simplot Process consists of a variety of microbial genera, developed at the University of Idaho through selection of anaerobic microbes that have been most effective in degrading nitroaromatic compounds.

Anaerobic microbial mixtures have been developed by the University of Idaho for Simplot for both the pesticide dinoseb (2-sec-butyl-4,6 dinitrophenol) and trinitrotoluene (TNT).

The consortium becomes active at redox potential of -200 mV or lower.

The initial step in the metabolism of nitroaromatic compounds is a reduction of the nitro substituents to amino groups, producing amino-nitro compounds. These intermediate compounds are further degraded to simple organic acids, and hydroxylated aromatics, which can be subsequently mineralized by indigenous bacteria.

A.5 Advantages

- * TNT concentrations have been reduced by more than 99.4% using The Simplot Process, achieving regulatory cleanup levels.
- * Complete anaerobic biodegradation of TNT is achieved without the formation (accumulation) of toxic intermediate compounds.
- * Breakdown of TNT is complete, resulting in innocuous byproducts, mainly organic acids and carbon dioxide.
- * TNT is degraded using The Simplot Process at temperatures considerably lower than is required for other biological remediation methods.
- * Periodic mixing is sufficient for optimum degradation.
- * The Simplot Process has been proven effective in the presence of other commonly found contaminants at military sites, including other explosives such as RDX, HMX, nitrotoluenes, and nitrobenzenes.
- * The Simplot Process is a cost-effective alternative to traditional technologies for both large and small situ. Costs are often less than half of the cost to incinerate. Total costs are site-specific and determined by treatability studies.
- * Remediated soils are rich in organic content and with high nutrient value, suitable for returning to the site.
- * Liability is reduced because contaminated soil is remediated without being transferred off-site.
- * Treatment of any contaminated site is completed within one season.

A.6 Limitations

- * Each site must be individually assessed by treatability studies.
- * Presence of co-contaminants may require additional processing, or may be unsuitable for the Simplot process.

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