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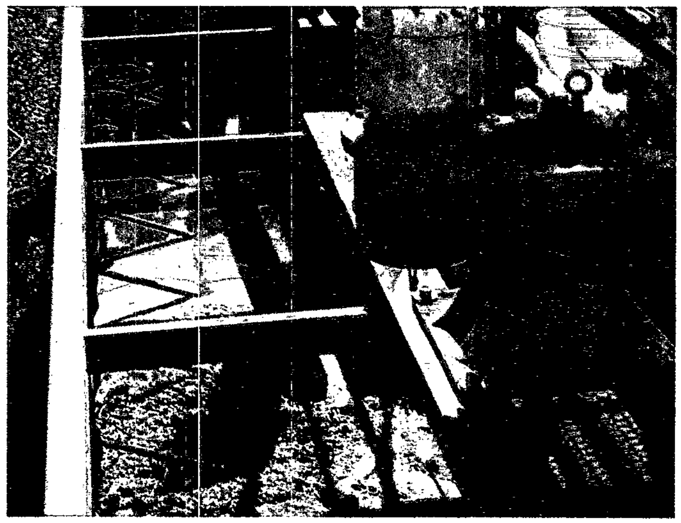
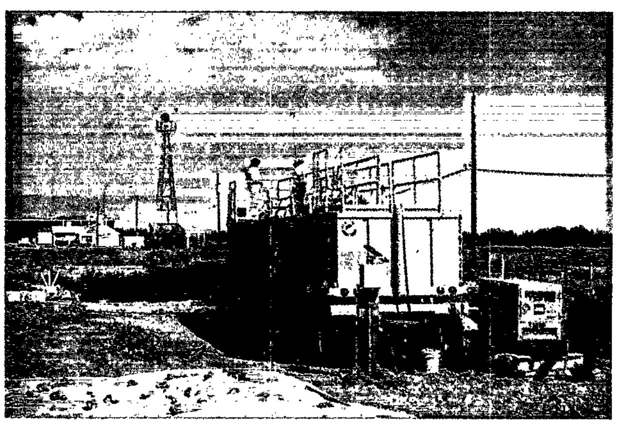
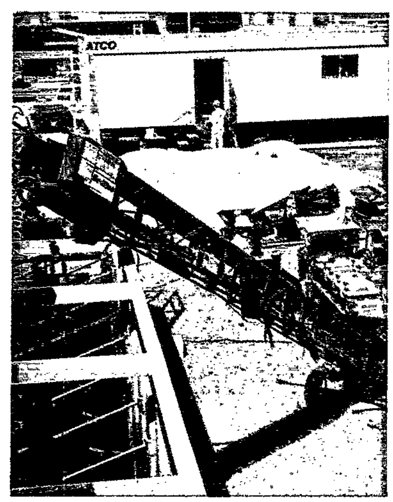
J.R. Simplot Ex-Situ Bioremediation Technology for Treatment of Dinoseb-Contaminated Soils

Innovative Technology Evaluation Report







SITE

SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

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EPA/540/R-94/508
September 1995

J.R. SIMPLOT
EX-SITU BIOREMEDIATION TECHNOLOGY

FOR TREATMENT OF
DINOSEB-CONTAMINATED SOILS

INNOVATIVE TECHNOLOGY EVALUATION REPORT

NATIONAL RISK MANAGEMENT RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental 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

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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. It was prepared for EPA's Superfund Innovative Technology Evaluation (SITE) Program by the Process Technology Division of Science Applications International Corporation (SAIC). Contributors and reviewers for this report were Dr. Ron Lewis and Mr. Robert Stenberg of the EPA-NRMRL.

EXECUTIVE SUMMARY

This report summarizes the findings of an evaluation of the J.R. Simplot Ex-Situ Bioremediation Technology on the degradation of dinoseb (2-*sec*-butyl-4,6-dinitrophenol) an agricultural herbicide. This technology was developed by the J.R. Simplot Company (Simplot) to biologically degrade dinoseb and other nitroaromatic contaminants in soil. This technology is also known as the Simplot Anaerobic Bioremediation (SABRE™) system. Engineering assistance was provided to Simplot by Envirogen, Inc. This evaluation was conducted under the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Program. A companion evaluation is also being performed on this technology to determine its effectiveness in biodegrading another nitroaromatic compound, TNT (2,4,6-trinitrotoluene).

Conclusions

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

- The J.R. Simplot Ex-Situ Bioremediation Technology can reduce levels of dinoseb in soil by >99.8% in less than 23 days at an average temperature of 18°C based on an average pre-treatment soil concentration of 27.3 mg/kg (dry basis) and a final post-treatment concentration below the detection limits of the analytical instrumentation. The 95% confidence interval about the pre-treatment soil was 26.4 mg/kg to 28.3 mg/kg.

- Anaerobic biodegradation of dinoseb may be achieved without the identification of known toxic intermediates by HPLC and GC/MS analysis.

- The preferred operating temperature range of the bioreactor is 35 to 37°C *(1)*. However, the process successfully operated during the SITE Demonstration with an average bioreactor temperature of 18°C.

- Although beyond the process design, other compounds such as 2,6-dichloro-4-nitroaniline (nitroaniline); parathion; malathion; and 4,4'-DDT were estimated to be reduced from parts-per-million levels in the pre-treatment soil to below their respective analytical detection limits in the post-treatment slurry. Atrazine levels in the post-treatment slurry were estimated to be approximately half the levels found in the pre-treatment slurry, however, the negative process control showed a greater decrease in the levels of this compound. The process was estimated to have no effect on compounds such as chlordane (alpha, gamma, and technical); and endosulfan (I and II).

- The cost associated with this technology for treatment of 3,824 m^3 (5,000 yd^3) of dinoseb-contaminated soil in four lined pits is approximately $127/$m^3$ ($97/$yd^3$). This does not include costs for excavating the dinoseb-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.

Other conclusions that may be drawn regarding this technology, based on treatability studies and other pertinent information include:

- The presence of heavy metals in the feed soil does not adversely affect the process. As this technology is a sulfate reducing process, toxic metals in the feed soil, such as: cadmium, lead, etc, are converted into their sulfide forms, therefore making the metals less toxic *(2)*. Simplot claims that this technology is less susceptible to the effects of toxic metals than other bioremediation systems.

- If the feed soil contains > 1,000 mg/kg of hydrocarbons as measured by EPA Method 418.1 (Total Recoverable Petroleum Hydrocarbons) then the hydrocarbons will be toxic to the microorganisms *(2)*. However, the cloud point separation technique can be used to remove the hydrocarbons from soil prior to initiation of the J.R. Simplot bioremediation technology.

- The Simplot system can handle most types of soil, however, pre-processing of the soil is required prior to feeding it to 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. If the soil to be treated contains large rocks or debris, then this larger fraction must be passed through a soil washing system to remove surface contamination and separate the fine materials. The washwater and the fines are then added to the bioreactor for treatment. Alternatively, the larger fraction may be crushed and treated in the bioreactor.

- Treatability studies and, to a limited extent, the Demonstration Test have shown that continuous mixing of the bioreactor is not required *(3)*. A static system can achieve acceptable results provided that the soil, water, and carbon source are well-mixed during loading of the bioreactor.

The J.R. Simplot Ex-Situ Bioremediation Technology was evaluated based on the nine criteria used for decision-making in the Superfund Feasibility Study (FS) process. Table ES-1 presents the evaluation.

Table ES-1. Evaluation Criteria for the J.R. Simplot Ex-Situ Bioremediation Technology (page 1 of 2)

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 eliminating exposure to contaminants in soil. Prevents groundwater contamination and off-site migration. Requires measures to protect workers and community during excavation, handling, and treatment.	Requires compliance with RCRA treatment, storage, and land disposal regulations (for hazardous waste). Excavation, construction, and operation of on-site treatment unit may require compliance with location-specific ARARs. Emission controls are 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.	Effectively removes contamination. Involves well-demonstrated technique for removal of contaminants.	Presents potential short-term risks to workers and nearby community, including noise exposure and exposure to airborne contaminants (e.g., dust, volatile organic compounds, etc.) released into the air during excavation and handling. These can be minimized with correct handling procedures and borders. Provides reduction in contamination levels; duration of treatment determines final contaminant levels.	Reduces toxicity and mobility of soil contaminants through treatment. Does not produce any known toxic intermediates as a result of biodegradation when conducted properly. If not fully dried, increases volume of treatment material by addition of water to create a slurry.

(Continued)

Table ES-1. Evaluation Criteria for the J.R. Simplot Ex-Situ Bioremediation Technology (page 2 of 2)

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 monitoring pH, redox potential, and temperature). Once on-site, the small portable bioreactor can be assembled and ready to load within two days. The lined pits, or larger modular bioreactor requires approximately four days. After excavation, bioreactor loading activities (soil and water) are a function of treatment volume. After treatment is complete, the small bioreactor can be emptied and demobilized in three days. Treated soil can be placed in the excavated area and used as fill material. For lined pits and erected bioreactors, the integrity of the liners can be breached when treatment is complete, and the liner abandoned in place.	\$127/m^3 (\$97/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 dinoseb-contaminated soil similar to the SITE Demonstration treatment soil. Costs presented are also based on a 30 day batch treatment time. 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 this Program was performed by the University of Idaho on 9,000 kg (9.9 tons) of soil contaminated with 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 was formed by the process, but the concentration of this intermediate was reduced to near the analytical detection limit within 45 days *(3)*. 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. This evaluation of the J.R. Simplot Ex-Situ Bioremediation Technology is based primarily on the results of the SITE Demonstration conducted at the afore-mentioned airport with supporting information from the bench-scale treatability studies conducted by the University of Idaho.

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 formation of any known toxic polymerization products.

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 Monitoring and Measurement 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 characterizations are identified in the Monitoring and Measurement Technologies Program. New technologies that provide faster, more cost-effective contamination and site assessment data are supported by this program. The Monitoring and

Measurement 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 Demonstration, Emerging Technology, and Monitoring and Measurement Technologies Programs through 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.

The results of Demonstration Program are published in four basic documents: the SITE Demonstration Bulletin, the Technology Capsule, the Innovative Technology Evaluation Report (ITER), and the Technology Evaluation Report (TER). The SITE Demonstration Bulletin provides preliminary results of the field demonstration. The Technology Capsule provides relevant information on the technology, emphasizing key features of the results of the SITE field demonstration. The ITER provides detail information on the technology and the results of the SITE field demonstration. The TER contains the raw data collected during the field demonstration and provides a quality assurance review of this data. Both the SITE ITER and TER are intended for use by remedial managers making a detailed evaluation of the technology for a specific site and waste.

1.3 The SITE Demonstration Program

Technologies are selected for the SITE Demonstration Program through 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.

1.4 Purpose of the Innovative Technology Evaluation Report (ITER)

This ITER provides information on the J.R. Simplot Ex-Situ Bioremediation Technology for treatment of dinoseb-contaminated soils and includes a comprehensive description of this demonstration and its results. 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 Ex-Situ Bioremediation Technology is designed to destroy nitroaromatic compounds without forming any toxic intermediate compounds. The theory of operation behind the Simplot technology is that soils contaminated with nitroaromatic 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 symbiotically exist without oxygen. Studies have found that anaerobiosis with redox potential less than -100 mV promotes the establishment of an anaerobic microbial consortium that degrades nitroaromatic compounds completely *(1)*. Under *aerobic* or microaerophilic conditions, degradation of nitroaromatic compounds may form polymerization products that are potentially toxic. *Anaerobic* degradation of nitroaromatics using the J.R. Simplot technology takes place without the formation of these polymerization products.

Execution of the Simplot bioremediation technology is carried out by mixing a carbon source (a J.R. Simplot Company potato-processing 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, however, treatment soils may also be inoculated with the necessary consortium to enhance degradation rates. For small soil volumes (less than 31 m^3), treatment may take place in small, mobile bioreactors. For larger soil volumes, treatment may take place in large modular bioreactors or lined pits.

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 be obtained from the following sources:

The J.R. Simplot Ex-Situ Bioremediation Technology

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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 provided 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 extensively on these data since only limited information is available on other applications of the technology. This SITE Demonstration was conducted on soil contaminated with dinoseb (2-*sec*-butyl-4,6-dinitrophenol). A companion SITE Demonstration of this technology is being performed on soil contaminated with TNT (2,4,6-trinitrotoluene), and another Innovative Technology Evaluation Report will be provided at a later date.

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 indigenous to the local soil.

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 by-product. This potato starch mixture is made up of 42% solids: 215 mg of starch per gram; 6.7 mg of total nitrogen per gram; 2.6×10^4 culturable heterotrophic bacteria per gram; and 8×10^3 culturable amolytic bacteria per gram. This starch by-product is normally discarded by the potato-processing industry, but in this case is beneficially utilized by the bioremediation system. The potato-processing by-product was used as a carbon source for the purpose of this demonstration because it was readily available to the J.R. Simplot Company. Any other carbon source may also be used but only this specific starch was used during treatability studies.

The degradation of dinoseb using this bioremediation technology is not as temperature dependent as other biological systems. Optimal temperatures for dinoseb degradation using the Simplot Process are 35 to 37°C. Despite average slurry temperatures of 18°C during the Demonstration Test, the Simplot Process was still able to degrade dinoseb to below the analytical detection limit in less than 23 days. However, the degradation rate can be restricted if freezing conditions exist. This problem can be overcome by adding heaters to the system, but at an additional cost to the remediation. The temperature dependence of degradation of other nitroaromatic compounds has not yet been determined for comparison with other biological systems.

The Best Demonstrated Available Technology (BDAT) for dinoseb-contaminated soil is incineration. The destruction and removal efficiency (DRE) for incineration is >99.99%. This Demonstration Test has shown that treatment by the J.R. Simplot Ex-Situ Bioremediation Technology can attain >99.8% removal. Removal efficiency was determined based upon remediation of the treated soil to levels below the analytical detection limits. Treatment by bioremediation may be more time-consuming than incineration since the amount of contamination that is biologically degraded is a function of time, however, any alternative technology that can economically compete with incineration 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 dinoseb is approximately \$127/m^3 (\$97/yd^3) for 3,824 m^3 (5,000 yd^3) of soil treated in four lined pits. This cost is based on a 30 day batch treatment time. It does not include expenditures incurred for excavating the dinoseb-contaminated soil. 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 total costs for treatment using the J.R. Simplot Ex-Situ Bioremediation Technology are substantially lower than costs for other technologies suitable for the destruction of dinoseb.

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 2-1. The performance of the technology during the Demonstration Test with respect to ARARs is discussed below.

Table 2-1. Federal and State ARARs for the J.R. Simplot Ex-Situ Bioremediation Technology (page 1 of 3)

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 secured 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.

(continued)

Table 2-1. Federal and State ARARs for the J.R. Simplot Ex-Situ Bioremediation Technology (page 2 of 3)

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 50 ppm PCBs may be landfilled or incinerated. Treated wastes and/or oversize greater than 50 ppm must be 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.

(continued)

Table 2-1. Federal and State ARARs for the J.R. Simplot Ex-Situ Bioremediation Technology (page 3 of 3)

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

Prior to treatment, the soil was characterized by performing chemical and physical analyses. The treatment soil was analyzed for dinoseb, pesticides, chlorinated herbicides, and metals. Tests were also performed to characterize the soil type; particle size distribution and Atterberg limits of the soil were determined. The soil was found to contain dinoseb, a RCRA-listed waste (P020), and high levels of other pesticides and herbicides including 2,6-dichloro-4-nitroaniline (nitroaniline); atrazine; and technical chlordane. Low levels of malathion; parathion; endosulfan; and 4,4'-DDT were also detected. The soil was classified as a clayey sand with gravel. The results of these analyses indicated that, because it was RCRA-listed, the soil was subject to RCRA regulations. (Only soils that are defined as hazardous by bearing a RCRA characteristic or RCRA listing are subject to RCRA regulations). Because of the dinoseb contamination, the soil was also classified as an extremely hazardous soil according to the Washington State Department of Ecology (WAC 173-303-9903). The soil did not contain PCBs, and therefore the ARARs pertaining to materials contaminated with PCBs were not applicable to this situation. It is unlikely that soil 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 soil was watered down to minimize dust generation. 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, and then homogenized with the carbon source and fed directly into the bioreactor. In the future, Simplot will mix the carbon source directly with the slurry water before soil addition.

Before it was fed into the bioreactor, the Demonstration Test soil was screened to remove rocks and other debris greater than 12.7 mm (0.5 in) in diameter. Because dinoseb is water-soluble, this oversize fraction was rinsed with water to remove surface contamination. The oversize material was kept covered prior to the rinsing activities. In cases where a large portion of oversize material is present, a separate soil or rock washing technology may be used to treat this fraction. In some cases, it may be possible to crush the rocks and then feed them into the bioreactor. It should be noted that, although soil or rock washing reduces the volume of contaminated material, waste requiring further treatment or disposal will remain. In some cases, the contaminated material resulting from soil or rock washing may be treated by the J.R.

Simplot Ex-Situ Bioremediation Technology. If stored in a waste pile, 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 bioreactor was monitored and maintained to prevent leakage or failure.

Once treatment was complete, the post-treatment slurry was sampled and analyzed for dinoseb, pesticides, and chlorinated herbicides. According to a case-specific ruling by the Washington State Department of Ecology (WADOE), the soil was no longer considered to be hazardous if dinoseb levels were reduced below the specified cleanup objective. The results of the analyses indicated that dinoseb in the post-treatment slurry was below the analytical detection limits and below the cleanup objective specified by the WADOE, therefore, the post-treatment slurry was not handled as hazardous waste.

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. The treatment slurry was pumped from the bioreactor without the need for decontamination based on analytical results. In cases where the cleanup objective is not met, the bioreactor must be decontaminated when processing is complete. Oversize material that was excavated and rinsed during the Demonstration Test was stored in a waste pile to be used as fill. Oversize material that was excavated but *not* rinsed 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 cleaned by a rock or soil washing technique with the washwater being remediated at a later date. Alternatively, the material may be correctly disposed of at a permitted facility.

Using a conservative approach, personal protective equipment and debris contaminated during the Demonstration Test were handled as hazardous waste. An EPA identification number was obtained and the waste was transported (accompanied by a hazardous waste manifest) by a licensed transporter to a RCRA-permitted facility for disposal. The oversize fraction, if not treated on-site, must be transported off-site for treatment or for disposal at a RCRA-permitted facility. Wastewater generated during the demonstration was suitable for discharge into the local sewage treatment plant.

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, modular bioreactors or lined pits may be erected on-site with minimal effort. The system may operate unattended for several days at a time, if necessary. The bioreactor appeared to be free of operational problems during the demonstration in Ellensburg, Washington.

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. For this Demonstration Test, monobasic potassium phosphate and 45.8 kg (100.7 lbs) of 182.75 kg (402.05 lbs) of dibasic potassium phosphate were used. These buffers were selected based upon previous treatability studies conducted on the Bowers Field soil. Based on a limited parametric study, it appears that the preferred pH range for dinoseb degradation is between 7.5 and 8.0 *(1)*. However, wide variations in the pH of the slurry at the outset of treatment during the demonstration (i.e., pH as low as 6.2 in the solid phase and as high as 10.5 in the liquid phase) did not seem to adversely affect the behavior of the consortium. Small amounts of sulfuric acid were added to the system at various intervals to correct the pH. The total quantity of sulfuric acid added was not recorded since the quantities were minor. Anaerobic conditions suitable for the microorganisms that are capable of degrading dinoseb exist when the redox potential is less than -100 mV *(1)*. These anaerobic conditions are achieved when aerobic microorganisms consume oxygen from the soil and lower the redox potential. The treatment slurry should be mildly agitated to keep the solid fraction in suspension during treatment. This enables the contaminant to pass 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 *(3)*. A static system 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 *(1)*. Successful treatment was achieved however, in 23 days during the Demonstration Test with bioreactor temperatures at an average of 18°C.

During the demonstration, excavated soil was screened to separate rocks and debris greater than 12.7 mm (0.5 in) in diameter. The screening process was much more time consuming than originally anticipated, partially due to inappropriately sized equipment. Additionally, rinsing of the resulting oversize fraction was not completed because of poor equipment selection and difficulties in operation. The pug mill utilized for homogenization of the pre-treatment soil and the J.R. Simplot Company potato-processing by-product was undersized and proved to be a significant impediment to efficient mixing operations. This portion of treatment (screening, rinsing, and homogenization) was highly labor intensive. 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. Again, both techniques were employed during the SITE Demonstration. 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 dinoseb 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 dinoseb. The medium to be treated must be free of toxic metals or any other compounds that may be detrimental to the appropriate microorganisms (e.g., hydrocarbons). To date, the levels of toxic metals that affect this technology have not been determined. Simplot claims that the presence of heavy metals in the feed soil will not adversely affect the process. Since this technology is a sulfate reducing process, toxic metals in the feed soil, such as: cadmium, lead, etc are converted into their sulfide forms. This makes the metals innocuous. Simplot claims that this process is less susceptible to the effects of toxic metals than other bioremediation systems. J.R. Simplot claims that greater than 1,000 ppm of total recoverable petroleum hydrocarbons (TRPH) is considered toxic to the microorganisms *(2)*. 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). It is also being demonstrated on another nitroaromatic compound, TNT (2,4,6-trinitrotoluene), in a separate SITE Demonstration.

Simplot claims that any soil type can be treated, provided that the soil (or liquid) is thoroughly mixed with the carbon source (J.R. Simplot Company potato-processing 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 must 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 12.7 mm (0.5 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 attempted by Simplot during the Demonstration Test. Because of inadequate equipment and lack of pertinent experience, the soil washing operations were not completed as part of the demonstration. For future operations, it is anticipated that, if required, this portion of treatment will be performed by an independent rock or soil washing vendor.

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 31 m^3 (40 yd^3), modular, fabricated tanks or lined pits are likely to be used. The large tanks are bolted together on-site and rented on a case-by-case basis. The lined pits are excavated on-site. Each large tank or lined pit can treat up to 956 m^3 (1,250 yd^3) of soil. If the treatment volume exceeds 956 m^3, multiple tanks or lined pits 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. The larger erected tanks or lined pits can be assembled in four to six days.

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. For the larger erected tanks or lined pits, the bioreactor can be emptied by breaching the integrity of the liner and removing the walls of erected tanks or by abandoning the lined pits in place.

2.6 Materials Handling Requirements

Before treatment can commence, the soil must be excavated, staged, screened, homogenized with the J.R. Simplot Company potato-processing by-product, 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. 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 30 m^3 (39 yd^3) in a 75,700-L (20,000-gal) portable bioreactor, approximately 29,000 L (7,650 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 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 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 successful treatment. Wastewater with few suspended solids may be discharged into a publically owned treatment works (POTW) or a surface water body. The remaining sludge can be pumped into lined pits for evaporation of the liquid phase with the dried product being used as fill material.

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 utilities, support facilities, and support equipment. These requirements are discussed below.

Utilities required for the Simplot bioremediation system are limited to water and electricity. For treatment using a bioreactor, water is needed to create a treatment slurry in the bioreactor. As mentioned above, approximately one liter (0.26 gal) of water is required for each kilogram (2.2 lb) of soil added to the reactor. Water is also required for cleanup and decontamination activities, if necessary. The J.R.

Simplot Ex-Situ Bioremediation Technology requires a three-phase 480-volt electrical circuit to power the agitators, and screening and homogenization equipment. The current needed is a function of the size of the equipment. Additional power is required for on-site office trailers, if present. Compressed air may be required if the bioreactor is to be lanced. During the demonstration, the bioreactor was lanced 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.

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 use as clean fill. 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. 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 nutrients into the soil (if not blended with the water) before treatment. 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 compounds. This SITE Demonstration was conducted to evaluate the performance of the technology with respect to dinoseb only. The behavior of other compounds was noted during the demonstration, and therefore data regarding the degradation (or lack of degradation) of these compounds are also presented in this report.

It has been established that high levels of hydrocarbons are 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. When using the cloud-point separation technique, surfactant and water are added to the waste in designated proportions, and the mixture is subjected to heat. This allows the organic phase to separate from the aqueous phase (containing the dinoseb contamination), while the solid phase simply separates by gravity. This technique produces an additional organic waste stream that must be treated by a separate technology or disposed of at a permitted facility.

The presence of heavy metals in the feed soil does not adversely affect the process. As this technology is a sulfate reducing process, toxic metals in the feed soil, such as: cadmium, lead, etc, are converted into their sulfide forms, therefore making the metals less toxic *(2)*. Simplot claims that this technology is less susceptible to the effects of toxic metals than other bioremediation systems.

Because the performance of the technology is temperature-sensitive, cold climates may adversely affect the rate of biodegradation. This was not a significant consideration during treatment in Ellensburg, Washington when temperatures were approximately at 18°C, below that considered optimal by the parametric study *(1)*, but other tests have indicated that treatment with operating temperatures substantially below the 35 to 37°C range slows the rate of degradation, as expected. At an additional cost, heaters may be installed to compensate for cold temperatures.

The execution of this technology may be limited by the availability of tanks for use as bioreactors. This limitation can be overcome by purchasing or fabricating bioreactors as required. For large-scale treatment, space requirements 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 remedies that are highly reliable and 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 *(4)*.

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 intermediates which were not previously present in the contaminated media. The J.R. Simplot Ex-Situ Bioremediation Technology anaerobically degrades nitroaromatic contaminants without the formation of known toxic intermediates, 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: (1) 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 dinoseb is a RCRA-listed waste (P020). RCRA regulations do not apply to sites where RCRA-defined hazardous wastes are not present.

Generally, hazardous wastes listed in 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, "clean" wastes are still classified as hazardous because the pre-treatment material was a listed waste. For the SITE Demonstration Test in Ellensburg, Washington, the WADOE determined that if dinoseb contamination could be reduced to below a specified cleanup objective, the material would no longer be designated a hazardous waste. This cleanup objective was based on risk-related studies conducted by the WADOE. Because the J.R. Simplot Company met these cleanup objectives during the Demonstration Test, the treated material was not considered a hazardous waste. For cases where the pre-treatment waste is defined as hazardous because it carries a characteristic (not a listing), it is anticipated that, once the contaminated material is treated by the J.R. Simplot Ex-Situ Bioremediation Technology, it will no longer be a hazardous waste. Contaminated PPE is subject to land disposal restriction (LDR) under both RCRA and CERCLA only if it contains more than 5% contamination per square inch.

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 requirements 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 semivolatile organic compounds 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 dinoseb 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 levels 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 dinoseb-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 to have a one-foot berm. They are each capable of treating 956 m^3 of soil using the J.R. Simplot Bioremediation Technology. Thus, throughout this cost estimate they will be referred to as "956-m^3" lined pits. Each pit is double lined with 30-mil HDPE and has an 8-ounce geotextile underlayment beneath the 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 30 m^3 (39 yd^3) of soil with an average dinoseb (2-*sec*-butyl-4,6-dinitrophenol) contamination level of 27.3 mg/kg (dry basis). The soil was classified as a clayey sand with gravel. Treatment of the soil during the Demonstration Test required 23 days. For the purpose of this economic analysis batch treatment times are assumed to be 30 days. The total treatment period for treating 3,824 m^3 of soil in four lined pits is approximately two 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 remediating a total volume of 3,824 m^3 of soil are approximately \$127/m^3 (\$97/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 3-1. Categories with no costs associated with this technology are indicated by a zero (0) in Table 3-1. 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 dinoseb-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 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.

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

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	30 Days		
Approximated Total Project Period	2 Months		
	$/m^3	$/yd^3	% of Total Cost
Site Facility Preparation Costs†	32.37	24.75	25.4%
Permitting & Regulatory Costs	---	---	---
Annualized Equipment Costs	27.18	20.78	21.3%
Startup & Fixed Costs	18.41	14.08	14.5%
Labor Costs	12.97	9.91	10.2%
Supplies Costs	0.16	0.12	0.1%
Consumables Costs	34.28	26.21	26.9%
Effluent Treatment & Disposal Costs	---	---	---
Residuals & Waste Shipping, Handling, & Transport Costs	0.12	0.09	0.1%
Analytical Costs	1.67	1.28	1.3%
Facility Modifications, Repair, & Replacement Costs	0.22	0.17	0.2%
Site Restoration Costs	---	---	---
Total Costs	$127/m^3	$97/yd^3	

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

Table 3-2. Items Included in This Cost Estimate

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

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. 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 dinoseb-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 mild weather. If not, provisions for heating the bioreactor tanks will increase the treatment costs.
- The batch treatment time is 30 days. Costs will be directly effected if the treatment rate increases or decreases.
- Four lined pits are used to treat the dinoseb-contaminated soil. If Simplot scales their process up differently (such as using modular erected bioreactors, or different sizes and numbers of lined pits), then the treatment costs will vary.

3.4 Basis for Economic Analysis

The cost analysis was prepared by breaking down the overall cost into 12 categories:

- Site and facility preparation costs,
- Permitting and regulatory costs,
- Equipment costs,
- Startup and fixed costs,
- Labor costs,
- Supplies costs,
- Consumables costs,
- 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 cost categories reflect typical cleanup activities encountered on Superfund sites. 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 dinoseb-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 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

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	30 Days	
Approximated Total Project Period	2 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	32.37	24.75
Transportation of waste feed	---	---
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	0.46	0.35
Support equipment cost	24.88	19.02
Equipment rental	1.84	1.41
Total Equipment Costs	**27.18**	**20.78**
Startup and Fixed Costs		
Working capital	17.97	13.74
Insurance and taxes	0.22	0.17
Initiation of monitoring programs	---	---
Contingency	0.22	0.17
Total Startup and Fixed Costs	**18.41**	**14.08**
Labor Costs		
Supervisors	3.44	2.63
Health & Safety	0.71	0.54
Technicians	4.79	3.66
General	2.51	1.92
Secretary	0.52	0.40
Rental car	0.37	0.28
Travel	0.63	0.48
Total Labor Costs	**12.97**	**9.91**

(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	30 Days	
Approximated Total Project Period	2 Months	

	$/$m^3$	$/$yd^3$
Supplies Costs		
Personal protective equipment	0.16	0.12
Total Supplies Cost	0.16	0.12
Consumables Costs		
Fuel	0.21	0.16
Water	0.06	0.05
pH adjustment chemicals	34.01	26.00
Total Consumables Costs	34.28	26.21
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	0.12	0.09
Total Residuals & Waste Shipping, Handling & Transport Costs	0.12	0.09
Analytical Costs		
Operations	1.67	1.28
Environmental monitoring	---	---
Total Analytical Costs	1.67	1.28
Facility Modification, Repair, & Replacement Costs		
Design adjustments	0	0
Facility modifications	0	0
Maintenance materials	0.22	0.17
Equipment replacement	0	0
Total Facility Modification, Repair, & Replacement Costs	0.22	0.17
Site Restoration Costs		
Site cleanup and restoration	---	---
Permanent storage	---	---
Total Site Restoration Costs	---	---
TOTAL COSTS	$127/$m^3$	$97/$yd^3$

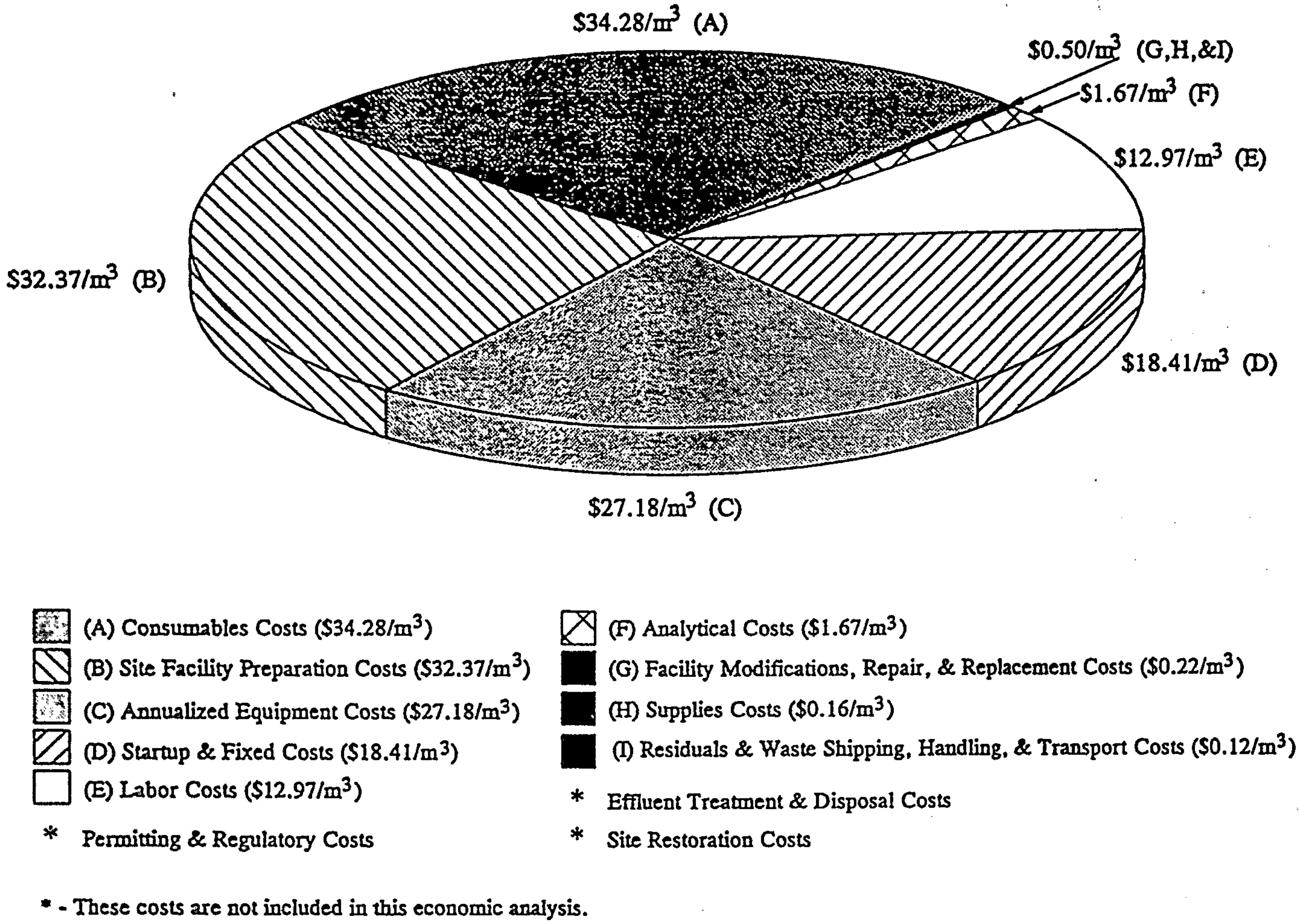


Figure 3-1. Estimated Costs for the J.R. Simplot Ex-Situ Bioremediation Technology

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 sub-contracted items that will only be used for one project.

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 *(5,6)* (assumed to be 10% of the original equipment cost) using the following equation:

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

Where

V	is the cost of the original equipment,
V_s	is the salvage value of the equipment,
n	is the equipment life (15 years), and
i	is the annual interest rate (6%) *(5,6)*.

For this cost estimate, purchased equipment includes: four hydro-mixers (used for 7 weeks) at a total cost of $40,000, and four data loggers (used for 7 weeks) at a total cost of $1,000. The total cost of the purchased equipment is thus $41,000. 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 reduction 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 two months, an office trailer at $330/month for two months, a telephone at $30/month for two months, portable toilet facilities at $30/month for two months, and a 50-kW generator at $1,500/month for two months.

3.4.4 Startup and Fixed 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 *(6)*.

The cost for the initiation of monitoring programs has not been included in this estimate. Depending on the site and the location of the system, however, local authorities may impose specific guidelines for monitoring programs. The stringency and frequency of monitoring 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 is 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 *(6,7)*.

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. 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. 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.

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 four weeks; two general labors at $15/hour/person for eight weeks; and one secretary at $25/hour for two hours a day, five days a week for 8 weeks. Travel includes four round trips (one trip for the supervisor, one trip for the health and safety engineer, and two trips total for the two technicians).

3.4.6 Supplies Costs

Supplies costs for this cost estimate are limited to personal protective equipment (PPE). The cost of PPE is estimated at $3 per set of PPE. It is assumed that 200 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 the 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 eight 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 some cases with the proper permits it may be possible that the integrity of the liner can be intentionally breached when treatment is complete, and the liner abandoned in place.

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 two 208-L drums of used PPE and decontamination water will be generated.

3.4.10 Analytical Costs

Only spot checks executed at Simplot's discretion (to verify that equipment is performing properly 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 32 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, however, impose specific sampling and monitoring criteria whose analytical requirements could contribute significantly 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 10% 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 Ellensburg, Washington and discusses the effectiveness of treatment at the Bowers Field site by the J.R. Simplot Ex-Situ Bioremediation Technology.

4.1 Background

Bowers Field is a county-owned airport located in rural Ellensburg, Washington. State regulatory agencies have detected dinoseb contamination at this site. Dinoseb (2-*sec*-butyl-4,6-dinitrophenol) is nitroaromatic compound used as an agricultural herbicide to defoliate potatoes and other legumes. It is a RCRA-listed waste bearing a P020 waste code. It is conjectured that the airport soil was previously contaminated with dinoseb by crop-dusting activities.

The fixed base operator at the airport contracted with the J.R. Simplot Company to clean up dinoseb-contaminated soil at Bowers Field. The cleanup was initiated in cooperation with the EPA under the SITE Demonstration Program. A partial site characterization was performed in November 1992 by Science Applications International Corporation (SAIC), a contractor to the EPA. The investigation was not intended to fully characterize the site, but to identify approximately 30 m^3 of dinoseb-contaminated soil for use in a SITE Demonstration Test. The results of the site characterization indicated that the levels of dinoseb contamination ranged from < 1 mg/kg (the analytical detection limit for these analyses) to 292 mg/kg. Average concentration of dinoseb in the test soil was estimated at approximately 50 mg/kg. Neither volatile nor semivolatile organic compounds were detected. Other pesticides, herbicides, and metals were identified as contaminants in the soil. Dinoseb 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 dinoseb contamination in soil could be reduced by at least 95% using their technology. This critical objective was to determine the effectiveness of the J.R. Simplot Ex-Situ Bioremediation Technology in degrading dinoseb in the test soil based on the 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 dinoseb contamination was a result of the J.R. Simplot Ex-Situ Bioremediation Technology;
- to determine if the reduction of dinoseb contamination was a result of biodegradation;
- to determine the relative toxicity of the test soil before and after treatment;
- to determine the presence of 6-amino-4-nitro-2-*sec*-butylphenol (a previously identified intermediate) in the soil before and after treatment;
- to determine if pesticides and herbicides other than dinoseb 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;
- to evaluate the effect of pH, temperature, and redox potential; and
- to develop operating costs.

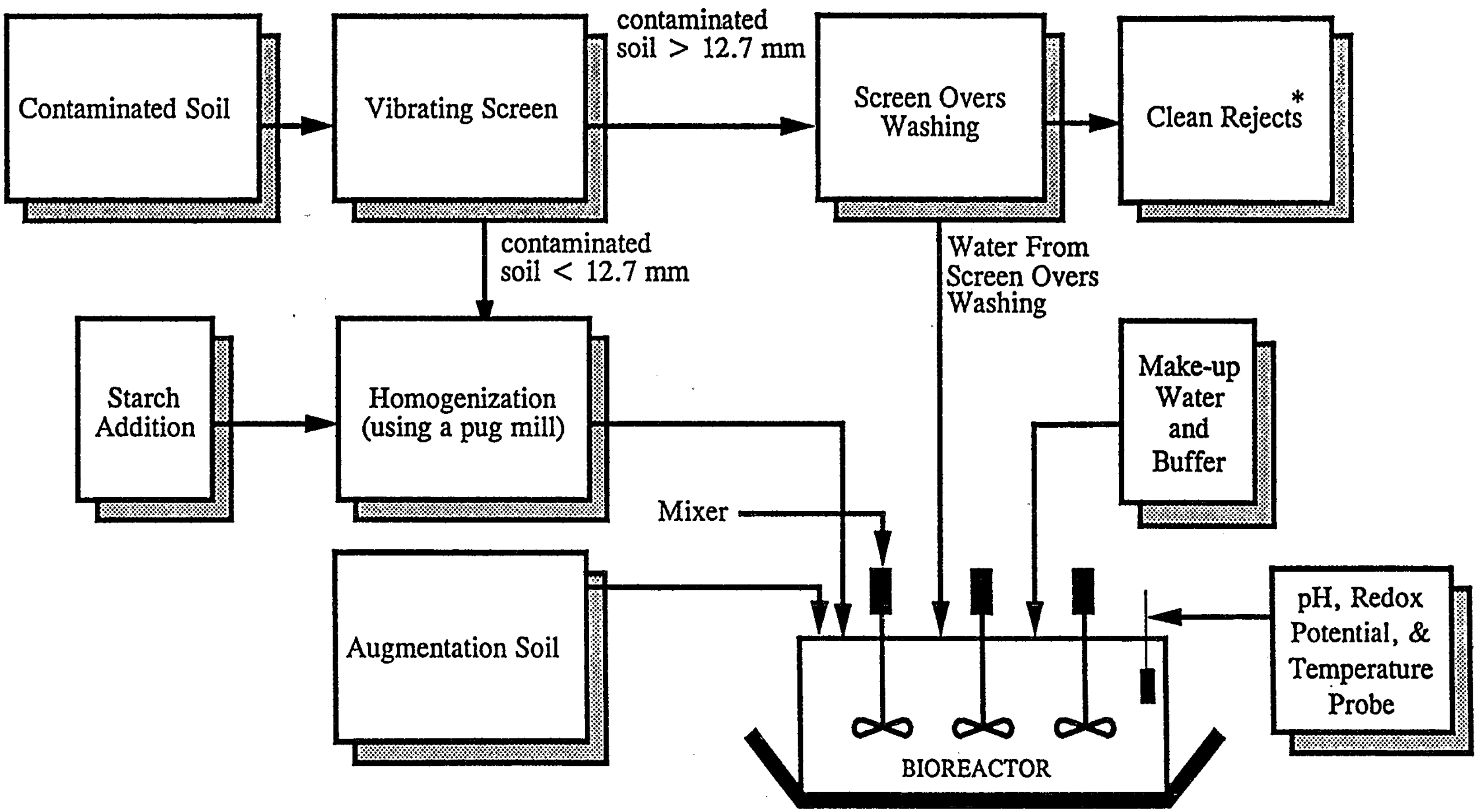
The use and manipulation of microorganisms for treatment of waste, particularly wastewater, has been applied for many years. Bioremediation, or enhanced microbial treatment, now has many other applications including soils, sludges, groundwater, process water, and surface waters. Treatment may take place under aerobic or anaerobic conditions. Although bioremediation has met much success, polymerization 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 without the formation of known toxic polymerization products.

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 volumes of soil, excavated, lined, in-ground pits approximately 15.2 m (50 ft) wide, 104 m (440 ft) long, and 1.2 m (4 ft) deep can be used, or, erected modular tanks with a volume of 2.84 million L (750,000 gal) are used. Both can treat up to 956 m^3 (1,250 yd^3) of soil. When the treatment volume exceeds 956 m^3, multiple lined pits or 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 30 m^3 (39 yd^3). The bioreactor for these tests was 12.2 m long, 2.4 m wide, and 2.6 m tall (40 ft × 8.0 ft × 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 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 -100 mV promote the establishment of the anaerobic microorganisms capable of degrading dinoseb and other nitroaromatic compounds *(1)*.

Figure 4-1 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 12.7 mm (0.5 in) in diameter. Since dinoseb is water-soluble, the rocks and debris at the Bowers Field site were rinsed with water to remove dinoseb contamination from the surface. Rinsing activities were not completed during the Demonstration Test due to the large percentage of material that was greater than 12.7 mm in diameter. The oversize material will be treated by a separate soil or rock washing technology or properly disposed of at a later date. The rinse water that was generated was combined with make-up water and placed in the bioreactor. A total volume of 28,900 L (7,640 gals) of make-up water was added to the bioreactor to provide the 1-L to 1-kg (0.26-gal to 2.2-lb) ratio required for treatment. Acids and phosphate buffers were added to the system to correct the pH. Batches of treatment soil and J.R. Simplot Company potato-processing by-product (2% by weight) were mixed together in a pug mill (homogenization unit) and added to the bioreactor by conveyor until all of the treatment soil was in the bioreactor. After the soil, water, and nutrients were loaded in the bioreactor, the mixture was augmented 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 indigenous microorganisms necessary for degradation of dinoseb using the J.R. Simplot Ex-Situ Bioremediation Technology. The soil at Bowers Field already contained the necessary microorganisms, however, the treatment slurry was augmented so that dinoseb degradation rates would be enhanced.



*Clean rejects if contaminants in the soil are water soluble.

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

The bioreactor was loosely covered and equipped with three mixers for agitation. The mixers were installed to achieve a well-mixed slurry in the bioreactor, however, "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 temperatures between 35 and 37°C, pH below 8.0 (ideally between 7.5 and 8.0 for dinoseb degradation), and redox potential <-100 mV *(1)*.

4.3 Methodology

Prior to commencement of the Demonstration Test, SAIC determined 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 findings of the site characterization previously performed by SAIC. The soil was stockpiled until excavation activities were complete. Excavated soil was then passed through a vibrating screen to separate out rocks and other debris greater than 12.7 mm (0.5 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 screened soil pile was leveled and shaped into a flat, truncated pyramid-like form. All sides of the pile were measured so that the total soil volume could be geometrically determined. Seven soil density samples were collected in metal sleeves of known mass and volume. 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. Three composite samples were collected from this pile for particle size and Atterberg limits determination.

The screened soil was placed in wheelbarrows to facilitate loading of the soil into a hopper that fed the homogenization unit (pug mill). J.R. Simplot Company potato-processing by-product was added to the soil prior to homogenization by the pug mill. Soil samples were collected from each wheelbarrow before the soil was fed to the pug mill and before the starch by-product was added. Samples of the J.R. Simplot Company potato-processing by-product were collected for dinoseb, pesticides, chlorinated herbicides, and metals analyses. These samples were held for analysis, unless it was found that the post-treatment samples had elevated concentrations from the pre-treatment samples for dinoseb, pesticides, chlorinated herbicides, and/or metals. Thus, these samples would help determine if the potato-processing by-product had introduced dinoseb, pesticides, chlorinated herbicides and/or metals to the bioreactor. Since the post-treatment samples did not have elevated concentrations from the pre-treatment samples, the potato-processing by-product samples were not analyzed.

In order to measure the variability of dinoseb contamination in the treatment soil, a grab sample was collected from every wheelbarrow fed into the hopper as mentioned above. After each four grab samples, the soil was homogenized and appropriate aliquots were collected. A total of 61 primary samples were collected for dinoseb analysis. Four field duplicates and four field triplicates were collected for dinoseb analysis to measure sampling and compositing variability. Matrix spike (MS) and matrix spike duplicate (MSD) analyses were performed on aliquots of five dinoseb samples. Gas chromatograph/mass spectrometer (GC/MS) confirmation of dinoseb was also performed on aliquots of four samples previously analyzed by high performance liquid chromatography (HPLC). These GC/MS scans, along with the HPLC scans, also allowed the identification and quantification of other compounds present.

A negative process control was set up prior to the start of the Demonstration Test as a means of comparing naturally occurring dinoseb degradation to degradation by the Simplot process. Grab samples were collected from each wheelbarrow 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. As microorganisms are indigenous to the site, it is expected that some natural degradation will occur, however, the rate of degradation is unknown at this time. No amino derivative or any other known toxic derivatives were found in the negative control, indicating that this natural process was not similar to the process occurring within the bioreactor. Due to uncertainties in the statistical evaluation, this presumed natural degradation will not be discussed further in this report and will be left for reader interpretation.

Thirteen samples each were collected for pesticides, chlorinated herbicides, and metals analysis. These samples were collected in a manner similar to the dinoseb samples except a grab sample was obtained from each of twelve separate wheelbarrows before the soil was homogenized and aliquots were collected. One field duplicate each was collected for pesticides, chlorinated herbicides, and metals analysis. The MS/MSD analyses were performed on aliquots of one pesticide and one chlorinated herbicide sample. The MS and analytical duplicate (AD) analyses were performed on aliquots of one metals sample.

Grab samples were collected from each wheelbarrow to comprise composite samples of the entire feed stream for toxicity tests. These toxicity tests included earthworm reproduction, early seedling growth, root elongation, and herbicide bioassay screening. Reference samples for the toxicity tests were also collected to compare to the toxicity of uncontaminated soil with dinoseb-contaminated soil. Except for having no contamination, this soil had the same characteristics and composition as the treatment soil. Although appropriate samples were collected, the toxicity tests were not performed. Since there were other toxic pesticides present in the test soil, it was determined at the beginning of testing that the toxicity analysis would be misleading. As toxicity tests are also expensive, it was decided that toxicity analysis should not be performed.

Because dinoseb is water soluble, the oversize material was washed with water to remove surface contamination. The washwater was collected and then sampled. Samples were analyzed for dinoseb, pesticides, chlorinated herbicides, and metals. Approximately 570 L (150 gal) of washwater was added to the bioreactor. Washing activities were not completed during the Demonstration Test, and the unwashed portion of the oversize material must be either cleaned using a separate soil or rock washing technology (with the washwater and fines being placed in the bioreactor for treatment at a later date) or properly disposed of at a permitted facility.

Based on the amount of soil to be treated, a total of 28,900 L (7,640 gal) of make-up water was added to the bioreactor. This water was sampled before introducing the soil into the bioreactor. Samples were analyzed for dinoseb, 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. This sample was to be sterilized to destroy any existing microorganisms and then returned to the vicinity of the bioreactor. Degradation of dinoseb in the bioreactor and lack of degradation in the sterile control under similar conditions would indicate that dinoseb degradation in the bioreactor was biological. The abiotic control was analyzed and found not to be sterile although it was exposed to 1.56 MRads of gamma radiation. Thus, it was decided that it not be used as a control.

Monitored parameters during remediation were pH, temperature, and redox potential. Measurements of these parameters were taken every 15 seconds and recorded by computer. During the course of remediation, conditions more than sufficient for anaerobic dinoseb degradation ($E_h < -200$ mV) were achieved in three days, and the pH stabilized at 7.1 as seen in Figure 2. However, due to the unusually cool summer experienced in the Pacific Northwest during 1993, the temperature in the bioreactor averaged only 18°C. This was lower than the preferred bioreactor temperature of 35 to 37°C *(1)*.

According to the developer, treatment time was expected to be approximately six weeks. Therefore, after 23 days (the anticipated midpoint), 10 samples were obtained to determine the progress of the remediation. Analysis of these mid-point samples indicated that the dinoseb had been completely degraded. Full post-treatment sampling of the bioreactor was then initiated.

All post-treatment slurry samples were obtained from random locations within the bioreactor. A total of 39 post-treatment slurry samples were collected and analyzed for dinoseb. Four field duplicate samples were collected for dinoseb to measure sampling variability. The MS/MSD analysis was performed on aliquots of four dinoseb samples, and GC/MS confirmation was performed on aliquots of four dinoseb samples. These GC/MS scans, along with the HPLC scans, also allowed the identification and quantification of other compounds present.

Six primary samples each were collected for pesticides and chlorinated herbicides analysis. One field duplicate sample each was collected to assess the sampling variability for pesticides and chlorinated herbicides. The MS/MSD analysis was performed on aliquots of one pesticide and one chlorinated herbicide sample.

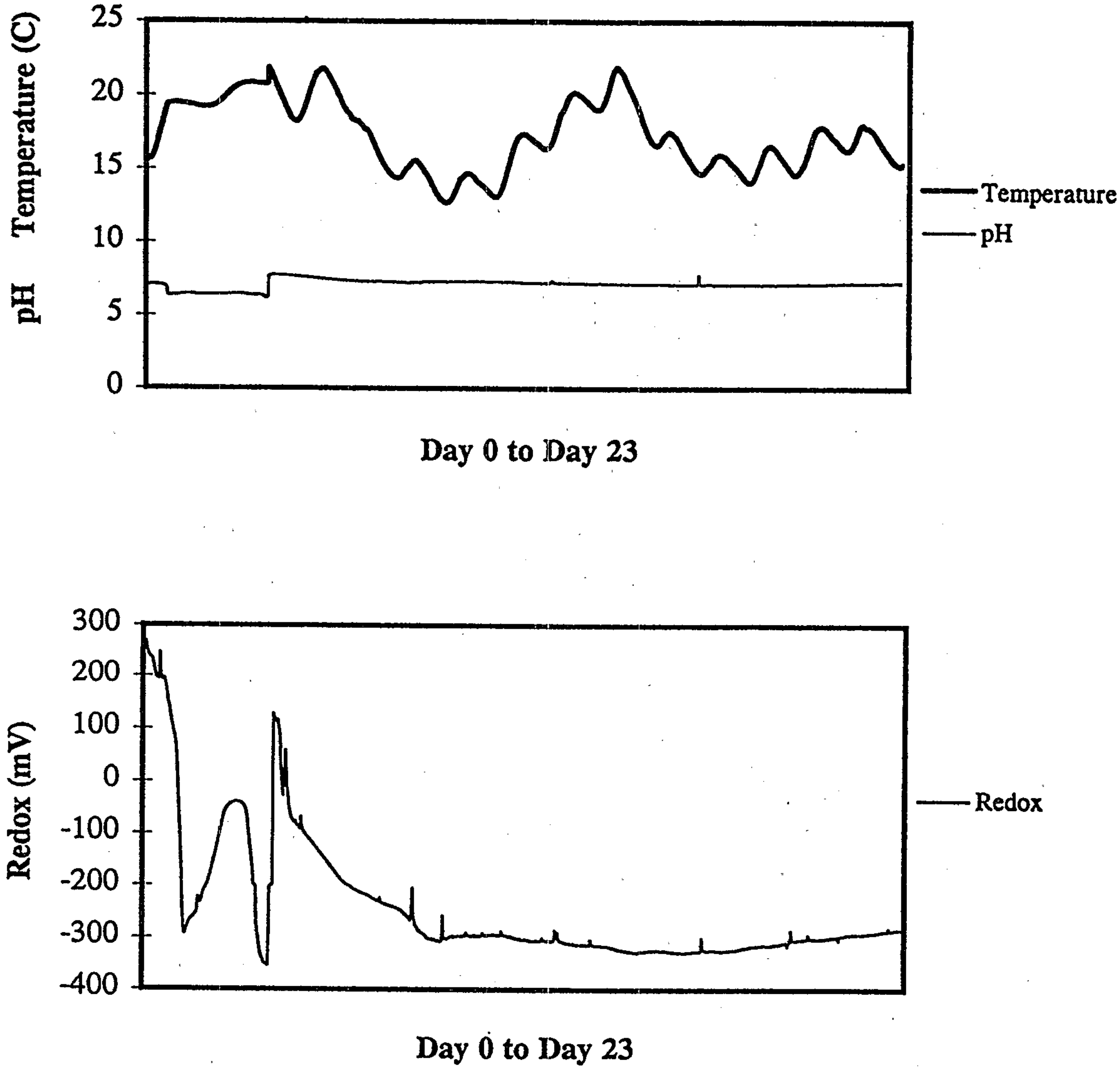


Figure 4-2. Monitored Parameters during Demonstration Test

Slurry samples were obtained for the post-treatment toxicity tests. Samples were collected for earthworm reproduction, early seedling growth, and root elongation toxicity tests. As stated previously, the toxicity tests were not performed.

4.4 Performance Data

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

4.4.1 Chemical Analyses

Dinoseb: A total of 110 primary samples (61 pre-treatment, 10 mid-point, and 39 post-treatment) were analyzed by the SAIC Analytical Laboratory for dinoseb using a high performance liquid chromatography (HPLC) method developed specifically for this demonstration *(8)*. This method is given in the SITE Technology Evaluation Report for this demonstration. This method gave analytical detection limits of 0.03 mg/kg for the solid samples and 0.015 mg/L for the liquid samples. (Because the mid-point samples were not concentrated in the laboratory, detection limits for these samples were 0.15 mg/kg for the solid phase and 0.15 mg/L for the liquid phase.) The average concentration of dinoseb in the feed soil, on a dry basis, was 27.3 mg/kg with a range of 14.0 to 34.2 mg/kg. The 95% confidence interval around this average was 26.4 to 28.3 mg/kg. No dinoseb was found in the pre-treatment make-up water samples. Upon arrival in the laboratory, the post-treatment slurry samples were phase separated, and the solid and liquid phases were analyzed separately. No dinoseb was found in either the solid phase or the liquid phase of the post-treatment slurry samples. Based on the average pre-treatment slurry concentration (on a dry basis) and the analytical detection limit for the post-treatment slurry samples (on a dry basis), the percent reduction of dinoseb in the slurry was >99.8%. The concentration of dinoseb in the pre- and post-treatment slurries was determined, on a dry basis, using the following expression:

$$[Slurry]_{Dry\ Basis} = \frac{(Wet\ solid \times S_f) + (Liquid \times L_f)}{(Fraction of Dry Solids, Slurry)}$$

where:	Wet Solid	=	Concentration of the wet solid phase in mg/kg.
	S_f	=	Weight fraction of wet solid phase.
	Liquid	=	Concentration of the liquid phase in mg/kg.
	L_f	=	Weight fraction of liquid phase.

Using the pre- and post-treatment concentrations of dinoseb in the bioreactor (analytical detection limit in the case of post-treatment samples), on a dry basis, the percent reduction was determined.

$$Percent\ Removal = \left(1 - \frac{C_f}{C_i}\right) \times 100\%$$

where: C_f = Post-treatment slurry dinoseb concentration in mg/kg (dry basis).
C_i = Pre-treatment slurry dinoseb concentration in mg/kg (dry basis).

No known intermediates from the degradation of dinoseb were found by HPLC analysis. To investigate this further, GC/MS scans were run on four selected pre-treatment and four selected post-treatment samples. These analyses confirmed that no known intermediates had been formed during remediation. Additionally, no new peaks were observed on the post-treatment sample chromatograms.

Analysis of the negative process control before and after treatment indicated that dinoseb, nitroaniline, and atrazine in the soil naturally degraded during the treatment period. However, dinoseb and nitroaniline levels in the negative process control were only reduced by 26.8% (from 28.0 mg/kg to 20.5 mg/kg, on a dry basis) and 51.0% (from 10.2 mg/kg to 5.0 mg/kg, on a dry basis), respectively. This is lower than the reduction of dinoseb and nitroaniline levels achieved in the bioreactor: >99.8% and >87.3% (on a dry basis), respectively. The accelerated rates of dinoseb and nitroaniline degradation seen in the bioreactor can therefore be attributed to the J.R. Simplot Ex-Situ Bioremediation Technology. All of the negative control data is based upon only 3 pre- and 3-post treatment measurements. Therefore, statistical evaluations indicating degradation is somewhat uncertain. The level of atrazine in the negative process control was reduced by 88.3% (from 55.6 mg/kg to 6.5 mg/kg, on a dry basis) while that in the bioreactor was only reduced by 52.5%. Degradation of atrazine is not attributed to the J.R. Simplot Ex-Situ Bioremediation Technology since natural degradation rates were greater than those seen in the bioreactor.

Pesticides and Herbicides: Samples were analyzed by Lockheed Analytical Laboratory for pesticides using SW-846 Method 8080 and for chlorinated herbicides using SW-846 Method 8150. Compounds were also detected by the HPLC and GC/MS scans performed by the SAIC Analytical Laboratory on aliquots collected for dinoseb analysis. Table 4-1 presents a summary of the average pre- and post-

Table 4-1. Other Compounds Reduced During the Demonstration Test

Compound	Average Pre-Treatment Slurry Concentration on a Dry Basis (mg/kg)	Average Post-Treatment Slurry Concentration on a Dry Basis (mg/kg)
Atrazine[*]	53.7	25.5
Nitroaniline[*]	11.9	<1.51
Malathion[†]	1.60	<1.51
Parathion[*]	2.30	<1.51

[*] Based on high performance liquid chromatography (HPLC) analyses.
[†] Based on gas chromatography/mass spectrometry (GC/MS) analyses.

treatment slurry concentrations of the compounds reduced during the Demonstration Test. Although not attributed to the J.R. Simplot Bioremediation Technology (based on the results of the negative process control discussed above), a >52.5 percent reduction was observed for atrazine (see Table 4-1). On a dry basis, the average pre-treatment slurry concentration of 2,6-dichloro-4-nitroaniline (nitroaniline) was 11.9 mg/kg. Like dinoseb, this nitroaromatic compound was also degraded to below its analytical detection limit in the post-treatment slurry samples. Based on pre- and post-treatment results in the slurry on a dry basis, nitroaniline was reduced by >87.3% (see Table 4-1). Further inspection of Table 4-1 does not indicate significant reductions of malathion or parathion. However, it is quite evident from the chromatograms that these compounds were present in the pre-treatment soil. The chromatograms for the post-treatment solid and liquid phases did not show any indication of the presence of these compounds. Malathion; parathion; and 4,4'-DDT were reduced from parts-per-million levels to below their analytical detection limits. Quantification of atrazine, nitroaniline, malathion, and parathion was possible through the use of standards. The 4,4'-DDT was identified in the pre-treatment samples, but no peaks could be found for this compound in the post-treatment samples. Accurate quantification of 4,4'-DDT could not be performed because a standard was not readily available. However, based on column manufacturer's recommendations and the peak height, the 4,4'-DDT concentration in the pre-treatment samples is estimated to be on the order of a part per million. The data presented in Table 4-1 are from the SAIC analyses alone. The methods used were not SW-846 methods, but rather methods that were specifically developed for this particular project. Details of the methods used can be found in Appendix A and Appendix F of the Quality Assurance Project Plan *(8)*.

The process had no noticeable effect on chlordane (alpha, gamma, and technical) and endosulfan (I and II). In each case, the change in average concentration was within the limits of analytical error, and definitive conclusions regarding changes in concentrations cannot be made. Table 4-2 presents a data summary (pre- and post-treatment slurry concentrations, on a dry basis) for compounds that were detected but appeared to be unaffected by the J.R. Simplot Ex-Situ Bioremediation Technology. Analytical Data listed in Table 4-2 is from SW-846 Method 8080.

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 not analyzed for metals. The metals concentrations were not expected to change due to remediation. Table 4-3 presents a summary of the pre-treatment metals data for the soil and the make-up water.

Toxicity: It was anticipated that the toxicity tests could be performed simultaneously on the pre- and post-treatment soils to determine if the relative toxicity of the soil had changed because of the degradation of dinoseb. However, it was found that the levels of pesticides and herbicides (in addition to dinoseb) in the pre-treatment soil negated the relevance of the analyses. To determine if the relative toxicity changes because of this process, toxicity testing (including earthworm reproduction, early seedling growth, root elongation, and herbicide bioassay screening) will be performed during the TNT SITE demonstration and reported in the associated Innovative Technology Evaluation Report (ITER).

Sterile Process Control: Immediately after collection, the sterile process control was shipped to the laboratory for sterilization using gamma radiation. The process control was subjected to 1.56 MRads of gamma radiation from a cobalt 66 source. However, it was found, by performing biological counts, that the control was not sterile. The control could not be further subjected to gamma radiation due to mechanical problems with the radiation source.

Table 4-2. Compounds Unaffected by the J.R. Simplot Ex-Situ Bioremediation Technology

Compound	Average Pre-Treatment Soil Concentration on a Dry Basis (mg/kg)	Average Post-Treatment Solid Phase Concentration on a Dry Basis (mg/kg)
Chlordane (alpha)	1.92	1.74
Chlordane (gamma)	2.21	1.97
Chlordane (technical)	25.7	16.9
Endosulfan I	2.72	1.61
Endosulfan II	2.12	2.52

4.4.2 Physical Analyses

Prior to treatment in the bioreactor, the soil was screened to separate out material greater than 12.7 mm (0.5 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 sand with gravel. The density of the screened soil was determined to be 1.22 g/cm^3 (76.2 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, wastewater, and the rocks and debris with diameters greater than 12.7 mm (0.5 in). Prior to the Demonstration Test at Bowers Field, the Washington State Department of Ecology (WADOE) established a dinoseb clean-up level below which

Table 4-3. Summary of Pre-Treatment Metals Data

Compound	Average Soil Concentration on a Dry Basis (mg/kg)	Average Make-Up Water Concentration (μg/L)
Aluminum	16,400	267
Barium	122	200
Beryllium	1.1	5.0
Calcium	5,800	18,600
Chromium	21.8	10.0
Cobalt	12.3	50.0
Copper	27.9	25.0
Iron	36,900	4,490
Lead	22.1	100
Magnesium	4,990	10,400
Manganese	584	24.6
Nickel	25.5	40.0
Potassium	2,310	2,220
Sodium	634	9,040
Vanadium	110	50.0
Zinc	181	51.2

the soil no longer presented a hazard to human health and, therefore, would no longer be considered hazardous. After treatment in the bioreactor at Bowers Field, the dinoseb concentrations in the treated soil and liquid were below the analytical detection limits as noted in Section 4.4.1 of this report. The treated soil was then replaced within the excavated area and used as fill material. In states where clean-up levels have not been established or when the clean-up levels are not met, then disposal of the soil at a RCRA-permitted facility may be necessary. If nitroaromatic compounds other than dinoseb are remediated, then disposal of the soil at a RCRA-permitted facility is only required if components of the waste are listed or the material has hazardous waste characteristics.

Water was used to wash the dinoseb from the separated rocks and debris. This was performed by the J.R. Simplot Company during the Demonstration Test; however, when the percentage of oversize material becomes excessive, a separate soil or rock washing vendor may provide assistance in this task. The rinse water was then added to the bioreactor with the make-up water to be remediated by the process. After treatment in the bioreactor at Bowers Field, the dinoseb concentration in the water was below the analytical detection limit. In most instances, the wastewater can be disposed through a publicly owned treatment works (POTW), assuming the appropriate permits have been obtained.

The third waste stream—the untreated rocks and debris—may present a disposal problem. During the Demonstration Test, only a portion of the rocks and debris greater than 12.7 mm (0.5 in) in diameter were washed. Logistical difficulties in executing the washing procedures left a large portion of the oversize material untouched. When material greater than 12.7 mm in diameter represents a high percentage of the excavated soil, a separate soil or rock washing technology is required for clean-up of this fraction or the material must be transported off-site for disposal at a RCRA-permitted facility. For the oversize material that was washed during the Demonstration Test, it was assumed that the washing process transferred the dinoseb from the rocks to the rinse water since dinoseb is highly water soluble. The decontaminated rocks and debris were then replaced in the excavated area as fill material. In cases where the nitroaromatic compound is not water soluble, the soil washing process separates the coarse fraction from the fine particles (where contamination is greatest) and then places the fine particles into the bioreactor. The oversize rocks and debris from the soil washing process may still require 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 may be 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 into a publically owned treatment works (POTW). A national pollutant discharge elimination system (NPDES) permit may be required to discharge into surface waters. 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 to 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 Issues

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 time, 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. 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. For lined pits, heavy equipment operators are required to excavate the pits, and 12 workers are required for 16 hours to install the liner in each pit.

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 equipment (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 sheeting. 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 minimized 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 by-product 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.

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 may minimize 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, however, 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

In addition to the demonstration performed on dinoseb in Ellensburg, Washington, the J.R. Simplot Company is also participating in a second SITE Demonstration to evaluate the ability of this technology to degrade another nitroaromatic compound, TNT (2,4,6-trinitrotoluene), at the Weldon Spring Ordnance Works in Weldon Spring, Missouri. The pre-treatment level of TNT in the test soil at this site is approximately 1,500 mg/kg. The treatment is being performed using a bioreactor identical to the one used in Ellensburg, Washington. These two bioreactors are the latest in the line of development for this process. Prior to these demonstrations, biodegradation of nitroaromatics using this technology had only been achieved in treatability studies performed by the University of Idaho.

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.

6.2 Scaling Capabilities

To date, this SITE Demonstration represents the largest scale of remediation performed using the J.R. Simplot Ex-Situ Bioremediation Technology. During the demonstration, a small portable bioreactor was used to degrade 30 m^3 of dinoseb contaminated soil in Ellensburg, Washington. An identical bioreactor is currently being used to perform the same scale of remediation at the TNT site in Weldon Spring, Missouri.

Simplot (in cooperation with an environmental remediation company) has proposed that the remediation of greater volumes of soil will require the use of lined, excavated pits or, alternatively, using 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 the rotating use of four 3,800,000-L (750,000-gal) tanks over a complete project period of seven months. This period includes excavation, tank erection, remediation, and demobilization. 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 30 days, similar to the remediation time required during SITE Demonstration. The maximum rock size that could be handled would be 38.1 mm (1.5 in) in diameter; all larger rocks would be crushed to this diameter.

This scenario is being proposed to remediate the entire Bowers Field site in Ellensburg, Washington. In Reedley, California, excavated pits are being proposed to bioremediate dinoseb contaminated soil. In addition, excavated pits are being used to destroy TNT contamination at a site in Bangor, Washington. The economic analysis given in Section 3 of this report is based on this remediation effort.

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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 Bioremediaton 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 nitrotoluene explosives, as well as many pesticides, including dinoseb, a herbicide banned because of health concerns.

The Simplot Process was demonstrated to degrade dinoseb (2-*sec*-butyl-4,6-dinitrophenol) to non detectable limits (15 ppb) which is less than the maximum allowable concentration specified by the Federal government. The Simplot process is an anaerobic bioslurry for the degradation of nitroaromatic compounds in soil or aqueous phases. In this demonstration, the Simplot Process was used to clean soil contaminated with the herbicide dinoseb which is a RCRA-listed waste (PO20).

The Simplot Process was demonstrated by the J.R. Simplot Company and Envirogen, Inc. at Bowers Field, a former crop dusting site in Ellensburg, Washington. Dinoseb contamination had occurred at this site, beginning in the 1940's until the 1970's. At Ellensburg, Dinoseb was degraded to less than detection limits in soils and water, from a beginning concentration of 28 ppm, resulting in overall reduction greater than 99.9%.

Other agricultural chemicals were also found in the Ellensburg soil. These included DDT, malathion, parathion, nitroanaline, atrazine, chlordane and endosulfan. The Simplot Process was entirely effective in the presence of these co-contaminants.

Optimal temperatures for The Simplot Process have been determined to be between 35 and 37°C. The summer of 1993 in the Ellensburg area was cold and wet, resulting in average ambient temperatures that did not exceed 18°C. The Simplot Process was entirely effective, even with sub-optimal temperatures, resulting in total degradation of dinoseb within 23 days.

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.

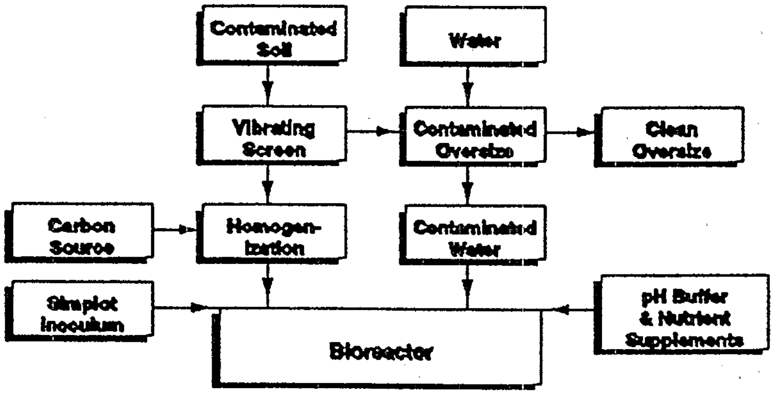
A.2 Process

The Simplot Process begins when contaminated soil is placed in a bioreactor with specially prepared water in a one-to-one ratio by weight. Water is prepared by adding nutrients, pH buffers, and a special carbon source (a Simplot potato starch 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 dinoseb-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.

The Simplot Process



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 agricultural 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.

A.4 Technical Information

This technology is designed to treat soils contaminated with nitroaromatic contaminants. Anaerobic microbial mixtures have been developed for the pesticide dinoseb and for TNT. These contaminants can be reduced to less than one part per million 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-dinitro-phenol) 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 aminonitro compounds. These intermediates are further degraded to simple organic acids, and hydroxylated aromatics, which can be subsequently mineralized by indigenous bacteria.

A.5 Advantages

- Dinoseb concentrations have been reduced by more than 99.9% using The Simplot Process, achieving cleanup levels below the analytical detection limit of 15 ppm.
- Complete anaerobic biodegradation of dinoseb is achieved without the formation (accumulation) of toxic intermediates.
- Breakdown of dinoseb compounds is complete, resulting in innocuous byproducts, mainly CO_2.
- Dinoseb 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 on agricultural sites, including nitroanaline, parathion, malathion and atrazine.
- The Simplot Process is a cost-effective alternative to traditional technologies for both large and small sites. 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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