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BIOREMEDIATION: EFFECTIVE TREATMENT OF PETROLEUM-FUEL-CONTAMINATED SOIL, A COMMON ENVIRONMENTAL PROBLEM AT INDUSTRIAL AND GOVERNMENTAL AGENCY SITES

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ABSTRACT

Bioremediation methods are receiving increased attention for degradation of petroleum-fuel-hydrocarbon contamination in soils. An in situ bioremediation demonstration is being conducted on petroleum-fuel-contaminated soil at Kwajalein Island, a remote Pacific site. Bioreaction parameters studied include water, air, nutrient, and microorganism culture addition. This paper presents planning and design aspects of the demonstration that is scheduled to be completed in 1993.

INTRODUCTION

Both natural and anthropogenic practices have made petroleum hydrocarbon contamination essentially ubiquitous on this planet. Such contamination, especially that imposed by aromatic hydrocarbons, may pose environmental and health risks to sensitive biological species as well as to ground water sources for potable drinking water. Such contamination in complex geologic matrices may also be difficult to treat by traditional engineering means. Biodegradation methods are receiving increased attention for treatment of petroleum-contaminated soils and ground water, and current bioremediation studies are beginning to shed

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light on the biological and chemical factors controlling biodegradation of hydrocarbons. Consequently, bioremediation processes are becoming methods of choice for degradation of such contamination.

Recent history contains many examples of diesel and fuel oil spills associated with civilian and military practices, with some at remote locations (e.g., desert, tropical islands, ice-locked tundra). At these remote locations, logistic complexity may require low-technology in situ bioremediation processes. Furthermore, bioremediation appears to be cost-effective relative to cleanup of nonremote sites when compared with other methods requiring complex technologies.

An in situ bioremediation demonstration is being conducted on petroleum-fuel-contaminated soil at Kwajalein Island, a remote Pacific site. This paper discusses demonstration planning and design as well as some site characterization information. The demonstration is scheduled for completion in 1993.

BACKGROUND

The U.S. Army Kwajalein Atoll (USAKA) Base is located in the Republic of the Marshall Islands (RMI), which is situated in the west central Pacific Ocean. USAKA is located approximately 2,100 nautical miles southwest of Honolulu, Hawaii, and 700 nautical miles north of the equator. Kwajalein Atoll forms the largest enclosed lagoon in the world and consists of approximately 100 small islands with the total land area of 5.6 mile^2.

Kwajalein Island is about 3.5 mile long and 0.3- to 0.5-mile wide with a land surface area of about 1.2 mile^2. The population of the Base is about 3,000 including Army and subcontractor personnel and their families.

USAKA has significant petroleum hydrocarbon contamination resulting from years of military activities. Given the remoteness of USAKA, the lack of sophisticated remediation technologies and waste disposal facilities on-site, as well as the amenability of petroleum hydrocarbons to biodegradation, USAKA requested through the Hazardous Waste Remedial Action Program (HAZWRAP) that a project be initiated to evaluate the feasibility of using bioremediation for environmental restoration of contaminated sites in Kwajalein Atoll. The demonstration discussed in this paper is part of that feasibility evaluation.

DEMONSTRATION SITE AND CHARACTERISTICS

The demonstration site (approximately 130 x 160 ft) is located on Kwajalein Island in the proximity of diesel fuel storage tanks (Figure 1). Initial hydrocarbon contamination concentrations at the site ranged from 400 to 500 mg/kg soil (dry weight). The treatment goal is 100 mg/kg soil (dry weight). Other initial soil conditions were: temperature, 82 to 84 °F; water content, 5 to 22 wt % from the land surface to ground water (~ 5.5 ft); pH, slightly alkaline at 7.4 to 8.5; phosphate, 3 to 10 mg P/L in soil extract (typical); nitrate, very low or absent; salinity, moderate at 500 to 1300 µmho/cm (typical); permeability, adequately high; and total bacteria, 1000 to 1,000,000 organisms/g of soil. Microbes indigenous to the island are capable of surviving under the petroleum-based-fuel- or lubricant- (POL) contaminated conditions, and bioactivity could be stimulated by the addition of nutrients (e.g., N, P, K).[1]

Detailed analyses and biological observations made on USAKA soil and water samples at The University of Tennessee (UT), Oak Ridge Associated Universities (ORAU), and Oak Ridge National Laboratory (ORNL) supported the concept that bioremediation may be an effective method of removing many of the hydrocarbons contaminating Kwajalein Atoll. The studies indicated that (1) the technical approach for bioremediation should include the addition of nutrients to contaminated areas and (2) adding additional microorganisms to the bioremediation areas could increase the hydrocarbon degradation rate. The soil and ground water of the atoll

contain a wide variety of aerobic and anaerobic microorganisms, and the number of organisms per gram of soil ranged from 10^3 to 10^8. No sterile environments were detected, although assays of ester-linked phospholipid fatty acids from the soil samples suggested that most of the microorganisms were not actively dividing and may be starved for certain essential nutrients. There was some evidence that the more heavily weathered hydrocarbons (i.e., generally larger molecules with partially oxidized substituents) may be relatively difficult to degrade by biological methods.[2]

DEMONSTRATION OBJECTIVES

The overall objective of this demonstration is to determine whether bioremediation can be used to clean up petroleum hydrocarbon-contaminated soil on the island. Specific objectives include: (1) evaluating multiple processes for bioremediation in a rigorous manner to determine the potential and limitations; (2) determining the mechanisms of removal/destruction of hydrocarbon compounds in order to elucidate the nature and extent of bioremediation that may occur; and (3) providing an information base that can be used in the effective design, operation, and monitoring of full-scale bioremediation processes on other islands in the Pacific.

DEMONSTRATION

The bioremediation demonstration work consists of several distinct work tasks: site characterization, treatability studies, demonstration test cell design and equipment procurement, soil sampling and equipment shakedown and evaluation, treatment and monitoring regimens, test cell and system installation, demonstration operation, site decommissioning, and final reporting.

In situ processes being evaluated include sparging with air through a center well within the cell; intermittent flushing (infiltration and percolation of water with addition of nutrients); saturation flushing (continuous infiltration and percolation of water with amendments); enrichment with microorganisms (using indigenous microbes); and controls of water only with no other amendments. Ex situ processes evaluated will include addition of water, nutrients, microorganisms, and tillage. The ex situ tests will use soil piles excavated from contaminated construction sites and will be conducted concurrently with the in situ tests.

The experimental design includes use of test cells in duplicate with appropriate controls. The demonstration site layout of the planned arrangement of in situ test cells and ex situ test cells or treatment piles is shown in Figure 2. The treatment regimens will include treatment with (1) water and air; (2) water, air, and nutrients; and (3) water, air, nutrients, and microorganism enrichment. The test cells are approximately 8 x 8 ft and of sufficient depth to penetrate the fresh ground water lens under the island. Each test cell can supply water, nutrients, and microorganism amendments as necessary to maintain the treatment regimens. A vertical schematic or cross-section of an in situ test cell is shown in Figure 3.

Monitoring of each demonstration test cell includes completion of comprehensive environmental characterization, microbiological analysis, and contaminant concentration determination (e.g., soil pore gas; soil temperature, moisture, and pressure; soil solution composition; groundwater depth and concentrations; bulk soil characteristics). Analyses will be conducted both on- and off-site.

Laboratory-scale soil column studies are being conducted in order to optimize and establish the test cell treatment regimens. The column studies were designed to quantitatively control the addition of water, nutrients, and enriched cultures of indigenous microorganisms. Analysis of the chemical and microbiological information provided by the soil column tests will enable determination of appropriate treatment regimens.

Installation of test cells and equipment will be accomplished during 1992, and the demonstration period is expected to require a minimum of 3 months in order to obtain definitive analytical information. After completion of the demonstration in 1993, it is anticipated that the resultant information from this rigorously controlled bioremediation demonstration will assist in planning of full-scale bioremediation activities at other petroleum-fuel-contaminated sites.

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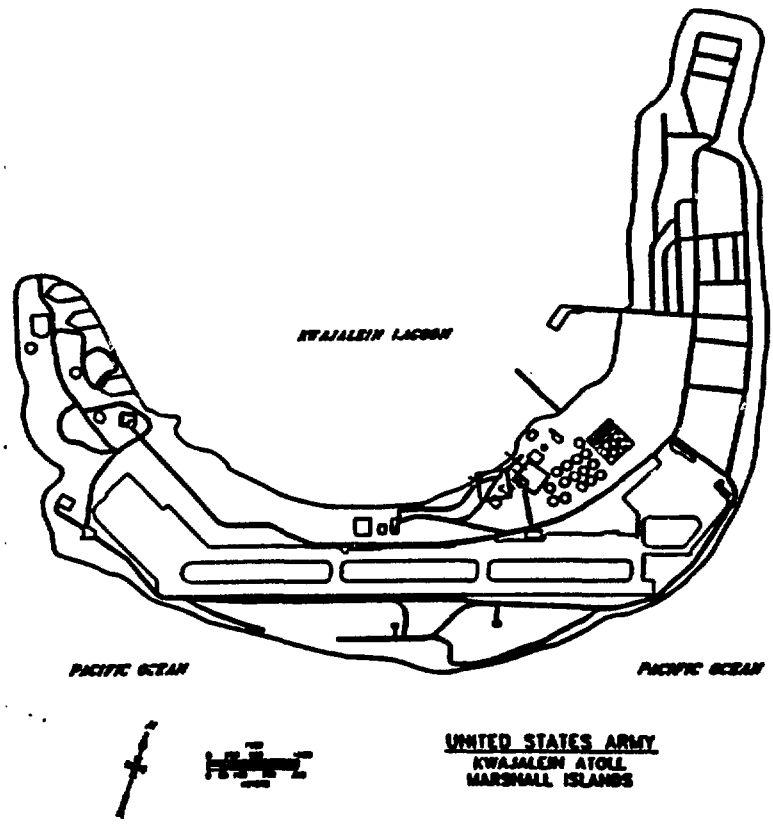

Figure 1. Site map of the demonstration area on Kwajalein Island.

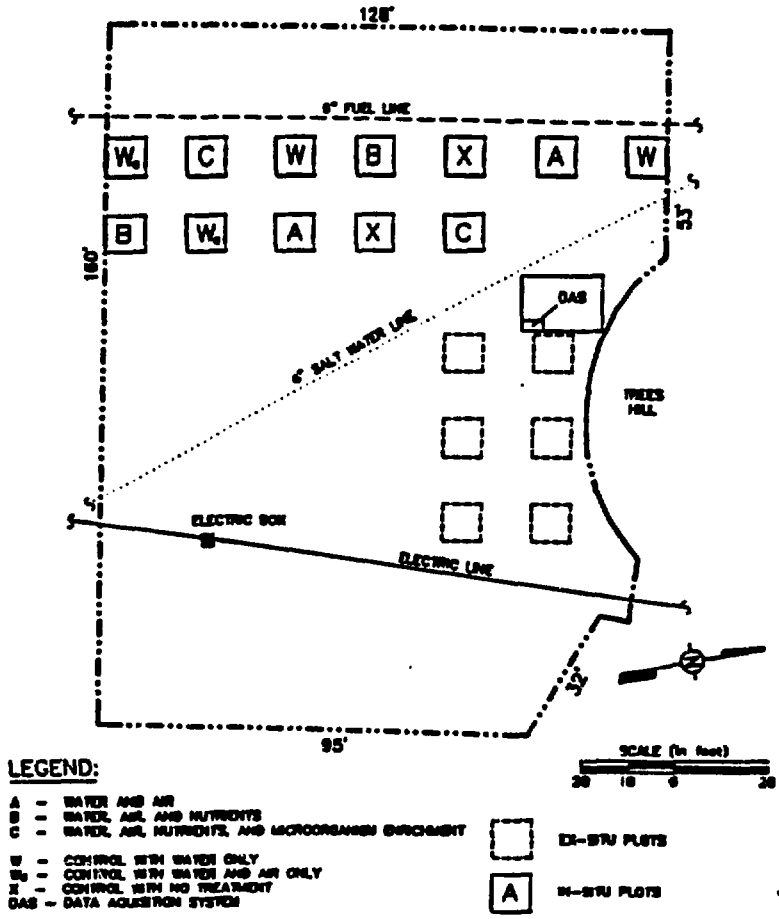

Figure 2. Test cell layout for bioremediation demonstration.

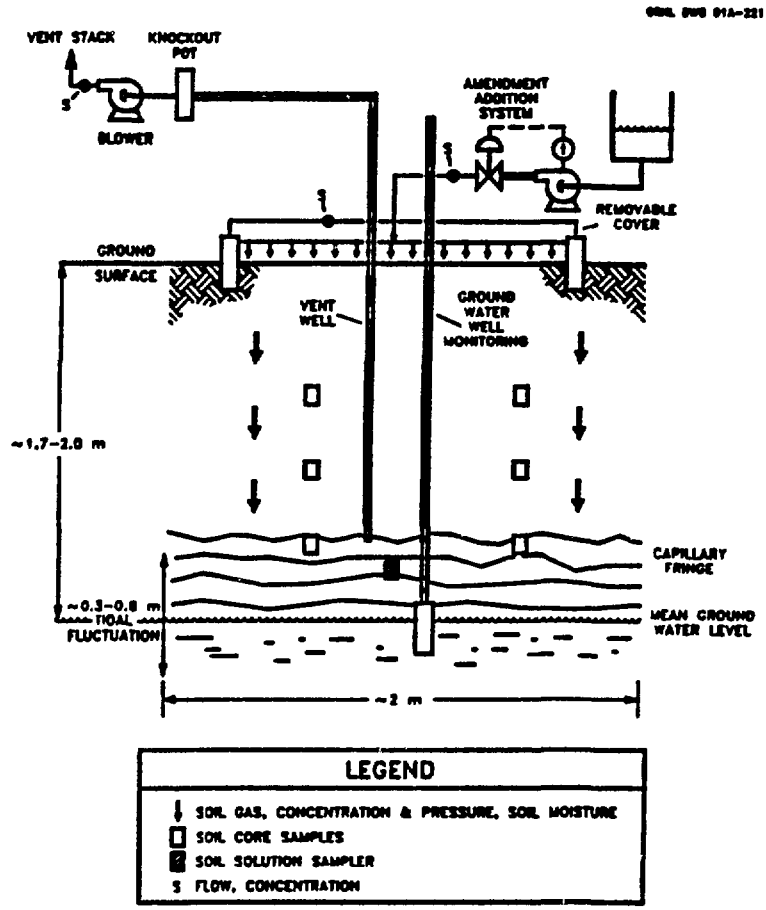

Figure 3. In situ test cell cross section.

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