BIOREMEDIATION OF PETROLEUM SPILLS IN ARCTIC AND SUB-ARCTIC ENVIRONMENTS:

A FEASIBILITY STUDY

Report No. AK-RD-90-07

STATEWIDE DOT&PF RESEARCH

BIOREMEDIATION OF PETROLEUM SPILLS IN ARCTIC AND SUB-ARCTIC ENVIRONMENTS:

A FEASIBILITY STUDY

Part of Fairbanks International Airport Crash Fire Rescue (CFR)
Fire Training Facility Remediation

by

Michael D. Travis
Research Specialist
Alaska Department of Transportation and Public Facilities
Statewide Research
2301 Peger Road
Fairbanks, Alaska 99709

November 1989

Publication Cost $2.00

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Introduction

Alaska is not immune to petroleum spills. The supertanker Exxon Valdez accident proved how vulnerable Alaska is to large oil spills. However, this accident overshadows other spills which have occurred throughout the state. Examples of previous spills are:

1. July 19, 1977. More than 80,000 gallons of Prudhoe Bay crude oil from the Trans Alaska Pipeline was sprayed over the tundra at valve station #7 on the coastal plain north of Franklin Bluffs (Johnson, 1981).
2. February 2, 1978. An act of sabotage of the Trans Alaska Pipeline resulted in over 500,000 gallons of crude oil spilled at Steele Creek just south of Fairbanks (Johnson, 1981).
3. August 25, 1989. About 25,000 gallons of crude oil spilled at the 2-U production pad at the Kuparak field in Prudhoe Bay (Fristoe, 1989).

Unaided rehabilitation of petroleum spills can affect tundra soils for up to 30 years (Cairns and Buikema, 1980). Effects of oil spills on sub-arctic forest soils last for at least a decade (Sparrow and Sparrow, 1989). Natural remediation is slow because of the cold dominated climate and short growing season. This persistence was documented in two experimental 2,000 gallon spills of crude oil on a black spruce forest north of Fairbanks (Sparrow, Davenport, and Gordon, 1978; Johnson et. al., 1980; Sparrow and Sparrow, 1989). One spill was applied in winter and the other in summer. In both sites all oil saturated vegetation died after one growing season. Soil temperatures increased from the lack of vegetative cover and the dark stained ground. After two years, the active layer increased from 19 in. to 36 in. (Johnson et. al., 1980). After ten years, significant amounts of oil could still be found in the soil and vegetative growth was still inhibited (Sparrow and Sparrow, 1989).

These examples convey the need for developing cost effective technologies to remediate petroleum spills in northern environments. This paper investigates the possibilities of utilizing bioremediation to clean up hydrocarbon contamination of soils and groundwater in both arctic and sub-arctic regimes. The Valdez oil spill, Kuparuk spill, and soil and groundwater contamination at the Fairbanks International Airport are analyzed and remediation solutions are proposed.

Bioremediation

Bioremediation is the process of enhancing indigenous microbes in soil and groundwater to metabolize organic contaminates into harmless by-products. "Pump and Treat" methods such as air stripping and activated charcoal adsorption only remove the contaminant, thus still requiring an ultimate disposal plan. The U.S. Environmental Protection Agency (EPA) is very optimistic about the capability of bioremediation to clean up oil spills. Eric Bretthauer, EPA Acting Assistant Administrator for the Office of Research and Development said, "Bioremediation is a potentially powerful approach to reducing the time required to decrease the environmental effects of oil and other chemical spills" (USEPA, August, 1989).

Petroleum products are readily degraded by bacteria which live naturally in soil and groundwater. Bacterial growth is limited by temperature, oxygen, and nutrients (nitrogen and phosphorous). The enhancement of these factors will increase the microbial population and/or the metabolic rate. Therefore, the rate of hydrocarbon degradation is increased.

Oil degrading microorganisms are widely distributed in the Arctic soils. All are capable of altering the chemical composition of Prudhoe Bay crude oil (Cairns and Buikema, 1980). Microbial abundance decreases with soil depth. This is because oxygen, nitrogen, phosphorous content, and temperatures decline with depth.

Pseudomonas spp. are the most common bacteria found in arctic soils which degrade oil (Lindstrom, 1987). Large populations of oil degrading bacteria occur naturally at oil seeps in Umiat, Alaska and Cape Simpson (Cairns and Buikema, 1980). Microbes from Cape Simpson can degrade discarded motor and lubricant oil and greases. Most of these microbes are Pseudomonas spp. bacteria.

Microbial populations naturally increase in response to petroleum spills. Sparrow et.al., 1978, and Sparrow and Sparrow, 1989 found that microbial populations in sub-arctic taiga soils were stimulated by oil contamination. Again, Pseudomonas spp. predominated. To enhance this response, oxygen and nutrients must be supplied to the soil. This is done by three general methods:

1. Land Treatment or Farming.
2. Passive In-situ Treatment of Soil and Groundwater.
3. Dynamic In-situ Treatment of Soil and Groundwater.

Land farming is a very inexpensive method to employ biodegradation processes. Oil contaminated soils are spread over an impermeable liner up to a maximum depth of 1 foot. The soil is allowed to aerate for at least 3 days to allow for the vaporization of toxic hydrocarbon aromatics. Fertilizer with a nitrogen:phosphorous:potassium (N:P:K) ratio of 10:1:1 is then added every two weeks. Lime is used to adjust the soil pH to 6.5 - 8.0. Weekly tilling incorporates oxygen and nutrients into the soil and breaks up the hydrophobic surface crust. Oxygen is a crucial parameter to land farming (Lee et. al., 1988 and Mitchell, Loyanchan, and McKendrick, 1979). Frequent tilling only aerates the top one foot layer of soil. During the entire process, the soil must be kept within 25% to 85% of its capacity to hold water. Microbes need a water interface to assimilate nutrients, oxygen, and petroleum.

Fertilizer was tilled into crude oil contaminated soils of the Swan Hills area in Alberta, Canada (Cairns and Buikema, 1980). The fertilizer ratio and application rate was 67:59:102 kg/ha for N:P:K. Bacterial degradation of the oil was greatly increased. The oiled soils were very impervious to water penetration. Frequent tilling minimized this effect. If the soils were contaminated less that 2.5% by weight, it was completely remediated within one year (Mitchell, Loyanchan, and McKendrick, 1979). If the soils were contaminated up to 13.7% by weight, it took 5 years of frequent tilling and fertilizing to degrade the oil. The natural biodegradation half life of the oil was reduced from 20 to 30 years to 1 year (Mitchell, Loyanchan, and McKendrick, 1979).

The biodegradation of Prudhoe Bay crude oil was studied on several plots in Palmer, Alaska (Mitchell, Loyanchan, and McKendrick, 1979). Both frequent tilling and fertilization of the plots were necessary to accelerate decomposition. Plots that received

0.25 gallons/ ft^2 grew plants after the first year. The 0.50 gallon/ft^2 plots took two full growing seasons to support plants again and four years to completely remediate the site. The maximum depth for significant microbial degradation was 6 inches in the plots which received no fertilizer or tilling. These plots were oxygen, nitrogen, phosphorous, and potassium limited.

Although frequent tilling aerates the soil and provides for remediation in greater soil depth, it also drys out the soil. Excessive soil drying limits microbial growth. Therefore, adequate water must be applied during tillage.

Frankenberger (1988) found that an inorganic fertilizer with a N:P ratio of 10:1 provided the best enhancement for oil degrading bacteria. Urea did little to stimulate the microbes.

Northern climates have cold soil temperatures which restrict the growth of microbes. Sheets of clear polyethylene significantly raise average summer soil temperatures. Soils in northern Quebec were stripped bare of vegetation and covered with clear polyethylene. When compared to plots without polyethylene, the temperatures of the covered plots were 6° C higher than the control plots (Nicholson, 1978). Dinkel (1966) examined daily average soil temperatures of plots covered with polyethylene sheets at Palmer, Alaska. He found that at a 10 inch depth, the soil temperatures rose up to 30° F higher than the uncovered soil. Esch (1982) used 6 ml. polyethylene sheets to warm ground in the Fairbanks, Alaska area that was stripped of vegetation. The active layer increased from 4 feet to 8 feet within two years. Esch noted that gravel sprayed with a light coating of oil had a higher average daily temperature than clean material. The darker color absorbed more solar radiation and enhanced the greenhouse effect under the polyethylene. Esch also noted that the polyethylene sheets became brittle and cracked during the first winter. This reduced its capacity to warm soils during the second summer.

Interior Alaska has warm summers which stimulate bacterial growth. Therefore, the polyethylene covering is not necessary except during early spring and late fall months. However, arctic environments would benefit from increased soil temperatures. A method is discussed later in the report which describes the use of polyethylene to raise contaminated soil temperatures while still providing adequate aeration.

Passive in-situ systems utilize injection wells or infiltration galleries to insert nutrients and oxygen into oil contaminated soil and groundwater. The nutrients are introduced upstream of the contaminate plume. The nutrients then diffuse through the soils and groundwater to stimulate bacterial populations. Figure 1 displays a typical passive system. Limited control of the flow of nutrients and contaminates is a major disadvantage in this method.

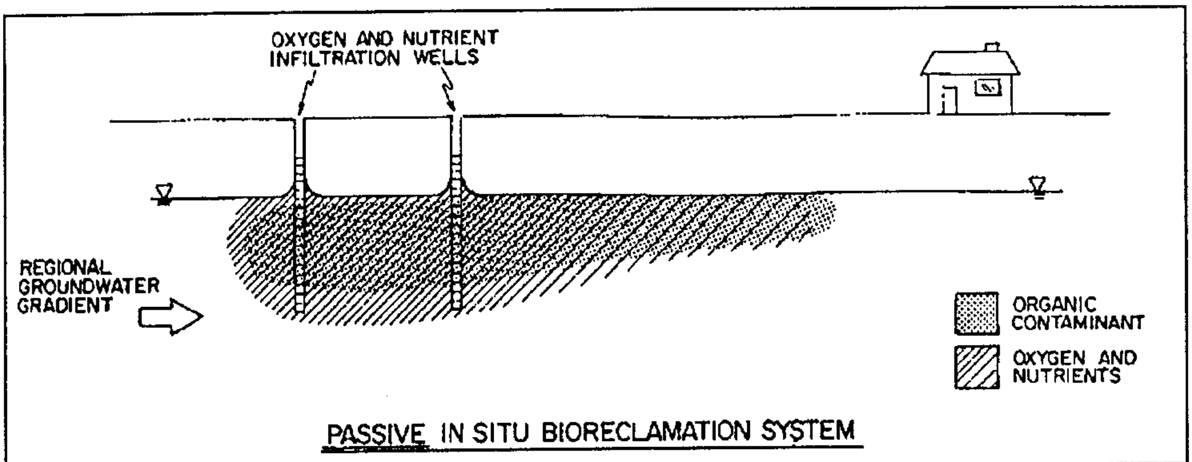

Figure 1. Passive In-situ Bioreclamation (from Wilson and Brown, 1989).

Frankenberger, et. al. (1989) used the passive technique to successfully remediate a 1,000 gallon diesel spill in San Bernardino County, California. Soils were contaminated up to 1500 mg/kg of soil. A series of two-week interval injections of nutrients (N,P, & H_20_2) were poured into seven injection wells for 4 months. The nutrients were mixed with 35 gallons of water in a 50-gallon cement mixer in the following quantities: NH_4NO_3, 250 mg/l; K_2HPO_4, 100 mg/l; H_2O_2 (30%), 100mg/l. A batch was made for each well. The bioreclamation was initiated in April, 1984 and terminated in October, 1984 upon no detection (<1 mg/kg) of hydrocarbons.

Oxygen is a critical parameter for in-situ bioremediation systems (Wilson and Brown, 1989, Eckenfelder, 1989). Two methods are used to supply oxygen to the contaminated soils and aquifers; 1. atmospheric air injected by air spargers; and 2. hydrogen peroxide (H_2O_2) introduced by injection wells or galleries. Air spargers are subject to fouling from fungi and can only increase the oxygen content up to 10 ppm. The biological oxygen demand of the contaminants easily overwhelms the increased oxygen and limits the effects within close proximity to the spargers (Yaniga and Smith, 1985). Hydrogen peroxide breaks down in the following manner: $2H_2O_2 \rightarrow 2H_2O + O_2$. Therefore, 100 ppm of H_2O_2 injected into the groundwater will yield 50 ppm of oxygen. This is sufficient oxygen to stimulate bacteria to degrade the contaminants throughout the plume. The maximum H_2O_2 concentration used for injections is 100 ppm (Wilson and Brown, 1989). Remediation is halted when there is no longer a significant oxygen demand. An indication of this is when the dissolved oxygen (DO) levels within the contaminated area are within 2 ppm of upstream levels.

Usually only nitrogen and phosphorous are injected with H_2O_2 to stimulate microbes (Wilson and Brown, 1989). Other trace elements and minerals are readily available in the subsurface environment.

Dynamic in-situ systems utilize well pumps to develop a cone of depression around the well casing to control the spread of contaminants and injected nutrients. Figure 2 displays an example of a dynamic system. This system also offers the advantage of trapping free floating contaminants in the cone of depression. A scavenger pump removes these contaminants to a container for disposal.

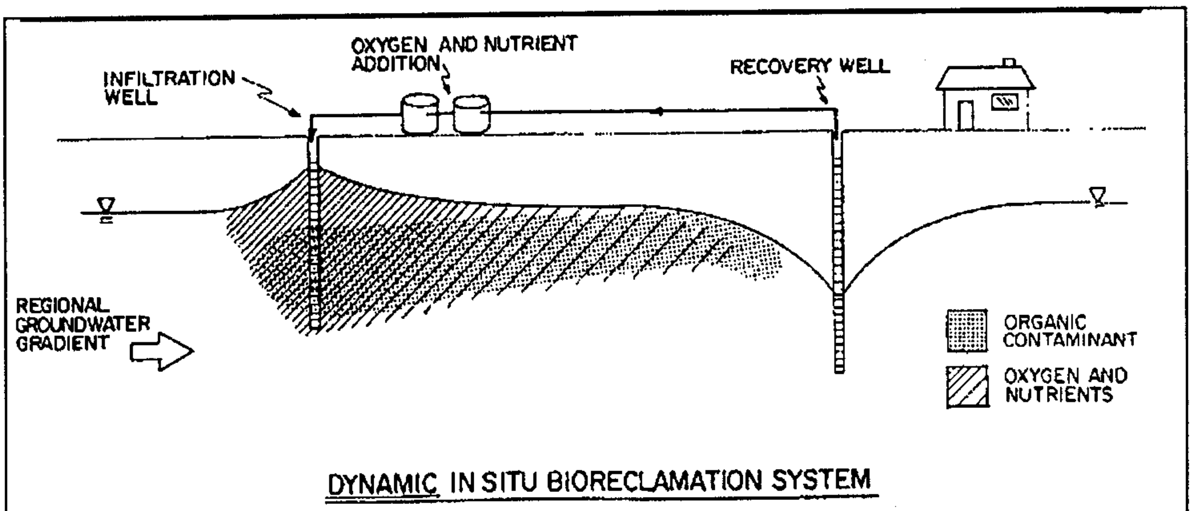

Figure 2. Dynamic In-situ Bioreclamation (from Wilson and Brown, 1989).

A dynamic system was utilized to remediate an EPA Superfund site in Northwestern Montana (Piotrowski, 1989). It was the first time that EPA mandated bioremediation for clean up. Creosote and pentachlorophenol (PCP) contaminated the soils to a depth of 70 feet. The aquifer contamination was 4 -5 ppm. Only H_2O_2 was injected for 150 days. At the end of this period, DO levels began to rise dramatically. Tests showed the contamination was degraded below detection limits.

Other examples of dynamic systems are: 1. Ambler, Pennsylvania. About 100,400 gallons of gasoline was degraded below detection limits within 10 month (Lee et. al., 1988). It was estimated that conventional techniques (i.e., airstrippers and activated carbon) would take about 100 years to achieve this level of clean up.; 2. Ohio. It took 18 months to biodegrade 99% of a 900 gallon spill of unleaded gasoline (Wilson and Brown, 1989).; and 3. Lakehurst, New Jersey. About 85% to 93% of a 4,000 gallon ethylene glycol spill was remediated in 26 days (Flathman, Jerger, and Bottomley, 1989).

There is no single remedial approach which is universally applicable to every site and contaminant. The choice of a particular treatment process is determined by an understanding of the transport and persistence of the contaminant. Successful application of bioremediation techniques require the integration of each site's hydrology, chemistry, and microbiology. The hydrology must allow for timely transport of nutrients through the soil and groundwater. The soil permeability must be greater than 10^{-4} cm/sec (Eckenfelder, 1989). The soil and water chemistry must be compatible with the nutrient introduced. Soils high in iron will precipitate phosphorous which restricts soil permeability. The soil pH must be between 6.5 and 8 to optimize microbial growth. The presence of heavy metals can restrict bacterial growth. Also, the treatment process can induce metal mobilization (Lee et. al., 1988). The microbes present must be able to degrade the contaminant. Pseudomonas spp. bacteria optimize the degradation of toluene at a contaminant concentration of 29 ppm (Lindstrom, 1987). Introduction of foreign microbes alone to degrade contaminants has had limited success (Lee et. al., 1988).

Organic contaminants potentially exist in the subsurface as a vapor phase and three condensed phases: 1. mobile free product (free phase) 2. residually contaminated soil (absorbed phase); and 3. contaminated groundwater (dissolved phase). Although the dissolved phase contains only a small fraction of the total product (1 to 5%), groundwater is the major long term mechanism for the spreading of contamination. This is because of its high mobility and greater volume of contaminated material than the other two phases.

Most of the contaminant (about 62% of the amount spilled) is present as free phased material (Wilson and Brown, 1989). Table 1 represents the estimated phase distribution of a typical gasoline spill in a medium sand aquifer (Wilson and Brown, 1989).

Table 1

Phase Distribution of a Typical 30,000-Gallon Gasoline Spill*

Phase	Contaminated Volume Cu. Yd.	% of Total	Contaminant Volume (Gallons)	% of Total
Free phase	7,100	1.0	18,500	62
Adsorbed (soil)	250,000	20.0	10,000	33
Dissolved (water)	960,000	79.0	333	1-5

* Medium sand aquifer, depth to water approximately 15 feet.

The amount of dissolved phased contaminant in the groundwater is small compared to the adsorbed phase in the soil. Soil slowly releases the contaminant. Therefore, the soil is always a source of pollution and both mediums must be treated simultaneously. In-situ bioremediation systems do this. Typical "pump and treat" systems rely on the soil leaching its contaminants into the aquifer. This is a slow process and explains why the pump and treat systems (i.e., airstripping and activated carbon) require a much longer time period than bioremediation to remediate a site. In the long term, bioremediation is cheaper than pump and treat methods. EPA recognizes this fact (Wilson et. al., 1989).

Bioreclamation has higher initial costs than conventional methods, however the treatment process is shorter (Wilson and Brown, 1989). Figure 3 shows the cost comparison between the bioremediation and pump and treat methods for a typical 900 gallon petroleum spill. Costs associated with bioremediation demonstrated a savings of about 50 to 80% over simple pump and treat systems (Wilson and Brown, 1989 and Lee et. al., 1988). The time frame for clean up was about 70% less than pump and treat systems.

A 1,320 gallon spill of waste solvents and fuels was bioremediated within 72 days (Lee et. al., 1988). The total cost of the remediation was $180,000. The estimated cost of carbon adsorption was $470,000 to $850,000 and would take from 10 to 20 years. The estimated cost of excavation ranged from $600,000 to $1.5 million and still required a final treatment plan.

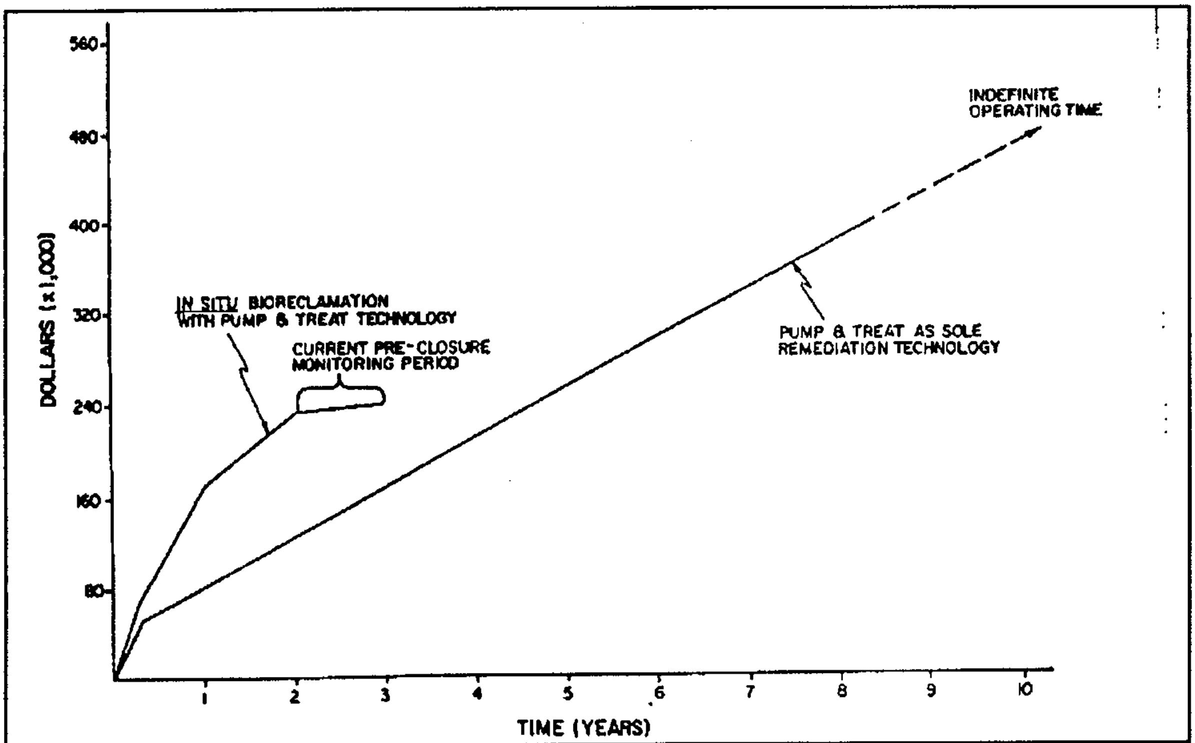

Figure 3. Cost Comparisons Between Bioreclamation and "Pump and Treat" Systems (from Wilson and Brown, 1989).

Valdez Oil Spill

Just after midnight on March 24, 1989, the Exxon supertanker Valdez ran aground on Bligh Reef and spilled approximately 11 million gallons of Prudhoe Bay crude oil in Prince William Sound. About 1,000 miles of shoreline were coated with the thick product. EPA founded the Alaska Bioremediation Project to demonstrate the effectiveness of adding nutrients to enhance the bioremediation of crude oil on the beaches. The project is authorized by the Federal Technology Transfer Act. It is performed in cooperation with the Exxon Company USA (USEPA, Addendum, July, 1989). William K. Reilly summed up EPA's hopes that the project would be successful: "The Alaska oil spill tragedy demonstrated the primitive state of our oil spill cleanup procedures and technologies - and the need to develop and encourage the use of innovative clean up techniques such as bioremediation."

A study site was selected in Snug Harbor on Knight Island. The beach had uniform sized cobbles and gravels, a gradual sloping shoreline, and protection from storms. Two types of fertilizers were applied to separate 2,000 yd^2 plots: 1. a water soluble mixture that was anchored in the intertidal zone; and 2. an oleophilic fertilizer that was sprayed directly onto the beach plot. Two control plots were also monitored to compare the rates of natural bioremediation with the treated plots.

The surfactants in the oleophilic fertilizer immediately dispersed the surface oil clinging to the substrate. The oil was broken up into smaller particles which enhanced biodegradation. Three weeks after the first application, a visual inspection was made of the plots. The oleophilic treated plots showed a striking disappearance of oil from the rock surfaces. However, the oil showed no signs of being remediated below the surface or between rocks.

Upon contact with the ground and water, the olephilic fertilizer quickly breaks down into olec acid and urea. The urea provides the nitrogen for biodegradataion. However, Frankenberger (1988) demonstrated that urea does little in stimulating microbes to degrade petroleum spills. A nonsuitable nitrogen source is a possible reason for the limited degradation observed at Snug Harbor.

The water soluble fertilizer treated plots degraded oil six times faster than the control areas (USEPA, Addendum, July, 1989). It penetrated the substrate faster than the oleophilic treatment. However, it did not break up the oil on the surface.

EPA determined that the plots should be sprayed with the oleophilic fertilizer twice a day and drip irrigated with the water soluble fertilizer to maximize biodegradation (USEPA, July, 1989). EPA estimates that without bioremediation, it would take at least 5 to 10 years to degrade oil from the Alaskan shoreline. With bioremediation, this period will be cut in half to 3 to 5 years (USEPA, August, 1989).

The following is a possible application of the knowledge gained from the Valdez oil spill. Petroleum spills on work pads occur frequently during project construction on Alaska's North Slope (Johnson, 1981). Bioremediation of these contaminated gravels is possible in arctic environments but careful attention must be given to the following parameters: temperature, oxygen, and nutrients. The gravel temperature can be significantly raised by utilizing Esch's (1982) method of covering oil contaminated gravels with clear 6 ml. polyethylene sheets. The oxygen can be supplied by placing perforated hoses underneath the polyethylene and irrigating the gravel with a 100 ppm hydrogen peroxide solution. The nutrient source would be a water soluble fertilizer which contains an inorganic nitrogen source (i.e., ammonium nitrate) at a ratio of 10:1:1 and a surfactant. The mixture would also be distributed through the hose system.

Figure 4 displays the theoretical layout of the system. The contaminated gravels must be placed on an impermeable liner which can withstand severe winter temperatures. The liner must be bermed and sloped slightly to drain. An abandoned gravel site could easily be converted into a containment area. The gravels would then be uniformly spread across the liner to a maximum depth of 1 foot. The gravels must be exposed to the air for at least 3 days before covering with polyethylene. This will provide time for the toxic volatile hydrocarbons to vaporize.

Leachate would be captured and recycled. The water source must come from an untreated pond. A portable swimming pool could be used to mix the nutrients and provide a reservoir for the system. The tank would be covered with a floating insulated swimming pool cover and the tank walls should be sprayed with 3 inches of polyethylene foam. All exposed pipes to the gravels must be insulated. To facilitate operations, the system should be used when the daily average temperature is above 32° F. In Prudhoe Bay, this time period is from about June 15 to September 1 (Hartman and Johnson, 1984).

Kuparuk Field Spill

On August 25, 1989, an accident on the 2-U production pad in the Kuparuk Field released about 25,000 gallons of crude oil over 1.6 acres of tundra (Fristoe, 1989). The oil

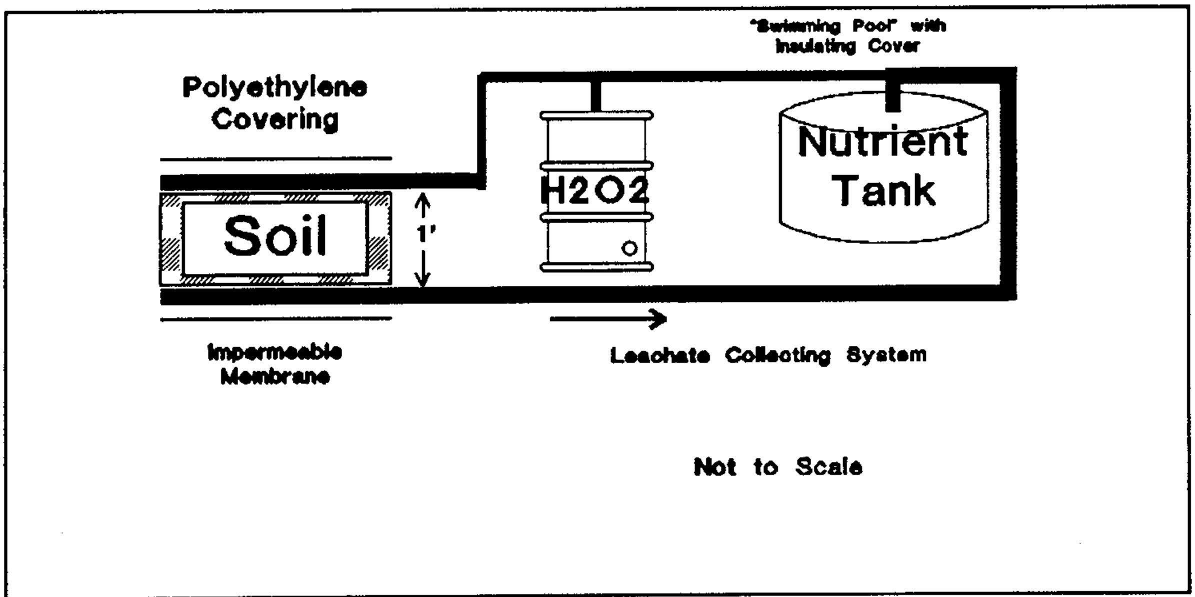

Figure 4. Arctic Bioremediation of Contaminated Gravel Pads.

penetrated the entire 18 inch depth of the active layer. This is a particularly harmful situation. The oil has penetrated the soil and resides in the general plant rooting zone. These conditions produce high vegetation kills and require many years to degrade. This is due to a decline in soil nitrogen, root destruction, and changes in microbial content (Cairns and Buikema, 1980).

Bioremediation is a viable alternative to reclaiming this site. The process requires removing the material, placing gravel to minimize thawing of excavated ground, remediating the soil, spreading the treated soil back over the artificial cover, and reseeding. The contaminated soil must be ripped out just after freeze up to minimize damage to the surrounding tundra. The excavated area must be left exposed throughout the winter, so the ground will solidly freeze. Then a gravel fill must be placed over the excavation.

The thermal resistance of saturated unfrozen tundra is about 5.6 $^\circ$F hr ft^2/BTU ft. Therefore, the total R value is 8.4 $^\circ$F hr ft^2/BTU ft. The thermal resistance of thawed, uncompacted gravel is 1.64 per foot. Thus, 5.1 feet of gravel must be placed over the excavation to match the thermal protection of 18 inches of tundra. Since the affected area is 1.6 acres, the total fill necessary is 355,450 ft^3! This is cost prohibitive and thus some permafrost melting will have to be accepted and a thinner gravel cover used. I recommend placing at least a 1 foot cover. Esch (1982) noted that clean gravels have a higher albedo and reflect a significant amount of solar radiation. Hence, there is an added thermal resistance, as well as a lower input of heat. Esch observed about a 10% reduction in thaw rates over a 2 year period when 1 foot of gravel was placed on ground that had its vegetation removed as compared to bare, stripped plots.

Mitchell, et. al. (1979) observed remediation times for plots contaminated with Prudhoe Bay crude at the rate of 0.25 and 0.50 gallons/ft^2. It took 1 and 2 years, respectively, before plants could grow again. The Kuparuk spill inputted 0.36 gallons/ft^2. Therefore, it will take at least 1.5 years of bioremediation before plant material can reestablish itself again.

The contaminated soil must be spread out over an impermeable liner to a maximum depth of 1 foot and allowed to melt and aerate. A water soluble fertilizer with a N:P:K ratio of 10:1:1 is then sprayed over the entire soil and thoroughly mixed in with a shallow plow and harrowed. The bioremediation system is essentially the same as shown in Figure 4. When the soil is remediated, it must be placed on top of the gravel, reseeded, fertilized, and tilled into the top 6 inches of the gravel pad (Johnson, 1981).

Fairbanks International Airport (FIA) Crash Fire Rescue Site Remediation

The FIA Crash Fire Rescue (CFR) Site was a training facility for airport fire fighters. The fire fighters flooded shallow pits with water and then poured a layer of #1 fuel. The fuel was ignited and training activities were performed. The fire burns until the layer of fuel is consumed. Unfortunately, unburned fuel seeped into the underlying gravels and aquifer.

Test borings showed the site is underlaid with about 3 feet of sandy gravel, followed by about 3 feet of sandy silt, and lastly, loose silty fine sand. No permafrost was discovered. Within each burn pit, the gravels possessed a moderate hydrocarbon odor. The water table was about 6 feet below the average ground level. This level is anticipated to fluctuate according to the season. Only a slight sheen of floating hydrocarbons was discovered (Shannon & Wilson, 1989).

The top 3 feet of contaminated gravel must be scraped off and land farmed on an impermeable liner. The growing season is longer in Fairbanks and summer temperatures are adequate to remediate the sandy gravels without covering with polyethylene. The gravels would be fertilized twice a month at 60 lbs/acre with 10:1:1 and tilled once a week. The gravels would be kept moist through irrigation.

Figure 5 displays the dynamic bioremediation system for the CFR site to treat the rest of the soil column and groundwater. The system would be constructed at each burn pit. An infiltration gallery would be constructed where the contaminated gravels were excavated. The gallery consists of backfilling with large rock and placing perforated pipe in the trench. The gallery will diffuse the nutrients and hydrogen peroxide throughout the soil column and water table.

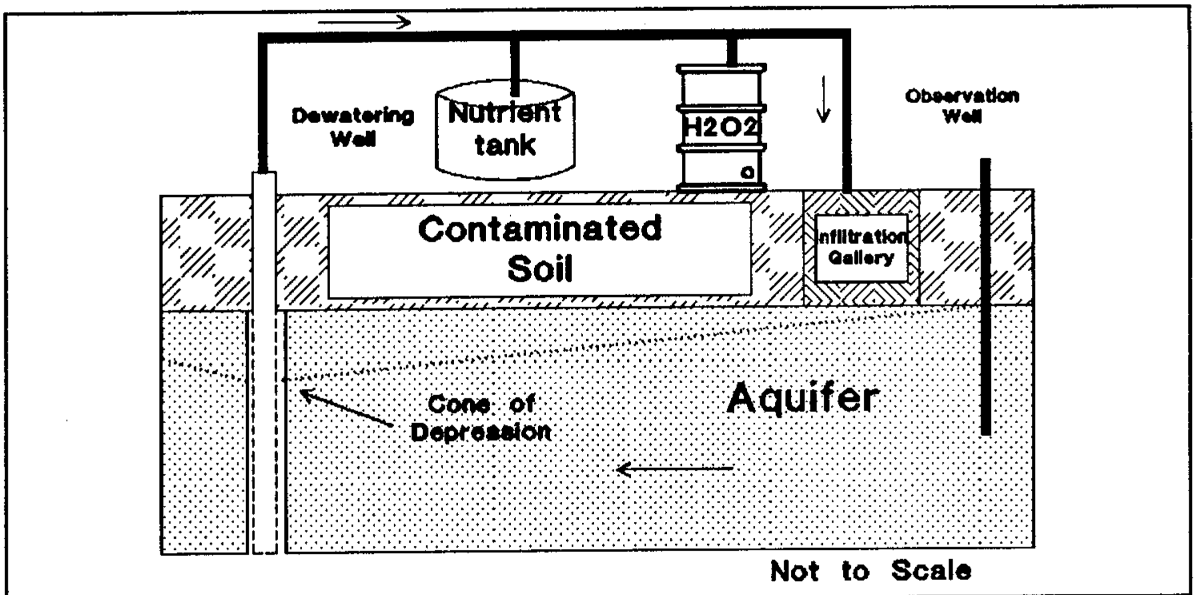

Figure 5. Bioremediation of Fairbanks International Airport Burn Site.

A six inch well casing 20 feet deep would be placed just downstream of the contamination plume. Several observation wells would be constructed around the plume boundary. The rate of water withdrawl from the six inch casing is determined when the cone of depression was detected at the observation wells. The water would be mixed with hydrogen peroxide at 100 ppm and reinjected into the soil and groundwater through the gallery. Nitrogen and phosphorous would be continuously introduced to the infiltration gallery. The fertilizer mixtuure will contain 250 mg/l of ammonia nitrate (NH_4NO_3) and 100 mg/l of potassium phosphate (K_2HPO_4). Since only a slight sheen was detected at the sampling wells, active recovery of floating free product is not cost effective and would not be pursued.

This bioremediation system would only be operated when the average daily temperatures are above 32 °F. This period is between April 21 and October 7 (Hartman and Johnson, 1984). Remediation of the soil and water to hydrocarbon levels below detection is anticipated to take two summers.

Conclusions

Hydrocarbon degrading microbes are abundant in arctic and sub-arctic soils. If the environmental parameters are enhanced, these microbes will accelerate the degradation of petroleum spills into harmless byproducts. Microbes accelerate the degradation of oil spills when temperature, oxygen, and nutrient levels are increased. Polyethylene coverings significantly raise summer soil temperatures. However, special attention must be given to oxygen transport. Hydrogen peroxide injected into soils and groundwater at 100 ppm significantly elevates oxygen levels without detrimental effects to microbes. Frequent tilling of the contaminated soil helps to oxygenate the soil and break up the water impermeable surface. Fertilizers that utilize inorganic sources of nitrogen and contain N:P:K ratios of 10:1:1 stimulate microbial growth.

The start up costs of bioremediation systems are generally more expensive than conventional pump and treat systems. However, bioremediation usually cleans up a site in less time. Therefore, overall costs are up to 80% less. While bioremediation is not a universal solution, it does warrant serious consideration when analyzing alternatives.

Bibliography

Buikema, A.L. and J. Cairns. 1984. Restoration of Habitats Impacted by Oil Spills. Buttersworth Publishers. p. 135-155.

Dinkel, D.H. 1966. Polyethylene Mulches for Sweet Corn in Northern Latitudes. In Proc. American Society for Horticulture Science. Volume 89.

Eckenfelder, W.W. 1989. In-Situ Treatment of Contaminated Soil and Rock. Technomic Publishing Co., Inc. Lancaster, PA. p. 39-48.

Esch, D.C. 1982. Permafrost Prethawing by Surface Modification. Alaska Department of Transportation and Public Facilities Statewide Research. Fairbanks, AK. 46 p.

Flathman, P.E., D.E. Jerger, and L.S. Bottomley. 1989. Remediation of Contaminated Groundwater Using Biological Techniques Groundwater Monitoring Review. Winter Edition. p. 105-119.

Frankenberger, W.T. 1988. Use of Urea as a Nitrogen Fertilizer in Bioreclamation of Petroleum Hydrocarbons in Soil. Bull. Environ. Contam. Toxicol. Vol. 40: 66-68.

Frankenberger, W.T. 1989. In Situ Bioremediation of an Underground Diesel Fuel Spill: A Case History. Environmental Management. Vol 13. No. 3. p. 325-332.

Fristoe, B. 1989. Personal Communication. Alaska Department of Environmental Conservation. Fairbanks, AK.

Hartman, C.W., and P.R. Johnson. 1984. Environmental Atlas of Alaska. University of Alaska, Fairbanks, AK. 95 p.

Johnson, L.A. 1981. Revegetation and Selected Terrain Disturbances Along the Trans Alaska Pipeline, 1975-1978. CRREL Report 81-12. 115 p.

Johnson, L.A., E.B. Sparrow, T.F. Jenkins, C.M. Collins, C.B. Davenport, and T.T. McFadden. 1980. The Fate and Effect of Crude Oil Spilled on Sub-arctic Permafrost Terrain in Interior Alaska. EPA-600/3-80-040. March, 1980. Corvallis, OR. 127 p.

Lee, M.D., J.M. Thomas, R.C. Borden, P.B. Bedient, J.T. Wilson, and C.H. Ward. 1988. Biorestoration of Aquifers Contaminated with Organic Compounds. National Center for Groundwater Research. Rice University. Houston, TX. p. 29-89.

Lindstrom, J. 1987. Enhanced Biological Destruction of a Toxic Aromatic Hydrocarbon. M.S. Thesis. University of Alaska, Fairbanks, AK. 121 p.

Mitchell, W.W., T.E. and Loynachen, J.D. McKendrick. 1979. Effects of Tillage and Fertilization on Persistence of Crude Oil Contamination in an Alaskan Soil. Journal of Environmental Quality 8: 525-532.

Nicholson, F.H. 1978. Permafrost Modification by Changing the Natural Energy Budget. Proceedings of the Third International Conference on Permafrost. Volume I. p. 61-67.

Piotrowski, M.R. 1989. Bioremediation: Testing the Waters. Civil Engineering. August, 1989. p. 51-53.

Shannon and Wilson. 1989. Final Report on Soil and Groundwater Investigations, Fairbanks International Airport Fire Training Pits. Alaska Department of Transportation and Public Facilities. Fairbanks, Alaska. 53 p.

Sparrow, E.B., C.D. Davenport, and R.C. Gordon. 1978. Response of Microorganisms to Hot Crude Oil Spills on a Sub-arctic Taiga Soil. Arctic. Volume 31: 339-347.

Sparrow, E.B. and S.D. Sparrow. 1989. Oil Spill Study - 10 Years Later. Agroborealis. Volume 21, Number 1, January, p. 5-7.

U.S. Environmental Protection Agency. July 1, 1989. Bioremediation Project Status Report. Office of Research and Development. Valdez, AK. 108 p.

U.S. Environmental Protection Agency. July 1, 1989. Addendum to Status Report. Office of Research and Development. Valdez, AK. 150 p.

U.S. Environmental Protection Agency. August, 1989. Status Report Document Number EPA/600/8-89/073. Office of Research and Development. Washington, D.C 16 p.

Wilson, S.B. and R.A. Brown. 1989. In Situ Bioreclamation: A Cost-Effective Technology to Remediate Subsurface Organic Contamination. Ground Water Contamination and Reclamation. American Water Resource Association. Winter Edition. p. 173-179.

Wilson, J.T., L.E. Leach, J. Michalowski, S. Vendegrift, and R. Callaway. 1989. In Situ Bioremediation of Spills from Underground Storage Tanks: New Approaches for Site Characterization, Project Design, and Evaluation of Performance. Project Summary. Document Number EPA/600/52-89/042. p. 1-5.

Yaniga, P.M., and W. Smith. 1985. Aquifer Restoration: In Situ Treatment and Removal of Organic and Inorganic Compounds. Groundwater Contamination and Reclamation. American Water Resource Association. August Edition. p. 149-165.