TECHNICAL MEMORANDUM
TECHNOLOGIES SCREENING FOR ADDITIONAL ALTERNATIVES
SITE INVESTIGATION REPORT ADDENDUM
MELVILLE NORTH LANDFILL
SITE INVESTIGATION (CTO172)
NETC, NEWPORT, RHODE ISLAND

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1.0 INTRODUCTION

This report presents the results of a remedial technology screening process, which is the initial phase of additional remedial technology development for the Melville North Landfill Site Investigation (SI) Addendum. This report was prepared by Brown and Root Environmental (B&R Environmental) at the request of the United States Navy, Northern Division (NORTHDIV) of the Naval Facilities Command (NAVFAC), under Contract Task Order (CTO) 172 of the Comprehensive Long-Term Environmental Action Navy (CLEAN) Contract No. N62472-90-D-1298.

The Final Melville North Landfill SI Report (B&R Environmental 1997) was submitted by the Navy to the Rhode Island Department of Environmental Management (RIDEM) on August 6, 1997. Remedial alternatives evaluated in the SI were developed from technologies that consisted of a low-permeability soil cover, limited landfill excavation and disposal, and groundwater control. These alternatives do not apply to a residential use scenario. As a result of subsequent discussions between the Navy and RIDEM, B&R Environmental was tasked to develop and evaluate additional alternatives to treat wastes in the Melville North Landfill. The candidate technologies evaluated for incorporation in the alternatives include bioremediation, soil washing, thermal desorption, and waste or soil segregation followed by off-site disposal. Chemical fixation/solidification was added to this list to provide an additional technology for inorganics. In addition, based on discussions between the Navy and B&R Environmental, it was determined that an impermeable cover and natural attenuation should also be included in the screening process. The technology screening and additional alternatives evaluations will be prepared as an addendum to the existing Final SI report.

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2.0 TECHNOLOGY SCREENING

In this phase, the candidate technologies are screened to determine their applicability based on site conditions and contaminants of concern. The screening evaluates technology application at hot spots, as well as for the entire landfill. Because the waste is partially below the water table, it is anticipated that a major component of some or all of the alternatives will be dewatering and subsequent treatment of the water. Following review and approval of this technology screening report, four alternatives will be developed, evaluated, and costed in the next phase.

The contaminants of concern are arsenic, lead, total petroleum hydrocarbon (TPH), benzo(a)pyrene and PCBs. Arsenic, lead, TPH and benzo(a)pyrene are widely distributed in the surface and shallow vadose zone soils at this site. These compounds exceed RIDEM's direct exposure criteria or GB pollutant mobility criteria.

Technology screening is based on the TPH cleanup level of 2,500 mg/kg. The TPH analyses used in the site investigation was the required EPA Method 418.1. This method provides a general measure of crude oil or petroleum product in soils but does not provide information on the composition and individual constituents of the hydrocarbon. This method is not specific to hydrocarbons; and can give false positive results for organic matter. Also the method is not a direct indicator of the risk (i.e., mobility, toxicity, and exposure to human and environmental receptors) posed by petroleum hydrocarbon contamination. Both mobility and toxicity are very dependent upon the relative amounts of individual constituents. Weathered crude oils and hydrocarbon products are typically less mobile and, thus, could pose a lower risk.

The matrix is expected to be highly heterogeneous, consisting of sand/gravel fill, metal debris, ash and cinders, steel rope and netting, and construction debris such as charred wood, lumber, glass, brick, asphalt and concrete. The volume of contaminated soil and landfill is estimated to be approximately 31,000 cubic yards. Of this volume, approximately 7,250 cubic yards is estimated to be present below the water table elevation.

PCBs were detected at levels exceeding remedial action levels only in one sample, which is expected to be a hotspot. Because of the potentially limited volume of contaminated soil expected to be present, this PCB hotspot can be most effectively addressed by excavation and off-site disposal at a suitable landfill. Therefore, this technology screening focuses on arsenic, lead, TPH and benzo(a)pyrene.

The technologies being considered to be most suitable for detailed evaluation include:

Waste segregation
Soil washing
In-situ bioremediation
Ex-situ bioremediation: bio pile/landfarming
Thermal desorption
Chemical fixation/solidification
Impermeable cap
Natural Attenuation

Evaluations of these technologies for effectiveness, implementability, and cost are presented in this section by general response action (ex-situ, in-situ, and containment).

2.1 WASTE SEGREGATION

Waste segregation consists of the separation of contaminated material by various fractions based on type of contaminant, material, and size. Ferromagnetic debris may be separated by electromagnets, tested for surface contamination, decontaminated, if necessary and recycled off site. Other debris may be separated by size classification using physical separation, vibrating bars, screens, etc., and the oversize material may be tested for surface contamination and disposed of off site at a landfill. The debris may be decontaminated with surfactant/solvent wash and water rinse operations and/or high pressure hot water/steam wash and water rinse operations. Depending on RIDEM requirements the decontaminated debris may be consolidated and backfilled on site or disposed of off site. A significant volume of wastewater from the decontamination would also require treatment/disposal off site. Either a leased mobile treatment facility or an off-site subcontractor can be employed for wastewater treatment, that must be determined based on value engineering.

Waste segregation cannot by itself remove contaminants from soil, but it can be used to reduce the contaminated soil volume. Waste segregation is most effective in this regard if the highest concentrations of contaminants in waste material are associated with the fine-grained fraction (silts and clays) of soil. The separation of the debris (drums, pipes, ropes, etc.) and other large-size media (gravel, rocks, etc.), both of which usually have relatively lower levels of contaminants adhering to their surfaces, can lead to a vast reduction in the volume of contaminated material requiring intensive treatment for removal/destruction of contaminants from soil. This technology is typically required as a pretreatment for ex-situ treatment technologies for contaminated soil for two main reasons: (1) removal of debris and other large-size media such as boulders, rocks, gravel, etc., that could damage downstream mechanical equipment used for soil treatment and (2) to reduce the total volume of contaminated soil requiring treatment/disposal.

Effectiveness

The use of waste segregation as a stand-alone technology for reduction of contaminated media volume has questionable effectiveness at this site because the contaminant concentration distribution in various particle-size fractions is difficult to assess with the available data. Based on a review of the video of the soil in the test pits at this site, it appears that visible contamination is present in various media sizes ranging from sand/silt to gravel/sand type material, therefore, a preliminary assessment indicates that separation of fine-grained soil alone may have limited effectiveness. However, if a contaminant-distribution with particle size analysis indicates to the contrary that the fine-grained fraction constitutes the majority of the soil contamination at levels exceeding remedial action levels, then this technology may be effective. However, the debris and nonrecyclable material must be disposed of on site to be viable as an alternative and to avoid being transferred to another landfill. Based on a review of a video recording of the debris present in the test pits, it appears that the metal debris (such a pipes, wires, ropes, etc.) may have a limited recycling value because of the corrosion and surface contamination present on them.

Implementability

Waste segregation is implementable. Equipment and subcontractors are available for implementation of this technology.

Cost

Cost of waste segregation can vary considerably depending on the variety of waste materials and sizes to be separated. At this site, because of the large quantity and types of waste materials present in the site, it is likely that several stages of operation would be required, thereby causing the costs to be high. Moreover, if decontamination and wastewater treatment are required prior to off-site disposal of the debris, then additional costs would be incurred.

Conclusion

Based on available information, waste segregation is unlikely to be effective as a stand alone technology for reducing the contaminated soil volume. This technology would be useful as pretreatment for removal of the debris and oversize media for the protection of mechanical equipment in soil treatment processes and is retained for further consideration.

2.2 SOIL WASHING

Soil washing uses physical/chemical processes to remove contaminants from the soil. The physical process involves waste segregation to remove debris other than large-size material from soil. Typically, soil particles (in particular fine-grained soil particles) have the highest concentrations of contaminants. Following waste segregation, soil washing uses a solvent (organic or aqueous) to extract contaminants from the soil particles. Wastewater treatment is often a major component of soil washing because the contaminants are extracted from the soil into the liquid phase.

Waste segregation is required to remove oversize material and debris such as office wastes, drums (if encountered), metallic debris, rocks, bricks, concrete rubble, glass, cinder and asphalt fragments, etc. The oversize material and debris must be decontaminated using pressurized water/steam washing and scrubbing to remove contaminants that may adhere to the surface. The decontaminated material may be disposed of on site (depending on RIDEM policy) or off site in an industrial landfill. The washing process involves mixing the soil and the solvent in reactor vessels; the walls of the vessel and the mixing mechanism could easily be damaged by oversize material and debris. Therefore, oversize material must be removed by a series of physical and screening mechanisms such as bar screens, vibrating screens, etc. Successively smaller sized material are removed in each screening stage. Eventually, soil particles (including stones, coarse sand, etc.) must be separated further by hydroclassification (sedimentation or cyclone separation) to remove the fine-grained (silt/clay, etc.) particles. Fine-grained soil particles, adhere to coarse-grained soil particles due to physical attraction and compaction. They can be most effectively removed by attrition scrubbing, followed by sedimentation and sludge formation. This sludge may then be dewatered to the extent practicable and disposed of off site as hazardous waste. This fine-grained fraction may be difficult to treat further by chemical extraction because separation from the solvent and adequate dewatering for on-site disposal is difficult to achieve. Therefore, off-site disposal may be more cost effective. The coarse-grained soil is typically less contaminated; This fraction is usually treated by chemical extraction and backfilled on site after the residual levels of contaminants are acceptable.

Chemical extraction consists of using either an acidic solution or a neutral solvent with a metal sequestering agent to remove the metal contaminants, and an organic solvent to remove the organic contaminants. It is unlikely that one type of solvent would be effective for removing both inorganic and organic contaminants. Therefore, the extraction process is likely to consist of a series of sequential processes. Following the extraction of inorganic contaminants into the solvent, further removal from the solvent would require processes such as chemical precipitation followed by solids dewatering and sludge treatment/disposal. Other processes such as ion exchange, reverse osmosis, etc., may be used to remove inorganics from the extract. The organic contaminants could be removed from the extract using a solvent or a surfactant-water solution. The extracted organics would then be separated to form a smaller volume of more highly concentrated liquid or be destroyed within the extract in one of several different ways, depending on the chemical-specific nature of the solvent and the process. Destruction processes include distillation, thermally induced phase separation, ultraviolet-light enhanced oxidation, etc. If the organic contaminants are removed from the extract as a separate phase, then they would have to be disposed of by incineration or recycling at an off-site facility. The solvent, which would be relatively free of the contaminants, would be recycled into the extraction process.

Effectiveness

Waste segregation and size-separation of soil is critical to the effectiveness of soil washing. As discussed above, contaminants are likely to be present in the highest concentrations in the fine-grained fraction of soil. Therefore, an extensive analysis of soil particle sizes would be required to determine whether physical separation alone or a combination of physical and chemical separation would be required to effectively remove the contaminants. Because arsenic and lead have distinct chemical natures (depending on their speciation), it is anticipated that their removal would require two separate extraction processes. For the same reason, it is likely that removal of arsenic and lead from the extract would require a minimum of two pH adjustment stages and two different chemical precipitating agents. Similarly, the use of an alternative process such as ion exchange would be difficult to implement. Although reverse osmosis may be effective, the compatibility of the solvent with the semi-permeable membrane used in this process would be a concern. Furthermore, removing organic contaminants would require a separate extraction process, followed by further treatment of the extract for the removal/destruction of the extracted organic contaminants. Because TPH is the main organic contaminant at this site, a water/surfactant solution may be an effective extraction process.

The success of soil washing in soil remediation is typically limited to sites where only a single contaminant is present or in the worst case when contaminants are of a similar chemical nature. Also, the probability of success is limited if fine-grained soils constitute a major fraction of the contaminated soil at the site.

Further evaluation of the effectiveness of soil washing requires bench-scale treatability studies. A particle size distribution analysis of the soil would be required to determine what fraction is most highly contaminated and whether physical separation alone will be effective. Based on available data, this technology-has questionable effectiveness at this site.

Implementability

The application of soil washing at this site is expected to be difficult to implement. The treatment system is expected to be extensive, consisting of multiple processes and the process control of the overall system is expected to be complex. Although remediation companies offer equipment and services for soil washing, because of the complexity of the process for this site, a new system would have to be designed.

The existing groundwater treatment plant at Tank Farm 5 or the temporary groundwater/ dewatering system at Building 179 have been suggested as a location to treat the wastewater from the soil washing process. The treatment plant at Tank Farm 5 is designed to remove inorganics using pH adjustment and solids removal, and to remove dissolved organic contaminants using ultraviolet (U.V.) oxidation and activated carbon adsorption. The Building 179 system is designed to remove suspended solids by filtration and dissolved organics by activated carbon adsorption.

The wastewater from the soil washing operation is expected to contain the COCs (arsenic, lead, and TPH) and a host of other inorganic and organic contaminants, and potentially oil/grease as floating free product. At this time, the design basis (process details) of the existing Tank Farm 5 groundwater treatment system is not known. However, it is suspected that at a minimum, some equipment and operational requirements would have to be modified to remove contaminants from this wastewater stream.

If an organic chelant type of solvent is used, then the recovery of the solvent would have to be addressed in a separate treatment facility. If water/surfactant is used to extract the TPH, frothing/foaming can be a significant problem. Therefore, additional synthetic anti-foaming agents may need to be added prior to wastewater treatment. Moreover, if water/surfactant is used, the mixing/agitation during wastewater treatment would have to be reduced, which might have an adverse effect on the design efficiency of the processes. The similarity and differences between the physical and chemical characteristics of normal groundwater and the expected soil-washing effluent must be evaluated during the soil-washing treatability study.

When a soil washing treatability study is performed, the soil washing effluent flow rate can be estimated and the effect of the hydraulic loading to the treatment system from the soil-washing effluent loading would have to be evaluated. Based on available information on the Tank Farm 5 treatment plant, it appears that the design hydraulic capacity of the treatment plant is less than 30 gpm. Assuming a remedial duration of 6 months for the entire volume of contaminated material, which is 31,000 cubic yards, and approximately a 2 to 1 ratio for water to soil volume, the flow rate from the soil washing treatment plant is expected to exceed the design capacity of the treatment plant. Therefore, the Tank Farm 5 system cannot be used for this purpose.

The Building 179 system has a design hydraulic capacity of 50 gpm, which is closer to the expected soil washing wastewater flow rate. However, the process capability of the system is limited. The Building 179 system does not include pH adjustment/precipitation for dissolved inorganic contaminants. Therefore, this system is unlikely to be effective.

Although soil washing requires a liquid-phase extractant, the initial waste segregation and size-separation processes would require dewatering portions of the soil/landfill material that would be excavated from depths below the water table. Prior to excavation, the water table elevation would have to be depressed using methods such as extraction wells or upgradient groundwater diversion discussed conceptually in Section 8.2.3.3 of the Site Investigation Report (B&R Environmental, August 1997). Any additional groundwater that may collect in the trench during excavation can be pumped and treated at either the Tank Farm Five wastewater treatment plant or Building 179 system. However, an estimate of the expected groundwater flow rate would have to be prepared to ensure that the design hydraulic capacity of the treatment systems is not exceeded. In addition, at a minimum, it is expected that pretreatment to remove oil/grease would be required before the groundwater can be treated at either wastewater treatment system.

A RCRA permit might be required if the contaminated soil samples do not pass the toxicity leaching characteristic procedure (TCLP) characteristics. However, this is not expected to be a concern because RIDEM (via letter to the Navy dated September 23, 1997) has expressed their cooperation with the Navy in clearing regulatory requirements for such actions.

Cost

Costs of remediation by soil washing are typically quoted on a unit cost per soil volume basis. The costs are typically high. In the application at this site, because of the complexity of the system, the costs are expected to be very high compared to bio pile treatment and thermal desorption to remove organic COCs. Potentially, the costs of soil washing to remove organic and inorganic COCs could be higher than those of bio pile treatment or thermal desorption followed by chemical fixation and solidification.

Conclusion:

Soil washing has questionable effectiveness for the media and COCs, and several cost effectiveness concerns exist. In particular, the contamination distribution in various particle sizes is not known; therefore, the effectiveness of physical separation alone is questionable, and the presence of different classes of contaminants renders the soil washing process highly complex. The main cost effectiveness concerns relate to the anticipated complexity of the soil washing process and the current lack of a suitable wastewater treatment system. Implementation of a soil washing system would be difficult. Therefore, because of effectiveness and implementability concerns, this technology is eliminated from further consideration.

2.3 CHEMICAL FIXATION/SOLIDIFICATION

This technology is used to immobilize contaminants through a variety of physical and chemical mechanisms. The process consists of mixing the contaminated medium (soil or sludge) with one or more chemical fixating agents and a pozzolanic agent. The fixating agents react with the contaminants, and depending on the chemical nature of the contaminants, are capable of reducing their solubility. The pozzolan binds with the medium and forms a solidified matrix, entrapping contaminants in the interstices of the matrix. This combination of fixation and solidification is most commonly used to minimize the leachability of contaminants and thereby their availability to migrate in the environment via rainfall infiltration followed by surface water/groundwater flow, etc.

Chemical fixating agents (such as sulfides, carbonates, etc.) may be required, depending on the contaminants of concern, the chemical speciation and concentrations of the contaminants, and the required level of reduction in leachability of the contaminants, etc. Pozzolans such as Portland cement, lime, cement kiln dust (CKD), etc., can also partially function as fixating agents because of the high pH levels of the pozzolanic mixtures. At high pH levels, several inorganics can form insoluble precipitates. However, certain amphoteric metals (such as arsenic) can form soluble compounds at high pH levels, and therefore, fixating agents must be used to immobilize them prior to solidification.

Typically chemical fixation and solidification is applicable to inorganic contaminants. In a medium contaminated with both inorganic and organic chemicals, the organic contaminants are usually entrapped without undergoing any chemical change, unlike inorganics. In such cases, the reduction in the leachability of the organic contaminants almost entirely depends on physically entrapping the contaminated particles. Sometimes, if the levels of organic contaminants (especially oil and grease) are high, the fixation of inorganics and the solidification processes can be adversely affected. In such cases, the chemical fixation and solidification process must be preceded by treatment to remove the organics.

Chemical fixation and solidification can be performed in-situ or ex-situ following excavation. The chemicals and pozzolans may be mixed in situ via augers, jets, or rotary mixing devices. The chemicals and pozzolan mixture would be supplied to the subsurface in the form of a slurry that is injected into the soil or is mixed with the soil. Ex-situ treatment would consist of the excavation of the soil, mixing of chemicals and pozzolans in a device such as a concrete mixer followed by deposition of the mixture in the excavated area. Typically solidification occurs over several weeks assuming that prolonged periods of low temperature weather do not occur.

Effectiveness

At this site, the direct contact exposure to inorganic and organic contaminants and the leachability of the organic contaminants are a concern. The organic contaminants (mainly TPH) that are present at levels exceeding groundwater protection standards would not be amenable to chemical fixation, as discussed earlier, and therefore, any reduction in their leachability would only be due to physical entrapment. Therefore, chemical fixation and solidification would only be effective in reducing direct exposure contact to the contaminants in the soil via incidental ingestion, dust inhalation, and dermal contact (to a limited extent) The TPH contaminant levels would not be reduced to levels that are protective of groundwater at the site.

Implementability

The equipment and services required for chemical fixation and solidification are available from several contractors and remediation firms. Both in-situ and ex-situ processes are available, with in-situ processes typically requiring less support equipment (such as preliminary size separation and screening) and less labor. One of the requirements for the process is ample water supply for mixing the soil with chemicals and pozzolans. However, excess water can also affect the effectiveness of the process, therefore, for in-situ treatment (because the chemicals and pozzolans are typically delivered in slurry form to the subsurface) high water table level conditions must be avoided. Since high levels of dissolved solids can interfere with most fixation processes, the use of surface water from Narragansett Bay is likely to be unacceptable. The chemical reactions associated with fixation and solidification are drastically affected by low temperature weather conditions, therefore, the remedial action must be planned to avoid winter operation.

In-situ application of this technology in a landfill where significant quantities of debris are present would be difficult. The buried debris can pose a significant impediment to the flow of the slurry and prevent adequate contact between the slurry and the soil. Moreover, since a significant portion (approximately 25 percent by volume) of the contaminated material is expected to be below the water table elevation, in-situ treatment of this material would require groundwater controls to depress the water table.

Waste segregation is required for the ex-situ treatment option to make solidification more effective and avoid equipment damage during mixing.

Although chemical fixation and solidification utilizes water, the initial waste segregation process would require dewatering the portions of the soil that would be excavated from depths below the water table. Prior to excavation and treatment of groundwater during excavation, upgradient groundwater controls would have to be addressed, as discussed earlier under soil washing.

A RCRA permit might be required if the contaminated soil samples do not pass the TCLP characteristics. However, this is not expected to be of concern because RIDEM (via letter to the Navy dated September 23, 1997) has expressed their cooperation with the Navy in clearing regulatory requirements for such actions.

These concerns can be adequately addressed. This technology is implementable.

<u>Cost</u>

Chemical fixation and solidification costs can vary from moderate to high depending on site-specific conditions. The in-situ treatment is typically less expensive than ex-situ treatment. Especially at this site where the contaminated soil and waste material are present in a heterogeneous mixture, in-situ treatment would be more cost effective than ex-situ treatment because wastes would not be generated from screening excavated material.

<u>Conclusion:</u>

Chemical fixation/solidification is expected to be effective in minimizing direct exposure to organic and inorganic contaminants of concern. Using this technology for minimizing leachability of TPH and PAHs is questionable and must be verified by treatability studies. Because of implementability concerns, in-situ chemical fixation and solidification is not considered suitable for application at this site, except in those limited areas where debris is not present in significant quantities or in areas where shallow debris can be easily removed prior to implementation. Therefore, ex-situ chemical fixation and solidification is retained for further consideration.

2.4 THERMAL DESORPTION

Thermal desorption is the use of a heating mechanism to volatilize contaminants, followed by their capture and treatment in the gas phase. Typically thermal desorption units operate at temperatures of 400 to 1000 °F, with direct heating of the medium using heated air and/or indirect heating of the soil using steam or oil in an enclosed unit. The soil is excavated and screened to remove oversize material (typically 2 inches or larger) and fed into a thermal desorption unit, which may have a rotary dryer, an auger screw, or a conveyor belt type of configuration.

The volatilized gases are removed by forced air or vacuum into an offgas treatment system. Offgas treatment is typically conducted by a baghouse to remove air-borne contaminated particles, a scrubber to remove fine contaminated particulates and acid gases, if any, and activated carbon adsorption to remove organic contaminants that have been volatilized from the soil.

Effectiveness

Thermal desorption would be effective for removing TPH and PCBs from the soil. The effectiveness of this process to remove inorganics depends on the chemical speciation of the contaminant. For example, the elemental form of lead has a boiling point of approximately 1740°C (CRC Handbook, 62 ed., 1981), which is beyond the higher limit of operation of most thermal desorption units, and would not be removed through thermal volatilization. On the other hand, organic lead such as tetraethyl lead (a constituent of leaded gasoline) which has a boiling point of approximately 200 °C (CRC Handbook, 62 ed, 1981), is more likely to be effectively removed via thermal volatilization. If present as cacodyl oxide (dimethyl arsenous oxide, a constituent of cacodylic acid, used as a weed killer) arsenic, has a boiling point of only 150 °C (CRC Handbook, 62 ed, 1981), and is very likely to be effectively removed through thermal volatilization. However, other forms of arsenic such as arsenic sulfide (used as a pigment and depilant) have boiling points higher than 600 °C, and are therefore, unlikely to be removed through thermal volatilization. Therefore, the primary mode of removing such inorganics that have higher boiling points than the operating limits of thermal desorbers would be through particulate emissions during drying (dust formation from loss of moisture from the soil) and forced air movement, which is not a reliable mechanism for contaminant removal. Therefore, the effectiveness of thermal desorption depends on the chemical speciation of the arsenic and lead, which must be determined either from historical information or by additional sampling. Treatability studies are required to determine the effectiveness of this process for removing the inorganics COCs, namely arsenic and lead.

Implementability

Thermal desorption units are available from several contractors and remediation companies. Typically the units are designed to operate at temperatures not exceeding 1000 °F. Some units can be adjusted to operate at higher temperatures, if necessary, to remove the inorganics. A clean water supply would be needed on site for the scrubber. Solid waste produced from the baghouse and scrubber would have to be disposed of at a suitable landfill off site. Spent activated carbon from the offgas treatment unit would need to be regenerated off site. Trained personnel services required for the startup and operation of the system are supplied with the units.

Waste segregation is required to ensure uniform heating of the soil particles and to minimize heat wastage to uncontaminated or less contaminated debris. Oversize debris can also damage mechanical handling equipment.

The removal of excess water from the soil is critical to the effectiveness of the thermal desorption process. Also, the initial waste segregation process would require dewatering portions of the soil that would be excavated from depths below the water table. Prior to excavation and treatment of groundwater during excavation, upgradient groundwater controls would have to be addressed, as discussed earlier under Soil Washing.

A RCRA permit might be required if the contaminated soil samples do not pass the TCLP characteristics. However, this is not expected to be of concern because RIDEM (via letter to the Navy dated September 23, 1997) has expressed their cooperation with the Navy in clearing regulatory requirements for such actions.

These concerns can be adequately addressed. This technology is implementable.

Cost

Costs for remediation by thermal desorption are quoted on a unit cost per soil volume basis. Costs including mobilization/demobilization, on-site engineering, and operating costs are averaged over the volume of soil to be treated. Typically, thermal desorption costs are moderate to high compared to other technologies. Operating costs might be on the higher end of the range for this application if higher operation temperatures are required to remove inorganics. Thermal desorption is expected to be more expensive than bio pile treatment.

Conclusion:

Thermal desorption is expected to be effective for removing the organic COCs, i.e., TPH and PAHs to achieve remedial action objectives. Its effectiveness for removing inorganic COCs is questionable, and therefore another technology may be required to address the inorganic COCs. This technology is retained for further consideration.

2.5 EX-SITU BIOREMEDIATION: BIO PILE/LANDFARMING

Bio pile treatment or land farming are ex-situ treatment technologies where the contaminated soil is excavated and biodegradation is promoted by aeration and by the addition of nutrients and moisture, as required. In the bio pile mode of treatment, the soil is heaped in piles and aeration is accomplished through pumping ambient air through pipes installed within each pile. In the land farming mode of treatment, the soil is spread out in a thin layer and aeration is accomplished by periodic turning or rototilling.

A waste segregation step is required to remove large debris for either option to make the process more effective, make the soil easier to handle, and avoid equipment damage during treatment. Screening and removal of debris would also be required if this technology is used as a component of a remedy that includes an impermeable liner to prevent rupture of the liner.

If treatability studies show that nutrient addition may be required, then aqueous chemical solutions containing appropriate elements such as nitrogen, phosphorus, potassium, etc. would be distributed by irrigation. To maintain a suitable moisture content for optimum biological activity, additional water may also be added.

Excess water infiltration would be prevented by the use of impermeable liners over the bio pile or an enclosed structure over the land farm. If volatile contaminants are also present, and the aeration is likely to cause volatilization before degradation can occur, then the off gases are contained within the liner and evacuated using vacuum extraction pipelines in a bio pile, followed by treatment. Off-gas containment and control is less efficiently performed in a land farm.

In both configurations, the soil is placed on a bermed impermeable liner or a concrete pad with a sloped base. The base is sloped to allow moisture from the aerobic respiration or excess water from irrigation to drain away from the soil into a sump and be recycled.

Effectiveness

Soil contaminated with gasoline, diesel, jet fuel, fuel oil, etc., have been successfully remediated at various sites using bio pile treatment or land farming. PAHs are also amenable to biodegradation by these methods. Half lives for degradation vary between a few months for lighter hydrocarbons (less than 10 carbon-chain length) up to over a year for heavier hydrocarbons (15 carbon-chain length and greater) such as the Number 6 fuel oil sludge that is reported to have been disposed of at this site.

This technology is not effective for removing inorganic COCs such as arsenic and lead. Since ex-situ bioremediation would not reduce the inorganic contamination, additional remediation consisting of ex-situ treatment would be required to meet the remedial objectives.

Adequate supply of air is critical to the effectiveness of this technology in either configuration. In a bio pile configuration, soil containing a high silt or clay content may have an insufficient permeability to air because of clumping, however, in such cases, mixing of inert bulking material such as wood chips, shredded cardboard, etc., would be useful in combination with screening and shredding of the soil prior to piling. In a land farm configuration, aeration is of less concern because the turning or tilling operation would not only expose different portions of the soil to the ambient air; it would also break down clumps and create a greater surface area of exposure.

Bench-scale studies that were recently performed using soil contaminated with diesel, Fuel No. 2 and some Fuel Oil No. 6 at Tank Farm 50 showed that by oxygenation, nutrient and moisture addition (performed presumably at room temperature), approximately 87 percent reduction in TPH over 97 days was achieved (Fluor Daniel GTI, December 2, 1996). It is possible that a greater percentage of TPH degradation may not have been achieved because of the limited solubility (and consequently limited bioavailability) of the higher molecular-weight fraction associated with Fuel Oil No.6. In order to increase the bioavailability of these compounds, chemical addition (solvents and/or demulsifiers) may be required to desorb the compounds from the soil particles and render the more recalcitrant fraction of TPH amenable to biological action. However, if the soil is indeed amended with chemicals to solubilize the TPH, it would be very important to ensure that the impermeable liner under the land farm or bio pile does not have any leaks.

Assuming that the TPH constituents, and the naturally occurring biological and chemical conditions of the soil at the Melville North Landfill are similar to that of Tank Farm 50, similar levels of TPH degradation can be expected in the same duration using ex-situ bioremediation. However, if the differences are significant (in particular, if the TPH in the soils at the Melville North Landfill originates mostly from higher-molecular weight compounds present in Fuel Oil No. 6), then much lower levels of TPH degradation may be expected. If preliminary field testing shows that the TPH components and chemical composition of the soil (such as biological nutrient levels) are very different from those at Tank Farm 50, then a bench-scale treatability study would be required to demonstrate its potential effectiveness.

Implementability

Adequate area to place the bio pile or land farm is available. The area requirement for bio piles is less than that of land farms because the height of soil in a bio pile is typically 5 feet or higher compared to a landfarm that is typically limited to less than 1.5 feet thick. Because VOCs are not present in significant concentrations in the soil, off-gas treatment would not be required in either configuration. Since temperatures below freezing are detrimental to biological activity, optimum temperature control is more easily accomplished in a bio pile configuration by blowing heated air during winter months, if necessary. However, in a land farm, where heat generated by aerobic respiration is typically lost quickly, freezing cannot be easily prevented unless the entire area is enclosed within a temporary shelter and equipped with climate control.

As required for the implementation of ex-situ treatment technologies, waste segregation would be required for bio pile/landfarm treatment. However, it is not as critical to the effectiveness of landfarming as compared to bio pile treatment.

All of the equipment and services required are readily available.

The removal of excess water from the soil is important to the effectiveness of biopile or landfarming processes. Also, the initial waste segregation process would require dewatering of the portions of the soil that would be excavated from depths below the water table. Prior to excavation and treatment of groundwater during excavation, upgradient groundwater controls would have to be addressed, as discussed earlier under Soil Washing.

A RCRA permit might be required if the contaminated soil samples do not pass the TCLP characteristics. However, this is not expected to be a concern because RIDEM (via letter to the Navy dated September 23, 1997) has expressed their cooperation with the Navy in clearing regulatory requirements for such actions.

These concerns can be adequately addressed. This technology is implementable.

Cost

Capital and O&M costs are typically low to moderate, compared to most ex-situ physical/chemical treatment technologies, excluding common components such as excavation/dewatering.

Conclusion:

Bio-pile/landfarming treatment is expected to be effective and implementable to remove organic contaminants of concern, namely TPH and PAHs to achieve remedial action objectives. It would require an additional step to segregate large metal debris from the soil. Because it would not be effective for removing inorganics, subsequent treatment of the soil using another technology would be required. This technology is retained for further consideration.

2.6 IN-SITU BIOREMEDIATION

In-situ bioremediation consists of using naturally occurring microorganisms to biodegrade organic contaminants within the subsurface itself, without excavation. The technology relies on the stimulation of the microorganisms to degrade the contaminants aerobically rather than anaerobically. Depending on the type of contaminants and site-specific geochemistry, nutrients containing nitrogen, phosphorus, potassium, sulfur, etc., may need to be supplied to the subsurface. In addition, adequate moisture levels must be maintained in the vadose zone soil to serve as a transport medium for biodegradation to occur. If these nutrients and moisture are naturally available at sufficient levels, then oxygen may be the only lacking stimulant for aerobic biodegradation. Assuming that adequate amounts of nutrients and moisture are naturally available at this site, in-situ bioremediation can potentially be limited to distribution of oxygen and removal of gaseous products of biodegradation.

The distribution of oxygen (as ambient air) and removal of gaseous products may be performed by injecting air within the zone of contamination and extracting gases from the periphery. Gas injection and extraction may be performed using different configurations. To address the removal of vadose zone and saturated zone organic contamination, air injection would have to be conducted under the water table, followed by extraction of vapors in the vadose zone. The extraction of vapors in the vadose zone removes gases formed by biodegradation and also replenishes oxygen from clean air from surrounding clean soil or from above the ground surface. Air sparging also transports water vapor into the vadose zone.

Removal action areas excavated in 1995 in the central and southern sections of the site were backfilled with clean stone to allow for oxygen delivery should an in-situ bioremediation be implemented in the future. Five 12-inch diameter vertical pipes were installed in these areas. No other details exist for this system.

Effectiveness

Contaminants such as fuel-related organics are most amenable to aerobic degradation. Higher molecular-weight organics, such as the Number 6 fuel oil sludge that is reported to have been disposed of at this site, is also amenable to biodegradation, albeit at a much slower rate. Bench-scale studies that were performed using soil contaminated with diesel, Fuel No. 2 and some Fuel Oil No. 6 at Tank Farm 50 showed that by oxygenation (performed presumably at room temperature) approximately 75 percent reduction in TPH over 97 days was achieved (Fluor Daniel GTI, December 2, 1996). It is likely that adequate nutrients were not present to achieve higher levels of TPH degradation. Also, as discussed under ex-situ bioremediation, a certain fraction of TPH such as the higher-molecular weight Fuel Oil No. 6 compounds may not have been bioavailable. Assuming that the TPH constituents, and the naturally occurring biological and chemical conditions of the soil at the North Melville landfill are similar to that of Tank Farm 50, similar levels of TPH degradation can be expected using air sparging/vapor extraction. However, if the differences are significant (in particular, if the TPH in the soils at the Melville North Landfill originates mostly from higher-molecular weight compounds present in Fuel Oil No. 6), then much lower levels of TPH degradation may be expected in the same duration. If preliminary field testing shows that the TPH components and chemical composition of the soil (such as biological nutrient levels) are very different from those at Tank Farm 50, then a bench-scale treatability study would be required to demonstrate its potential effectiveness at the Melville North Landfill site.

In-situ biodegradation using air sparging/vapor extraction is likely to be effective for the biodegradation of organic COCs not only in the saturated zone soil but also the vadose zone soil. However, this technology would be ineffective for the removal or treatment of inorganic COCs therefore other technologies consisting of ex-situ treatment or containment would be required to meet the remedial objectives.

The effectiveness of in-situ bioremediation would be difficult to ensure at this site because the delivery of oxygen, moisture and nutrients to the contaminated zones would be impeded by the debris present at most areas of the landfill. Because of the site-specific factors that could impede the process, pilot-scale studies are required to evaluate the effectiveness of this technology.

Implementability

The principal implementability concern for this alternative would be determination of an adequate number and location for air sparging and vapor extraction wells. Because of the heterogeneous nature of the landfill material, several areas of air sparging/vapor extraction may be required; these may need to be dedicated to the location of the contaminant zones. Although little information exists on the existing piping configuration in the central and southern stone fill areas, this system could potentially be expanded.

The gases from biodegradation of fuel oil (long-chain hydrocarbons) and PAHs are expected to be relatively innocuous compounds such as carbon dioxide and water vapor. Exhaust air monitoring may be required only during startup to ensure that there are no other toxic VOC contaminants in the soil that are also being removed by vapor extraction.

As these concerns can be adequately addressed this technology is implementable

Cost

In-situ bioremediation using air sparging/vapor extraction is relatively low in cost compared to ex-situ processes.

Conclusion

In-situ bioremediation using air sparging/vapor extraction could be implemented at the site at relatively low cost. The existing piping configuration in the central and southern stone fill areas system could be expanded. This technology could be effective in reducing the organic COCs, i.e., TPH and PAHs. The heterogeneous nature of the soils and landfill materials and the subsurface debris could hinder the adequate distribution of oxygen, moisture and nutrients throughout the site. The treatment rate for the higher-molecular weight fraction of TPH, such as the residual fuel oil sludge components is expected to be relatively slow. Pilot-scale studies would be required to verify its effectiveness. Because it would not be effective for removing inorganics, subsequent treatment or containment of the soil using another technology would be required. In-situ bioremediation is retained for further consideration.

2.7 IMPERMEABLE CAP

An impermeable cap is a multi-layered cover consisting of one or more impermeable components, a drainage layer, and an erosion control layer. A gas management layer is required if significant quantities of puterscible wastes are expected to be present in the landfill. However, at the Melville North Landfill most wastes are inert construction-debris type of materials that are not expected to be producing any significant amounts of gaseous degradation products. Therefore, the following are the conceptual cap requirements for this landfill (from the bottom layer to the top):

- Geonet gas collection layer with passive vents, as a conservative measure

- Synthetic membrane with or without a geocomposite clay layer, as additional protection
- Drainage layer (typically a 12-inch thick sand layer with a minimum permeability of 1×10^{-2} cm/s)
- Vegetative and protective layer (typically top soil or soil fill layer with a thickness of 24 inches, and a final top slope toward drainage)

Geotextile layers must be included between the vegetative/protective layer and the drainage layer to protect the drainage layer, and over the synthetic membrane to protect it. Monitoring (groundwater and surface water) must be included to ensure that the cap is effective.

Because of the shallow groundwater table at the site and the presence of a significant quantity of waste submerged in the groundwater, the impermeable cap would be most effective in minimizing migration of contaminants if groundwater controls are implemented. Groundwater controls may consist of upgradient trenches and/or sheet piling walls (as discussed under Section 8.2.3.3 of the Site Investigation Report, B&R Environmental, August 1997) to cut off the influx of groundwater, followed by rerouting of the groundwater around the perimeter of the waste to eventually drain into Narragansett Bay

Because the wastes and contaminated media would be left on site, long-term groundwater monitoring and cap maintenance would be required to ensure that the cap continues to meet remedial action objectives.

<u>Effectiveness</u>

An impermeable cap would be effective in minimizing direct contact and migration of contaminants. The cap would minimize infiltration from precipitation. Therefore, the remedial objectives of preventing direct exposure and minimizing migration of contaminants to the groundwater can be achieved by using an impermeable cap. Long-term maintenance and monitoring would be required to ensure its continued effectiveness. In the event of a 100-year flood situation, the cap is likely to be disrupted, therefore, funds must be reserved and measures to repair the cap must be planned. The use of this type of cap would be most cost effective in areas of the site where the concentrations of contaminants are high and the potential for flooding is low.

Implementability

Services and equipment for placement of an impermeable cap are available. Administrative requirements are minimal.

Cost

Costs are typically quoted on a coverage area (square foot or square yard) basis. The capital and O&M costs are moderate to high.

Conclusion

This technology is effective and implementable but the cost is high. The low-permeability soil cover developed and evaluated in the SI, would perform the same function at much lower cost. The low-permeability soil cover provides a vegetative and protective layer that serves the purpose of minimizing direct contact. It also reduces infiltration (although not to the extent of an impermeable cap) by surface grading/sloping and drainage. Therefore the impermeable cover is not retained for further consideration.

2.8 NATURAL ATTENUATION

Natural attenuation allows naturally occurring physical/chemical/biological agents to dilute, disperse or degrade the COCs. Organic compounds are most amenable to natural attenuation. Natural attenuation of chlorinated alkanes/alkenes and aromatic (fuel-related) hydrocarbons has been shown to successfully remediate soil and groundwater contamination at several sites across the nation.

Chemical and biological degradation by indigenous agents at the site can potentially convert the toxic organic compounds into less toxic forms. In particular, biodegradation is a predominant mechanism of destruction of organic contaminants under suitable conditions (nutrient availability, temperature, pH, moisture, etc.) when a viable indigenous (naturally occurring) microbial population exists at the site. Petroleum hydrocarbons are most amenable to aerobic biodegradation. For heavier-molecular weight components such as those present in Fuel Oil No. 6, other mechanisms of natural attenuation such as volatilization, dilution/dispersion, chemical oxidation, etc., would be insignificant compared to aerobic biodegradation. Therefore, oxygen is an important requirement (in addition to nutrients, temperature, suitable pH, moisture, etc.) for natural attenuation of TPH levels at this site. It is important to note that these same requirements are also important for the success of bioremediation technologies (air sparging and landfarming) where optimum conditions are artificially provided if a deficiency exists. Such an artificial augmentation would not be provided under natural attenuation.

Effectiveness

Bench-scale studies that were performed using soil contaminated with diesel, Fuel No. 2 and some Fuel Oil No. 6 at Tank Farm 50 showed that under conditions of no amendment (i.e., no oxygenation or nutrient addition) performed presumably at room temperature, approximately 59 percent reduction in TPH over 97 days was achieved (Fluor Daniel GTI, December 2, 1996). However, it must be noted that the soil was mixed with groundwater, and therefore, adequate moisture might have been present. Assuming that the TPH constituents, and the naturally occurring biological and chemical conditions of the soil at Melville North Landfill are similar to that of Tank Farm 50, similar (or somewhat lower) levels of TPH degradation can be expected under natural attenuation. In fact, lower levels of attenuation are likely because conditions under natural attenuation (in particular night time and winter temperatures) would be less ideal than those of the controlled conditions of the laboratory bench-scale study. Also, other differences (in particular, if the TPH in the soils at Melville North Landfill originates mostly from higher-molecular weight compounds present in Fuel Oil No. 6) would have significant adverse effects on TPH degradation rates. If preliminary field testing shows that the TPH components, pore-space oxygen levels, pore-space moisture levels and chemical composition of the soil (such as biological nutrient levels) are very different from those at Tank Farm 50, then a bench-scale treatability study would be required to demonstrate its potential effectiveness for the vadose zone soil. A similar field testing would be required to evaluate the potential effectiveness in the saturated zone soil.

However, the technology would not address inorganic COCs. Other technologies must be considered following natural attenuation in order to address inorganics.

Implementability

A bench-scale treatability study would be required to ensure that natural attenuation is viable at this site. If adequate removal rates are predicted by the results of the bench-scale study, then, periodic monitoring of TPH concentrations would be needed to ensure that cleanup levels are being attained in a reasonable duration. It is expected that in order to maintain an adequate moisture level in the vadose zone soil, a minimum requirement would be periodic application of water to the surface of the soil.

Cost

Costs would be very low.

Conclusion

Natural attenuation may be effective in attaining cleanup levels for TPH and is retained for further consideration.

2.9 TECHNOLOGY SCREENING SUMMARY

A summary of the technology screening for additional alternatives is presented in Table 2-1. It presents the general response action, the remedial technology and process option, and provides a brief description of each process option followed by a summary of the screening comments. Only those process options which have retained will be used to develop the additional alternatives.

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TABLE 2-1
SUMMARY OF SCREENING OF TECHNOLOGIES FOR ADDITIONAL ALTERNATIVES MELVILLE NORTH LANDFILL NETC, NEWPORT, RHODE ISLAND

General Response Action	Remedial Technology	Process Option	Description	Screening Comments
Ex-situ Treatment	Physical/ Chemical	Waste Segregation	Separation of contaminated material by various fractions based on type of contaminant, material, and size.	Retain. Useful as pretreatment for removal of the debris and oversize media and waste volume reduction.
		Soil Washing	Removal of contaminants by physical separation of the contaminated fraction or chemical extraction of COCs followed by wastewater treatment	Eliminate. Contaminant distribution data by particle size fractions required to evaluate physical separation. Effectiveness is questionable for multiple classes of contaminants. Cost-prohibitive wastewater treatment requirements.
		Chemical Fixation/ Solidification	Immobilization of contaminants within a solidified matrix	Retain. Effective for meeting remedial action objectives for inorganic COCs. Pretreatment may be required for organic COCs.
		Thermal Desorption	Removal of organic COCs by controlled heating and treatment of off gases	Retain. Effective for organic COCs. Post treatment by another process may be required for inorganic COCs.
	Biological	Bio pile / Landfarming	Excavation and enhancement of biodegradation of organic COCs by aeration/tilling	Retain. May be effective for organic COCs. Post treatment by another process required for inorganic COCs.
In-situ Treatment	Biological	Air sparging/ Vapor extraction	Enhancement of biodegradation in the subsurface by injecting air into the saturated zone and extraction of vapors in the vadose zone	Retain. May be effective for organic COCs. Pilot-scale studies required to ensure effectiveness. Post treatment by another process required for inorganic COCs.
Containment	Horizontal/ Vertical barriers	Impermeable Cap/ Groundwater Controls	Use of either a mono-layer permeable cap or a multi-layer impermeable cap to minimize infiltration and direct contact with contaminants. Reduction of waste volume in contact with groundwater.	Eliminate - high cost. Remedial objectives can be met by using lower cost low-permeability soil cover.
Natural Attenuation	Biological	Indigenous Microbial	Allowing naturally occurring microbial community to degrade the organic COCs	Retain. If shown to be effective, would be most cost effective. Further analysis of site conditions and bench-scale treatability studies are required.

3.0 CONCLUSIONS AND RECOMMENDATIONS

The technology screening indicates that the following technologies are likely to be effective and implementable at the Melville North Landfill site:

- Waste segregation
- Ex-situ chemical fixation and solidification
- Thermal desorption
- Bio pile/landfarming treatment
- In-situ bioremediation
- Natural Attenuation

The treatment technologies noted above are most effective for treating either organic or inorganic contaminants. Bio pile/landfarming treatment and thermal desorption are likely to be more effective than in-situ bioremediation for treating organic contaminants. Landfarming without excavation may also be considered if the bench-scale treatability studies shows that the addition of chemical nutrients, water and other amendments would not mobilize the contaminants to the extent that their migration in the environment would pose a problem. However, the saturated zone soil would not be addressed by this variation of landfarming. Unless bench-scale studies are performed to show otherwise, ex-situ chemical fixation and solidification is expected to be effective for inorganic contaminants only. Each alternative would also feature other technologies such as waste segregation (for ex-situ treatment) and groundwater control (to reduce the excess water for ex-situ treatment and as a method of addressing saturated zone contaminant migration) as necessary.

Given the potential for the GB TPH Leachability criteria and the TPH Direct Exposure criteria to affect the selection of site remedy, additional soil sampling and analysis to fully characterize the petroleum composition at the site may be warranted. This characterization can be used to develop risk-based analysis for the individual TPH groupings, and a risk assessment. This additional characterization and assessment can be carried out concurrent with the development of the additional alternatives.

A method developed by the Massachusetts Department of Environmental Protection (MADEP) based on Method 8015 Modified, gives a measure of the aromatic content of the hydrocarbon in each of several carbon number ranges may prove useful in assessing risk from the site-specific TPH levels for direct exposure scenarios. The approach developed by the Total Hydrocarbon Criteria Working Group (TPHCWG), a national ad hoc committee, may be used for determining the presence of the groups or fractions with similar mobility in soils and addressing cross media exposure pathways such as soil leaching to groundwater.

Because natural attenuation, if effective, can lead to a tremendous cost savings, a preliminary analysis of its potential effectiveness is recommended. A preliminary field study to evaluate the TPH constituents and the suitability of natural conditions in vadose zone and saturated zone soil to biodegradation may be performed by analyzing for the following parameters: (1) TPH analysis by GC (EPA 8015 modified with Soxhlet extraction), (2) total organic carbon (Lloyd Kahn method), (3) ammonia-nitrogen (EPA 350.3), (4) ortho-phosphate (EPA 365.3), (5) soil gas analysis for oxygen, moisture content and methane levels, and (6) groundwater analysis for dissolved oxygen and methane. This analysis will also be used for a preliminary evaluation of the potential effectiveness of other bioremediation alternatives, namely biopile/landfarming treatment and in-situ air sparging/vapor extraction.

The potential alternatives that could be developed for this site consist of combination of organics treatment with either a soil cover or chemical fixation/solidification to address inorganics. Therefore, the following alternatives are recommended for development and evaluation:

1. Natural Attenuation Alternative

a) PCB hot spot excavation with off-site disposal

b) natural attenuation

c) soil cover

2. In-situ Bioremediation (Bio Sparging/Bio Venting) Alternative

a) PCB hot spot excavation with off-site disposal excavation

b) contaminated soil bio sparging/bio venting

c) soil cover

3. Bioremediation (landfarming without excavation) Alternative

a) PCB hot spot excavation with off-site disposal

b) groundwater controls

c) contaminated soil landfarming

d) soil cover

4. Ex-situ Treatment Alternative

a) PCB hot spot excavation with off-site disposal

b) groundwater controls

c) excavation/dewatering, waste segregation, decontamination with on-site/off-site disposal of debris

d) contaminated soil thermal desorption/chemical fixation and solidification and on-site backfilling

REFERENCES

1. Fluor Daniel, GTI, 1996. Laboratory Treatability Report- Final, Tank 50, NETC, Newport, Rhode Island. Prepared for Foster Wheeler Corporation, Boston, MA by Fluor Daniel, GTI, Inc., December 2, 1996.