



U.S. Department
of Transportation

Federal Highway
Administration

29

Memorandum

Subject Report on Alternative Treatment Technologies
for Hazardous Substances/Wastes

Date

18 APR 1990

From Acting Director, Office of Environmental Policy
Washington, D.C. 20590

Reply to
Attn of

HEV-20

To Regional Federal Highway Administrators
Federal Lands Highway Program Administrator

Attached is a copy of the subject report prepared by the Environmental Analysis Division for your use and distribution.

The information in this report will be useful to the Federal Highway Administration and the State highway agencies' (SHAs) environmental, right-of-way, design, geotech, and construction/maintenance specialists. This is a compendium of the primary treatment technologies currently used to remediate hazardous waste sites. Many of the technologies are being routinely used while some are innovative and have only recently been tested and proven effective and practical in the cleanup of hazardous substances/wastes. All are potential cleanup technologies to consider when dealing with site remediations. Before selecting and implementing any cleanup measures, the type and extent of contamination must be known (at least a good estimate), site-specific conditions analyzed, and cleanup measures coordinated with appropriate regulatory agencies.

We intend to update and reissue this report periodically to keep it current and applicable to SHAs' operations. Suggested revisions from the field are most welcome whenever new information becomes available. For further information or comments, please contact Messrs. Robert Falkenstein or Harry Bridges at (202) 366-2070/72.

Kevin E. Heanus

Attachment

ALTERNATIVE TREATMENT TECHNOLOGIES FOR HAZARDOUS SUBSTANCES/WASTES

This document summarizes the primary measures used to treat (i.e., destroy or reduce the mobility, toxicity, and volume of) hazardous substances/wastes that may be found during the development and construction of highway projects. It is intended as a useful reference to State highway agencies (SHAs) in selecting treatment alternatives, and will be updated periodically as these treatment technologies change. SHAs are encouraged to update the document based on their experiences with hazardous wastes, and to provide feedback on suggested revisions to Bob Falkenstein or Harry Bridges (202-366-2070/72).

1. Containment In-place or Off-Site

Applicable laws (CERCLA, SARA, RCRA)[§] and recent regulatory actions of USEPA and State regulatory agencies have stressed the need to treat hazardous substances/wastes to destroy the material or achieve permanent reduction of its toxicity, mobility, and volume. As a result, simple containment of the source/contaminant plume alone is usually no longer considered acceptable for final control and treatment. However, the nature of the site, the contamination, or lack of other available treatment alternatives may still warrant control by on-site or off-site containment. On-site containment may include in-place (in-situ) containment or excavation of the waste (ex-situ) with placement and containment nearby in the same area. Off-site containment entails removal to an approved off-site location. Containment measures may include control of the material by capping/enclosing using low-permeability soils (e.g., bentonite), compatible fabrics or liners, sheet piles, slurry walls, grout curtains, etc. Often included with containment is the requirement to first stabilize the material and to limit water access (i.e., runoff, run-on, groundwater) into the material so as to prevent erosion or saturation and leaching. Such controls may include vegetative cover and other erosion control measures, interceptor ditches, drainage relocations, trenches, subsurface drains, groundwater diversion wells (e.g., pump and treat systems), etc. Depending on the nature of the contamination and site conditions, it may also be possible to contain low hazard material within a specially designed vault or an "embankment cell" in the right-of-way or within the road structure itself (e.g., stabilized base or pavement).

Off-site containment entails excavation of the material and removal to a containment site where control measures as described above are utilized. The best example of off-site containment is disposal in a permitted secure hazardous waste landfill where extensive controls are integral long-term features. Example costs for off-site disposal may be .95 to \$1/ton/mile for transport and up to \$325/ton for disposal at a permitted treatment, storage, disposal facility. On-site and off-site containment measures must be coordinated with and approved by the appropriate regulatory agencies.

[§]Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Superfund Amendments and Reauthorization Act (SARA), Resource Conservation and Recovery Act (RCRA).

Use of on-site or off-site containment can often be carried out with minimum disruption of project schedules and such containment has been very cost-effective in the past, especially if no structural control measures are necessary. However, containment options are being increasingly limited and it is expected that in the future, containment will be even less practicable, less acceptable, and more costly due to:

- increasing shortage of acceptable hazardous waste landfill capacity;
- RCRA-imposed ban on land disposal of hazardous wastes unless pre-treated (see Federal Registers of 11/7/86, 7/8/87, 8/17/88, 11/22/89 for banned wastes and required pretreatment measures);
- SARA-imposed preference/requirement for treatment measures achieving destruction or permanent reduction of toxicity, mobility, and volume;
- continuing liability incurred for the material at any disposal site as long as the material is hazardous to health or the environment;
- frequent requirement for continuing post-disposal monitoring and followup reporting on the effectiveness of control/containment.

As a result, SHAs can expect to be faced with the need to evaluate, select, and apply more rigorous treatment measures such as described below.

2. Treatment Measures for Soil/Sludge/Sediments Contaminated with:

Heavy* Organics/Pesticides (non-volatiles and some semi-volatiles)

(*refers to high molecular weight)

- C1-7 Thermal Treatment (ex-situ)
- C6 Vitrification (in-situ)
- A8 Stabilization/Solidification (in-situ/ex-situ)
- B1-8 Chemical Treatment (in-situ/ex-situ)
- A1 Physical Pre-Treatment (ex-situ)
- A2 Soil Flushing (in-situ)
- A3 Soil Washing (ex-situ)
- D1-4 Biological Treatment (in-situ/ex-situ)

(Index letters/numbers refer to process descriptions in appendices)

Light Organics (volatiles and some semi-volatiles)

- C1-7 Thermal Treatment (ex-situ)
- C6 Vitrification (in-situ)
- B1-8 Chemical Treatment (in-situ/ex-situ)
- A1 Physical Pre-Treatment (ex-situ)

- A2 Soil Flushing (in-situ)
- A3 Soil Washing (ex-situ)
- A4 Vacuum Extraction (in-situ/ex-situ)
- D1-4 Biological Treatment (in-situ/ex-situ)

Metals/Other Inorganics

- A8 Stabilization/Solidification (in-situ/ex-situ)
- C6 Vitrification (in-situ)
- B1-8 Chemical Treatment (in-situ/ex-situ)
- A1 Physical Pre-Treatment (ex-situ)
- A2 Soil Flushing (in-situ)
- A3 Soil Washing (ex-situ)

3. Treatment Measures for Surface Water/Ground Water/Leachate/Process Water with:

Heavy Organics/Pesticides (non-volatiles and some semi-volatiles)

- C3-5 Thermal Treatment (ex-situ)
- B1-8 Chemical Treatment (in-situ/ex-situ)
- A1 Physical Pre-Treatment (ex-situ)
- D1-4 Biological Treatment (in-situ/ex-situ)
- A7 Carbon Adsorption (ex-situ)
- A6 Steam Stripping (ex-situ)

Light Organics (volatiles and some semi-volatiles)

- C3-5 Thermal Treatment (ex-situ)
- B1-8 Chemical Treatment (in-situ/ex-situ)
- A1 Physical Pre-Treatment (ex-situ)
- D1-4 Biological Treatment (in-situ/ex-situ)
- A4 Vacuum Extraction (in-situ/ex-situ)
- A7 Carbon Adsorption (ex-situ)
- A6 Steam Stripping (ex-situ)
- A5 Air Stripping (ex-situ)

Metals/Other Inorganics

- B1-8 Chemical Treatment (in-situ/ex-situ)
- A1 Physical Pre-Treatment (ex-situ)
- A7 Carbon Adsorption

Appendix A - Physical Treatment Processes

A1. Physical Pretreatment - includes sedimentation, filtration, evaporation, distillation, oil-water separation, centrifugation, chemical extraction, liquid extraction, reverse osmosis. These are standard solid-liquid or liquid-liquid separation techniques, usually applied ex-situ, which can be used to separate or concentrate contaminants from the media they are contained in. Additional treatment of the separated material is usually required. See references for additional information on applications and limitations. For example, a new technology called Basic Extraction Sludge Treatment (BEST) incorporates several of these physical treatments to treat oily sludges with high molecular weight organic contaminants. The waste is saturated with water, adjusted to pH of 10, a solvent (usually triethylamine - TEA) is added to extract the organics, the mixture is centrifuged and the resulting solids are disposed of. The liquid fraction is heated and decanted to separate the solvent with contaminated oil from water. The solvent/oil are further treated (e.g., air stripped) to recover the solvent. The unit processes about 100 tons/day and costs about \$175/cu. yd of sludge. Point-of-contact (POC) for BEST is Edward Bates, USEPA Cincinnati, 513-569-7774. Individual physical pre-treatments are generally low to moderate in cost. Also, commercial sources.

(Unless specific cost information is provided, general cost estimate categories are: low - \$10 to \$100/cu. yd.; moderate - \$100 to \$200/cu. yd.; high - \$200 to \$500/cu. yd.)

A2. Soil Flushing - is an in-situ extraction process for organic and inorganic contaminants in soil, accomplished by passing a non-toxic flushing/extracting solvent (specific to the contaminant (s) to be removed) through the soil. The solvent is applied by surface spraying/infiltration or injection followed by extraction from wells, treatment on the surface to remove contaminants, and reinjection of the solvent. The solvents may be water, with or without surfactants, acids or bases, chelating agents to dissolve metals, oxidizing agents, or reducing agents. Migration of solvent/contaminants into groundwater must be prevented with proper control measures. High concentrations of organic matter, high clay content, and complex mixed wastes interfere with effective flushing. Treatment rate is slow and flushing may result in large volumes of solvent containing low concentrations of contaminants. Channeling and uneven treatment may result from subsurface soil discontinuities. Costs are moderate to high, estimated at \$150 - \$400/cu yd of soil flushed. POC is Richard Trauer, USEPA Edison NJ, 201-321-6677.

A3. Soil Washing - is similar to flushing but is applied to excavated soil (ex-situ). Contaminated soil is screened, washed in scrubbers, dewatered, and backfilled or reused for other purposes. Treatment rate is estimated at 4 to 18 cu yds/hour. Estimated cost is \$150 - 200/cu yd.

A4. Vacuum Extraction - is an in-situ or ex-situ treatment that removes volatile organic contaminants (e.g., gasoline components, cleaning solvents, etc.) by applying a vacuum to the contaminated soil, then collecting and treating the contaminated air. Vacuum extraction can achieve more than 95% removal of volatile contaminants. If in-situ, the vacuum is applied by high-vacuum pumps to vertical or horizontal extraction wells (sealed at the surface) placed in the contaminated soil to draw out volatiles along with interstitial air. Fresh replacement air is drawn down from the surface or injected. Injected air can be heated to enhance volatilization. A new variation injects steam into the soil to enhance volatilization. Removed volatiles are processed through a liquid separator and treated by activated carbon adsorption, catalytic converter, incineration (afterburner), or dispersed to the atmosphere (if permitted). Any separated liquid is also treated to remove contaminants by aeration (e.g., air stripping) or other treatment. In areas with high groundwater, the volatiles and contaminated groundwater are removed together and treated. Dense impermeable soils limit the effectiveness and application of vacuum extraction. Monitoring wells may be needed to confirm that the treatment is obtaining uniform and adequate results. Vacuum extraction is now being frequently used and is offered by numerous commercial vendors. Cost is low to moderate, estimated at \$50 - \$200/ton of soil (\$40,000 - \$80,000/acre) and decreasing. However, treatment rate is slow. An example extraction rate is 600 Lbs of contaminant per month. It is particularly useful where surface structures or other conditions restrict excavation and ex-situ treatment.

Applied as an ex-situ technique, batches of contaminated soil are spread over a liner and a grid of vacuum-connected pipes which draw off the contaminants. POC is Paul De Perien, USEPA Cincinnati, 513-569-7797, and Mary Stinson, USEPA Edison NJ, 201-321-6683.

A5. Air Stripping - is an ex-situ treatment to remove volatile organics from water by separation/transfer to the air. Transfer is usually accomplished by pumping and distributing the leachate into the top of a "packed tower" filled with a high-surface area porous material (e.g., layers of plastic balls) across which is blown a countercurrent of clean air. Leachate drops down through the tower as clean air strips the volatiles. Air with contaminants is discharged at the top to the atmosphere (if permitted) or further treated with carbon adsorption, catalytic converter, or incinerated (afterburner). The concentration of contaminant should not exceed approximately 100 ppm. Air stripping is a widely used technique. Costs are moderate (\$5 to \$25 per 1000 gals treated). POC: Commercial sources.

(NOTE: The term "air stripping" is sometimes used to refer to the injection of heated or unheated air into soil to volatilize contaminants which are then removed by vacuum extraction.)

A6. Steam Stripping - is applied in the same manner as air stripping, except steam is used in the packed tower countercurrent to enhance volatilization of contaminants in the leachate. Discharged steam with

contaminants is collected, condensed, and treated further. Contaminant concentrations may range from 100 ppm up to 10% of the solution. Costs are moderate to high. POC: Commercial sources.

- A7. Carbon Adsorption - is an ex-situ treatment to remove dissolved volatile and some semi-volatile organic contaminants (also PCBs, pesticides) from leachate or air by passing the contaminated fluid over granular activated carbon (processed to maximize the number of adsorptive surfaces of the carbon atoms) arrayed inside cylindrical containers. The carbon has a strong but limited adsorption capacity. Spent carbon with contaminants must be periodically regenerated or disposed of. Carbon adsorption is not applicable to heavily contaminated media due to this limited adsorption capacity and cost of regeneration. Carbon adsorption is widely used to remove light to moderate contamination of leachate or air, and is often used as a polishing step after other treatment. Generally, contaminant concentrations should be less than 10,000 ppm; suspended solids should be less than 50 ppm; and dissolved organics less than 10 ppm. Treatment costs are moderate to high. POC: Commercial sources.
- A8. Stabilization/Solidification - is a category of mainly ex-situ techniques to reduce the mobility and reactivity of inorganic and non-volatile organic contaminants by fixing the material chemically (stabilization) and binding the material into a solid mass (solidification) with low solubility and low permeability to prevent leaching. The process entails a designed mixing of the contaminated material with appropriate parts of stabilization/binding agent(s) which cure to a solid mass which can then be disposed of (usually disposal is still under controlled conditions). Many of the stabilization/solidification agents are proprietary, and may be cement- or silicate-based pozzolan (with lime or gypsum), asphalt-based (thermoplastic), or organic polymers. Cement-based pozzolanic processes have been widely used. High levels of fines, organic material (particularly volatiles), borates, sulfates, and arsenates can interfere with curing and solidification. Costs are low to moderate and estimated at \$60 - \$200 per ton of contaminated material and decreasing. In-situ techniques are being tested. POC is Carlton Wiles/Ed Barth, USEPA Cincinnati, 513-569-7795/7669. Also, commercial sources.

Appendix B - Chemical Treatment Processes

- B1. Neutralization - or pH adjustment is an ex-situ (some limited in-situ) process that entails the addition of acidic or basic reagents to raise or lower the pH of liquids, soil, sludge, slurry. The purpose is to minimize corrosion potential, to improve the performance of pH-sensitive treatment processes, or to increase/decrease the solubility or reactivity of metals or other chemicals or compounds. Typical costs are low to moderate. POC: Commercial sources or publically-owned sewage treatment works (POTWs).
- B2. Precipitation/Flocculation/Sedimentation (also considered physical treatments) involve the ex-situ addition of appropriate non-toxic chemical precipitating or flocculating agents to contaminated liquids to cause target contaminants to settle out of solution as insoluble precipitants/flocculants. These can then be concentrated and removed by sedimentation, filtration, drying, and disposal. Typical costs are low to moderate. POC: Commercial sources or POTWs.
- B3. Oxidation/Reduction - involves the ex-situ (some in-situ) addition of appropriate non-toxic oxidation or reducing agents (and often catalysts) to contaminated liquids or soil which cause the chemical change (oxidation or reduction) of the contaminant to a more acceptable form (i.e., less toxic, less complex, more soluble, less mobile, more separable, etc.) and more amenable to further treatment/disposal. Example of oxidizing agents are oxygen, ozone, chlorine, hydrogen peroxide solution, etc. Reducing agents include iron, aluminum, zinc, and sodium compounds. The pH level is an important process control. POC: Commercial sources and POTW.
- B4. Glycolate Dechlorination - is an ex-situ treatment used to dechlorinate and thereby de-toxify several types of chlorinated organic compounds (e.g., dioxins, PCBs, chlorobenzenes). A process developed by General Electric involves mixing and heating contaminated soil (slurry) with potassium polyethylene glycolate (KPEG) reagent (other alkali metals are also used). Chemical reaction time is usually rapid (30 min to 5 hrs). Decontaminated soil is washed and excess reagent recycled. Products of dechlorination (e.g., phenol) may require further treatment. Cost is moderate to high, estimated at \$100 - \$300/ton. POC: Charles Rogers, USEPA, Cincinnati, 513-569-7757.
- B5. Hydrolysis - is the ex-situ process of degrading a contaminant by exposing it to chemical reagents (e.g., acids), light (e.g., ultraviolet radiation of transparent liquids), or enzymes to break molecular bonds of the contaminant to yield less toxic or non-toxic compounds. Widely used with low to moderate cost. POC: Commercial sources and POTW.

- B6. Chelation - involves the addition of a chelating agent which can form bonds (ligands) with targeted metal ions in solution, keeping the metal ions from reacting with other compounds to precipitate out of solution. Chelation acts to keep metals in solution to enhance separation and further treatment (e.g., as an aid to soil flushing). Widely used, estimated low to moderate cost. POC: Commercial sources and POTW.
- B7. Ion Exchange - is an ex-situ process primarily to remove toxic metal ions from solution in order to recover the concentrated metal for further treatment, recycling, or disposal. The process involves passing the contaminated solution through a specific resin with weakly held ions that replace the targeted metal ions. The resin has a limited capacity and must be replaced or regenerated when spent. pH and suspended solids concentration are important process controls. Highly concentrated wastes (greater than 25,000 ppm) should be separated by other measures. Costs are moderate to high. POC: Commercial sources and POTW.
- B8. "In-situ Detoxifier" - is a new technology which incorporates a variety of specifically designed physical and chemical (some biological) processes to treat in-situ wastes. The unit includes a "process tower" which is a drilling mechanism as well as a treatment agent dispensing and mixing mechanism, capable of penetrating to depths of 25 feet or more. The tower consists of two overlapping drills/mixers on hollow-core stems which allow the continuous injection/mixing of remediation agents (e.g., chemical treatment, biotreatment, stabilization/solidification, air or steam for stripping) with the contaminated soil. A shroud on the tower covers the surface to capture off-gas and vapors for further treatment. The tower also includes monitoring equipment to monitor, control, and adjust the treatment process. Treatment proceeds sequentially from vertical block to block. Cost is moderate to high, \$100 to \$400 per ton of contaminated soil. POC: Commercial sources. Paul dePercin, USEPA, Cincinnati, 513-569-7797 or Mary Stinson, USEPA, Edison NJ, 201-321-6683.

Appendix C - Thermal Treatment Processes

- C1. Fluidized Bed Incineration - destroys organic contaminants (mainly slurries and sludges) in a refractory-lined incinerator with surplus oxygen and with a moving bed of inert, granular material (sand). Combustion air is blown through the bed "fluidizing" the bed material and the contaminants. This process operates at lower temperatures (1400 F - 1800 F) than other incinerators due to the combustion efficiency of the turbulent mix of waste, fuel, oxygen, and hot bed material. Combustion residence time is usually in minutes. The incineration produces decontaminated ash and combustion gas which is discharged to the atmosphere (if permitted) or treated by a wet scrubber and baghouse to remove acid gas and particulates. This type of incineration is now widely used. Important variables to control are waste particle size, density, moisture content, heat content, ash content, as well as presence of metals and chlorinated- or sulfonated- compounds. Costs are moderate to high and can range from \$200 to \$500/ton. POC: Don Oberacher, USEPA, Cincinnati, 513-569-7510, Joe McSorley, USEPA Research Triangle Park, 919-541-2920. Also, commercial sources.

(Note: Circulating Bed Combustor is a more efficient variation using higher air velocity causing more turbulence and allowing lower incinerating temperatures (1500 - 1600 F)).

- C2. Infrared Incineration - destroys organic contaminants using infrared radiation from silicon-carbide heating elements in the absence of oxygen (pyrolysis) which allows operating temperatures as low as 800 F. Screened waste is transported through the incinerator on a conveyor belt. Some infrared incinerators burn with oxygen at higher temperatures. Residence time may be several minutes to several hours depending on the material being incinerated. Ash is discharged at the end of the conveyor, flue gas is passed through a secondary combustion chamber and through an air pollution control system. Control variables are similar to fluidized bed incineration. Cost is moderate to high, estimated at \$180 to \$500/ton. POC: Howard Wall, USEPA, Cincinnati, 513-569-7691. Also, commercial sources.

(Note: Other pyrolytic incinerators burn without oxygen and may utilize two chambers, one where organic material is incinerated at 1000 - 1400 F and a secondary chamber which burns off-gases from the first chamber at about 2200 F).

- C3. Rotary Kiln Incineration - destroys organic contaminants (solids, liquids, gases, or mixtures) in a slowly rotating, inclined, refractory-lined incinerator supplied with air. Wastes and auxiliary fuel are injected into the high end of the kiln and pass down the vessel through the combustion zone as it rotates. The rotation creates turbulence which enhances combustion. Operating temperatures range from 1500 to 3000 F. Residence time may be several minutes to several hours. Ash is discharged at the lower end, and flue gas is passed through a secondary combustion chamber and through an air pollution control system. Control

variables are similar to those for fluidized bed. Rotary kilns are the most widely used thermal treatment technology. Costs are moderate to high, estimated at \$200 for \$500/ton and decreasing. Capacity is about 6 tons/hour (portable units have less capacity). POC: Frank Freestone, USEPA, Edison NJ, 201-321-6632, and commercial sources.

- C4. Liquid Injection Incineration - burn a wide variety of liquid organic wastes injected through specially designed atomizer nozzles. Operating temperatures range from 1200 - 1300 F. Combustion residence time is usually in seconds. Some physical pretreatment and addition of auxiliary fuel may be needed to achieve satisfactory waste flow and combustion. Off-gases are treated for acids and particulates. Cost is moderate to high. POC: Commercial sources.
- C5. Wet Air Oxidation - uses elevated temperature and pressure to oxidize dissolved and finely divided solid organic contaminants in liquids. This process is well-suited to treat liquid organic wastes that are too dilute (i.e., less than 5% organic) to incinerate economically. Products of oxidation remain in solution or are released as off-gas which may require additional treatment. Highly chlorinated compounds cannot be efficiently oxidized by this method. Cost is moderate to high. POC: Commercial sources.
- C6. Vitrification - (primarily in-situ) destroys organic contaminants in the soil and immobilizes the waste in a glassy, solid matrix resistant to leaching. High temperatures are achieved with large electrodes (usually 4) inserted into the soil to the desired treatment depth. A conductive mixture of graphite and glass frit is placed on the surface between the electrodes to conduct current and begin the melting process. Contaminated soils are heated and melted at 2000 - 3600 F which volatilizes most organic contaminants. The melted soil continues to conduct the electric circuit after the graphite has been oxidized. As the molten mass extends downward, it incorporates non-volatile contaminants and destroys volatiles by pyrolysis. When the current ceases, the molten material cools and solidifies to a glass - like mass. A hood is kept over the area to draw off and treat gases rising from the process. The collapsed area above the melt is backfilled after cooling. Vitrification proceeds sequentially (block by block) until the contaminated area is treated. Cost is moderate to high, estimated at \$100 to \$400/ton. For processing a single block to a depth of 50 feet, treatment time can average 300 - 400 hours (3 to 5 tons/hour) and produces a vitrified mass greater than 1000 tons. POC: Steve James, USEPA, Cincinnati, 513-569-7877.
- C7. Low Temperature Thermal Stripping - removes volatile organic contaminants and some lighter semi-volatiles from soil by heating the contaminated soil in a rotary drum dryer or pug mill system at 550 F or less. An induced airflow conveys the off-gas with contaminants through additional treatment such as carbon adsorption, combustion afterburner, catalytic

converter, etc. Metals in the soil are not removed by this process and volatile metals may become more volatile as a result of heating. Cost is moderate. POC: Robert Thurnau, USEPA Cincinnati, 513-569-7692.

(This technology is an example of "thermal desorption," the use of low to moderate heat to enhance the volatility or facilitate the release of contaminants from the media (soil, sludge, water).)

Appendix D - Biological Treatment Processes

- D1. Landfarming - involves the excavation (ex-situ) and distribution of soil with organic wastes on the land surface with the addition, as needed, of nutrients, water, pH controls, and occasionally supplemental organic matter (as an additional energy source) to achieve biodegradation of the waste. Periodic tilling may be necessary to aerate and redistribute the waste, nutrients, and microorganisms. Some volatilization of contaminants will also occur, requiring attention to sensitive downwind receptors and coordination with local air quality regulatory agencies. If volatile emissions are a concern, the entire system can be covered with a gas-tight membrane and emissions collected for further treatment. Contaminated soil can also be placed on an impermeable liner with a granular leachate collection system for further treatment. Contaminants cannot be toxic to the degrading microorganisms and contaminant concentrations should be less than 10,000 ppm. Costs vary widely according to excavation costs, acquisition cost for sufficient land to spread the waste, frequency of tilling. Costs are estimated at low to moderate, \$15 to \$200/ton. Treatment time is usually long (weeks to months). POC: Ron Lewis or Eugene Harris, USEPA, Cincinnati, 513-569-7856/7862.
- D2. Biostimulation (also Bioenhancement) - is the in-situ process of adding nutrients, water, and an oxygen source (e.g., hydrogen peroxide injection or air injection/vacuum drag) to stimulate naturally occurring soil and groundwater microorganisms to degrade organic wastes in the soil and groundwater. The required products are delivered to the subsurface by upgradient injection wells or sprayed on an infiltration field. Extraction wells downgradient remove and recirculate treated groundwater and allow for additional treatment measures to be applied on the surface prior to reinjection. Indigenous microorganisms can generally be expected to degrade a wide variety of organic compounds given sufficient nutrients, oxygen, and time. Biodegradation is a relatively slow but economical process. Some in-situ processes can be completed in as little as 3 months. Process costs for in-situ biological treatment have been estimated at 30 - 60% of treatment costs by carbon adsorption or vacuum extraction. Biodegradation of a 300 gallon gasoline leak from a sand/gravel aquifer over 6 to 9 months is estimated to cost from \$72,000 to \$123,000. Cleanup of 2000 gallons of diesel fuel from fractured bedrock over 9 to 12 months is estimated to cost \$164,000 to \$257,000. Biodegradation of \$10,000 gallons of jet fuel in fine gravel over 14 to 18 months is estimated to cost \$411,000 to \$616,000. General cost of biodegradation is estimated at \$50 to \$125/cu. yd. POC: John Wilson/Robert Kerr, USEPA Ada, OK, 405-332-8800.
- D3. Bioaugmentation - involves the in-situ biodegradation of organic wastes by adding nutrients, water, and oxygen source, and specific microorganisms selected to degrade the targeted waste (microorganisms may be specially adapted or genetically manipulated). Costs are similar to biostimulation but with additional cost for development, culturing, seeding of specific microorganisms. POC: same as biostimulation.

D4. Waste Water Treatment - involves the ex-situ biological degradation of organic contaminants in surface vessels similar to standard sewage sludge treatment processes (POTW). Nutrients, oxygen, and microorganisms are added and continuously mixed in batch reactors until degradation is complete. The sludge is physically/chemically treated to separate solids from liquid; the solids are disposed of; and the liquid is reinjected or applied to an infiltration field. Air emissions and residual contaminants are monitored and may require additional treatment. Examples of waste water treatment technologies include:

- activated sludge treatment
- sequencing batch reactor
- rotating biological contractor
- trickling filter

Costs are low to moderate. POC: Commercial sources and POTW.

References

- California Department of Transportation. 1989. Alternative Technologies for Treatment of Hazardous Waste. CALTRANS Hazardous Waste Management Group, Sacramento.
- ENSR Corp./Sidley and Austin. 1989. Superfund Handbook: A Guide to Managing Responses to Toxic Releases Under Superfund (Third Edition). ENSR Corp, Acton, MA. Sidley and Austin, Chicago.
- Ghassemi, M. 1988. In-situ Technologies for Remediation of Contaminated Sites. URS Consultants, Long Beach, CA.
- Federal Highway Administration. 1990. Hazardous Waste: Impacts on Highway Project Development. NHI Course Manual. URS Consultants, Cleveland, OH.
- U.S. Environmental Protection Agency. 1987. A Compendium of Technologies used in the Treatment of Hazardous Wastes. EPA/625/8-87/014.
- U.S. Environmental Protection Agency. 1987. Underground Storage Tank Corrective Action Technologies. EPA/625/6-87-015.
- U.S. Environmental Protection Agency. 1988. Cleanup of Releases from Petroleum USTs: Selected Technologies. EPA/530/UST-88/001.
- U.S. Environmental Protection Agency. 1988. Technology Screening Guide for Treatment of CERCLA Soils and Sludges. EPA/540/2-88/004.