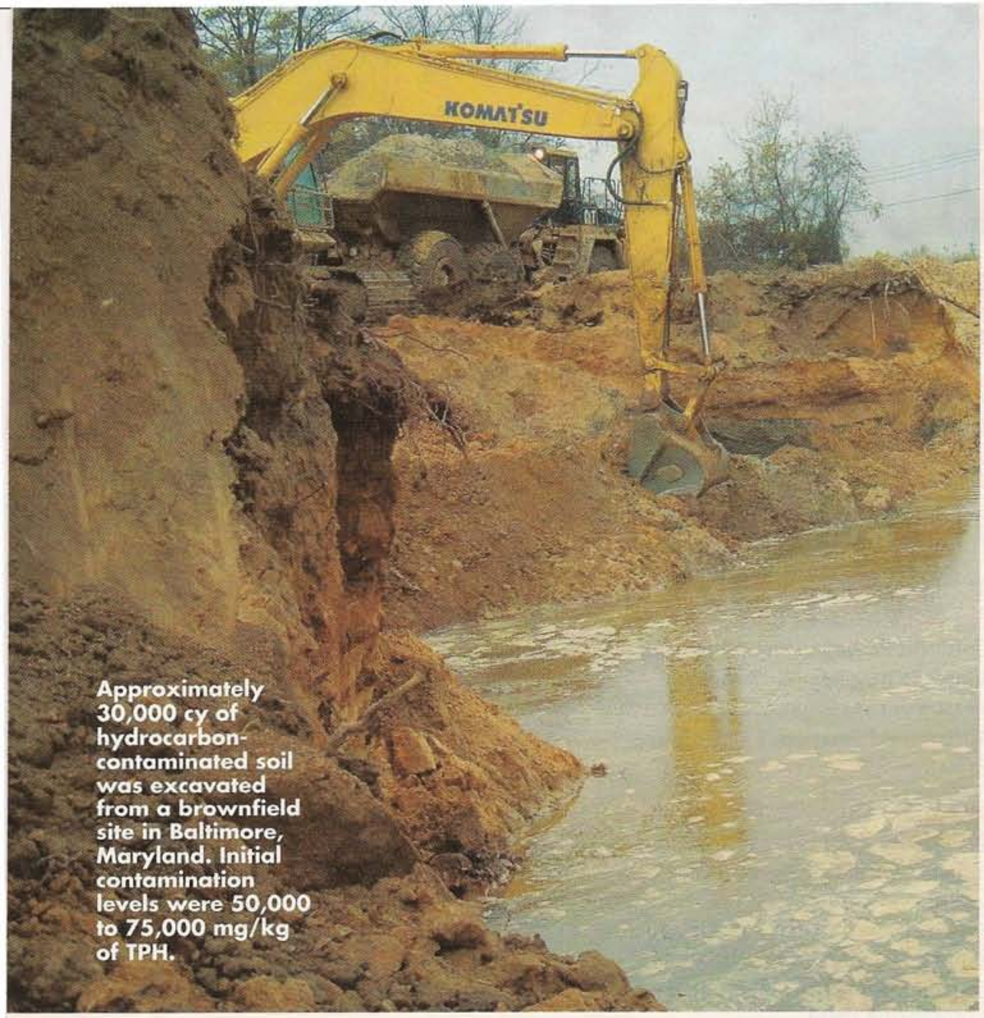

Approximately 30,000 cy of hydrocarbon-contaminated soil was excavated from a brownfield site in Baltimore, Maryland. Initial contamination levels were 50,000 to 75,000 mg/kg of TPH.

SOIL CLEAN-UP STRATEGIES

ENVIRONMENTAL REMEDIATION BY COMPOSTING

With close to 300,000 sites nationwide in need of clean-up over the next 30 years, composting is among the remediation technologies being put to use.

Craig Coker

CONTAMINATION of soils with toxic and/or hazardous materials can be traced back to industrial, military, municipal and agricultural activities. The extent of this contamination is significant. In 2004, the U.S. Environmental Protection Agency estimated that 294,000 sites will need to be cleaned up over the next 30 years. This includes 77,000 known sites and an estimated 217,000 sites yet to be discovered. Total clean up costs are estimated to be $209 billion.

These estimates include the seven major clean-up programs: National Priorities List (NPL, or Superfund); Resource Conservation and Recovery Act (RCRA) Corrective Action; Underground Storage Tanks (UST); Department of Defense (DOD); Department of Energy (DOE); Other (Civilian) Federal Agencies; and States and Private Parties (including brownfields).

If the risk of human or ecological health damage is deemed high enough, remediation is required. Remediation is the process of taking action to reduce, isolate, or remove contamination from an environment with the goal of preventing exposure to people or animals. Remediation can be done by physical (air stripping), chemical (reagent addition), thermal (thermal desorption), or by biological means. Biological remediation techniques include composting, phytoremediation and landfarming, and lesser known methods such as bioaugmentation, biostimulation and bioslurping. Composting is considered to be an *ex*-situ (meaning "out of place") treatment technology.

Part 1 of this article series discusses how composting technologies normally used for nonhazardous organic materials can be applied to contaminated site remediation. Part 2 will examine how the addition of finished compost to contaminated soils will help reduce toxic levels of pollution.

ENVIRONMENTAL CONTAMINANTS

There are over 330 listed environmental contaminants with known human and/or ecological health affects. They are segregated into six groups of organic chemicals and two groups of inorganic chemicals:

Organic Chemicals: Nonhalogenated volatile organics (i.e. methanol, carbon disulfide); Halogenated volatile organics (i.e. carbon tetrachloride, perchloroethylene); Nonhalogenated semivolatile organics (i.e. malathion, dimethyl phthalate); Halogenated semivolatile organics (i.e. pentachlorophenol (PCPs), polychlorinated biphenyls (PCBs)); Fuels (i.e. gasoline, diesel, fuel oil); Explosives (i.e. TNT, RDX, nitroglycerine).

Inorganic Chemicals: Metals (i.e. arsenic, cadmium, lead, zinc); Radionuclides (i.e. cobalt-60, uranium, radium).

Not all organic chemicals are amenable to biodegradation by composting. Radionuclides and metals cannot be remediated (broken down) by composting; however, metals can be adsorbed into less bioavailable forms. The rate at which microorganisms degrade contaminants is influenced by the following factors: specific contaminants present; oxygen supply; moisture; nutrient supply; pH; temperature; availability of the contaminant to the microorganism (clay soils can adsorb contaminants making them unavailable to the microorganisms); concentration of the contaminants (high concentrations may be toxic to the microorganism); presence of substances toxic to the microorganism, e.g., mercury; or inhibitors to the metabolism of the contaminant.

The main advantage of *ex situ* treatment (removal of soils) is that it generally requires shorter time periods than *in situ* treatment (in the ground), and there is more certainty about the uniformity of treatment because of the ability to homogenize, screen, and continuously mix the soil. However, *ex situ* treatment requires excavation of soils, leading to increased costs and engineering for equipment, possible permitting, and material handling/worker exposure considerations.

Brown Environmental Services formed a treatment pile about 3-feet deep covering an area of 7.5 acres. Two windrow turners (one shown above) were used for continuous agitation of the pile and to add an inoculum and nutrients.

BIOLOGICAL MECHANISMS

Composting can change organic chemicals and bind metals through several different mechanisms:

Biological degradation is the process where microorganisms break down water-soluble chemicals with enzymes in solution to utilize them for metabolism. Two processes that can modify an organic chemicals structure to make it more water-soluble are hydrolysis (adding water to break chemical bonds) and oxidation.

Extracellular decomposition is the process where microorganisms secrete enzymes to break down large organic molecules into a smaller form for easier absorption into the microorganism. This is how cellulose, hemicellulose and lignin are degraded in composting. Fungi are the source of most extracellular enzymes.

Intracellular decomposition takes place once the chemical has been absorbed by the microorganism. Mineralization, the process of converting an organic material to carbon dioxide and water, is the predominant process at work inside the microorganism.

Adsorption is an electrochemical process where positively- or negatively-charged organic molecules bind with their charge-opposite counterparts in organic matter and clays. This is the mechanism by which metals can be bound and become less bioavailable.

Volatilization is a physical process that changes a material from one physical state to another (i.e. from liquid phase to gas phase). Mixing of contaminated soils is a major source of volatilization (up to 30 percent of an organic chemical can be lost this way). Volatilization of hazardous chemicals is both a public health and air quality concern (EPA regulates 188 hazardous air pollutants under the Clean Air Act). Volatilization is highly temperature-dependent (higher temperatures produce more volatilization). Moisture can either block volatilization by clogging air channels with water or can increase it by liberating weakly-adsorbed chemicals. By breaking weak adsorption bonds, liberated hazardous chemicals can volatilize due to the agitation of excavation.

COMPOSTING CONSIDERATIONS

Traditional composting of nontoxic organic materials is based on proper recipe formulation, thorough mixing, aerobic composting and curing to produce a stable and mature compost for product markets in the shortest possible time at the least possible cost. Composting of contaminated soils has a different endpoint (the degradation of the contaminant), and product marketability is not an issue, so temperatures, time, C:N ratios, moisture content and porosity are somewhat less important considerations. Thermophilic temperatures have been shown to greatly accelerate the degradation of some contaminants (like polycyclic aromatic hydrocarbons (PAHs)), but at a greater risk of gaseous volatilization. (The Occupational Safety and Health Administration (OSHA) has set a limit of 0.2 milligrams of PAHs per cubic meter of air.)

In some cases, anaerobic conditions may be needed to degrade highly chlorinated compounds, a step which is then followed with aerobic treatment to degrade the partially dechlorinated compounds as well as the other constituents. Anaerobic microbial processes that are of significance in environmental remediation include denitrification, iron/manganese reduction, sulfidogenesis and methanogenesis. Sulfidogenic and iron-reducing microbial populations can dehalogenate and mineralize chlorinated and brominated aromatic compounds.

Moisture levels in the range of 20 to 80 percent are considered suitable for the bioremediation of soils, but the microbes in composting thrive best between 40 and 60 percent moisture. Nutrient process design is focused on C:N:P ratios, in which ratios of 120:10:2 are not uncommon. Each remediation project is different, due to variations in the nature of the contaminant, initial concentration of that contaminant, desired endpoint (often influenced by risk assessments), degradation rate (dependent on both the nature of the contaminant and the energy level of the compostable feedstocks), concerns over volatilization and leaching, and available space.

Composting can be done with aerated static piles, in-vessel systems, or with windrows. Windrow composting is considered to be the most cost-effective alternative, but it may also have the highest levels of fugitive emissions of Volatile Organic Compounds (VOCs). Composting with aerated static piles, also known as biopiles, is an effective means of remediating petroleum contamination.

MIXING CONTAMINATED SOILS

Remediation via composting can be accomplished by mixing contaminated soils with fresh, high-energy feedstocks or by simply adding a mature, finished compost to contaminated soils. A mix ratio of 30 percent soil and 70 percent feedstocks has been observed to reach thermophilic temperatures. A mix of 18 percent soil and 82 percent yard trimmings remediated 40 percent of the PCBs in a contaminated soil over a period of 370 days. Composting has been shown to be an effective approach to the remediation of explosives-contaminated soils, with degradation of 99.7 percent of TNT, 99.8 percent of RDX, and 96.8 percent of HMX at the Umatilla Army Depot. A mature, six-month old compost mixed with petroleum contaminated soils was observed to degrade petroleum at a rate eight times faster than with *in-situ* bioremediation (natural attenuation).

Due to the increase in volumes of materials to be handled by mixing contaminated soils with traditional compostable feedstocks, many *ex-situ* bioremediation projects will use inoculums of cultured indigenous bacteria and nutrient broths to create the proper conditions for biological degradation. In many cases, this inoculum of indigenous microbes has the same effect as recycling overs from compost screening back into the feedstock mixing system at a composting facility. Typically, indigenous microbes are capable of effecting remediation because they are acclimated to the contaminant as well as their microniche; however, research is currently underway at a number of facilities using exogenous, specialized microbes or genetically engineered microbes (GEMs) to optimize bioremediation. Several companies

Costs for remediation with composting vary with amount of soil to be treated, mix ratio of soil to compostables, availability and cost of amendments, type of contaminant and process design.

now make and market proprietary formulations of biodegradable surfactants, solvents, emulsifiers, degassing agents, nutrients, biostimulants and specialty strain, non-pathogenic bacteria. These liquid solutions are easily introduced into and mixed with the contaminated soil.

Costs for remediation with composting vary with the amount of soil to be treated, mix ratio of soil to compostables, availability and cost of amendments, type of contaminant and process design. Reported costs include: \$84 to \$190/ton for explosives-contaminated soil and \$266/ton for soil contaminated with PAHs, PCPs and VOCs. Costs for biopiles are reported to be as low as \$30 to \$60/ton.

There are limitations to the use of composting for remediation. These include: Challenges in scaling up from bench (or laboratory) to pilot to full-scale operations; Need for very large available space to compost many thousands of cubic yards of contaminated soils; Increase in the total volume of materials to be handled (due to addition of bulking agents), which can affect final disposal costs; Possible generation of intermediate decomposition products with even higher levels of toxicity during the biodegradation process; Volatilization of gases, with the attendant air pollution considerations; Possible increase in metal concentrations due to the loss of carbon in composting; and Potential for hazardous constituents that do not degrade to become nonextractable and bound to the soil matrix.

Figure 1. TOOELE Army depot treatment building plan TNT washout composting facility

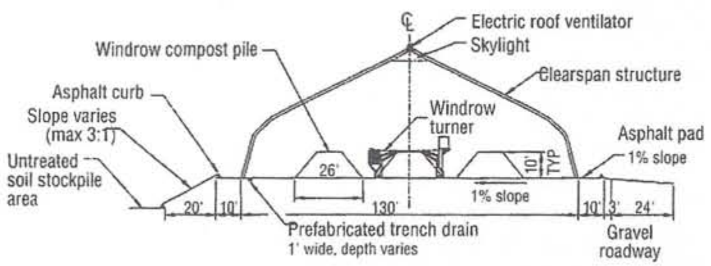

Illustration courtesy of U.S. Army

REMEDIATING FUEL OIL CONTAMINATION

Brown Environmental Services in Newtown, Pennsylvania recently completed a successful remediation of a two-acre fuel-oil contaminated site in Baltimore, Maryland under a Brownfield Agreement with the Maryland Department of the Environment, Oil Control Program. The 60-acre parcel near Baltimore Harbor used to house a heating oil company that offloaded fuel oil into a one million gallon above-ground storage tank. The new land owner, Obrecht-Riehl Properties, plans to convert the site to residential use.

Steven F. Coe, President of Brown Environmental Services, said his firm was hired as the prime contractor for the remediation work. Initial soil contamination levels were 50,000 to 75,000 milligrams per kilogram (mg/kg) of Total Petroleum Hydrocarbons (TPH). The remediation target was to reduce TPH levels to 230 mg/kg.

It was decided to use a carefully-screened form of bioaugmentation; Brown Environmental developed proprietary solutions of cultured bacteria to carry out the biodegradation. Approximately 30,000 cubic yards of soil were excavated, digging down two feet below the groundwater table. The excavated soil was formed into a treatment pile approximately 3-feet deep covering an area of 7.5 acres. Using two Brown Bear auger-type windrow turners, the pile was turned continuously, adding inoculum and nutrients. Nutrients were added to keep Carbon:Nitrogen:Phosphorus ratios at optimum levels. The same mix of inoculants and nutrients were used to simultaneously treat almost 20 million gallons of groundwater. The groundwater was cleaned to the point where it could be discharged without a permit from the State of Maryland.

Coe noted that the pile's temperatures rarely exceeded mesophilic levels (30°-35°C). Brown Environmental's approach to bioaugmentation does not require frequent temperature monitoring, and the project schedule allowed remediation to take place during summer months. It was able to meet the TPH target level of 230 mg/kg in over 80 percent of the pile within five months, and the Maryland Department of the Environment issued an approval letter in early August. Coe said costs for the project averaged \$25/ton, which he attributed to the extensive laboratory and pilot scale work completed to ensure they had the right bacterial inoculant. "We see our front-end investment in research and development as an insurance policy to ensure the certainty of success," he noted.

REMEDIATING EXPLOSIVES-CONTAMINATED SOIL

Tooele Army Depot (TEAD) was established by the U.S. Army in Tooele, Utah in 1942 to provide a storage depot for World War II supplies, ammunition and combat vehicles. Consisting of 23,610 acres, TEAD is now an ammunition storage and manufacturing facility for the Army. The TNT Washout Facility at TEAD was used for decommissioning explosive munitions, which included steam cleaning and rinsing munitions casings. The rinsewater flowed through a series of settling tanks and filters to a series of unlined, bermed washout ponds. Elevated levels (up to 20,000 mg/kg) of 2,4,6,-trinitrotoluene (2,4,6-TNT) and cyclotrimethlylene trinitramine (RDX) have been detected in the surface and subsurface soils at this facility.

The Army has decided to undertake Corrective Action at the TNT Washout facility in 2007. The remediation will include the excavation of approximately 10,000 cubic yards of 2,4,6-TNT and RDX contaminated soils, construction of a temporary treatment facility, bioremediation/composting of the contaminated soil, and backfilling areas with the treated soil. The majority of the explosives-contaminated soils are present at a depth of 7-feet below ground surface or less.

Composting was chosen by the Army as the remediation technology for TEAD based on successful similar remediation projects at Umatilla Army Depot in Oregon and Joliet Army Ammunition Plant in Missouri. (Reports on those remediation projects can be found in the following *BioCycle* articles: "Clean Up At Munitions Sites," March 1996; "Bioremediating Explosives Contaminated Soil," May 1999; "Military Wins With Bioremediation Through Composting," March 2001; and "Advances In Composting Contaminated Soils," November 2001.) Excavating explosives-contaminated soil does not raise the same issues about volatilization that can occur with chemically-contaminated soils. "These types of contaminants don't tend to volatilize," said April Fontaine, the project manager at the U.S. Army Corps of Engineers. "They tend to stick to soil particles."

The composting process selected for use at TEAD will be the turned windrow method, with 30 percent of the compostable mix consisting of excavated contaminated soil. The remainder of the compost recipe consists of wood chips (10%), alfalfa (15%), lettuce (10%), barley (10%), cow manure (20%) and poultry litter (5%). The lettuce, barley and animal manures are the nitrogenous amendments and alfalfa and wood chips are the bulking agents.

The composting amendments will be loaded into 12-14 cubic yard end dump mixing trucks until the truck is 70 percent full. The trucks will then drive to the soil stockpile area, where they will be filled to capacity with screened, untreated explosives-contaminated soil. The trucks will mix the ingredients together as they travel to the Compost Treatment Facility (Figure 1) where they will unload the mix to be formed into windrows. The Compost Treatment Facility is sized to treat three windrows, each 26-feet wide by 300-feet long. Approximately 18,000 gallons of water will be applied daily by a water truck to maintain soil moisture levels between 40 and 60 percent of the soil's water holding capacity. Windrows will be turned with a Frontier pull-behind windrow turner. Treatability studies conducted several years ago concluded that each batch of contaminated soil could be composted to meet the Corrective Action Goals (31 mg/kg for RDX and 86 mg/kg for 2,4,6-TNT) within 20 days and that thermophilic temperatures would be reached within three days and would stay at thermophilic elevated levels for more than 20 days.

The Compost Treatment Facility will be a 130-foot by 450-foot temporary Sprung Structure erected over a 4-inch thick asphalt concrete pad. The pad consists of a compacted layer of road-base material, 4-inches of asphalt concrete and a 4-inch asphalt curb around the edges.

While composting has been shown to be a viable remediation technique for many types of environmental contaminants, advances in biological engineering of formulated microbial solutions now appears to offer both cost and logistical advantages over composting as a remediation technology. ■

Craig Coker is a Principal in the firm of Coker Composting & Consulting in Roanoke, Virginia, who specializes in providing technical support to the composting industry in the areas of planning, permitting, design, construction, operations and compost sales and marketing.

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