Soils Contaminated with Explosives: Common Bio-Remediation Techniques Utilized

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ABSTRACT

The production and processing of munitions over the last 100 years has led to the disposal of wastes containing explosives and nitrated organic waste into the environment. The affected soils may contain toxic concentrations of 2, 4, 6-trinitrotoluene (TNT), Research Department Explosive (RDX, hexahydro-1, 3, 5-trinitro-1, 3, 5-triazine), and High melting Explosive (HMX, octahydro-1, 3, 5-triazine). Mutagenic effects have been associated with common military explosives and the by-products they can transform into. In the US, the Army alone has estimated that over 1.2 million tons of soil has been contaminated with explosives (Lewis et al., 2004). Due to the public health concerns the cleanup of these contaminated sites has been mandated. The US Army Environmental Center (USAEC) has dedicated several years to developing biotreatment alternatives to clean up these contaminated sites. This paper will look at three of the methods used to treat soil contaminated with explosives, incineration, composting, and bio-slurry reactors. Effectiveness, cost and time will be evaluated for each of these methods.

KEYWORDS

2, 4, 6-trinitrotoluene (TNT), Research Department Explosive (RDX, hexahydro-1, 3, 5-trinitro-1, 3, 5-triazine), High melting Explosive (HMX, octahydro-1, 3, 5-triazine), incineration, bio-slurry reactor, composting

1. INTRODUCTION

Groundwater, soil, and air pollution by hazardous and toxic substances is major problem facing the world today. A majority of the contamination comes from agricultural, industrial, and military activities (Boopathy, R., 2000). The manufacturing and processing of 2, 4, 6-trinitrotoluene (TNT) and other explosives has caused high concentrations of theses contaminants to become present in the soil at these manufacturing sites. Due to increasing regulations, demilitarization, and unwanted weapon systems, there are a growing number of munitions production plants that have been decommissioned. These plants must now be evaluated, and decontaminated to ensure public health and safety. Incineration has been the most effective and widely used method of soil remediation used in the past to decontaminate these munitions plants (Boopathy, R., 2000). Biological methods, are however, proving to be more cost effective, and safe. The purpose of this paper is to compare the methods of incineration, composting, and bio-slurry bioreactors as means of recovering soil contaminated by explosives. Incineration is not considered a bioremediation technique therefore; most of the focus will be on the methods of composting and bio-slurry reactors

2. INCINERATION

Incineration is the traditional cleanup method used for soil contaminated with explosives. This method is costly and is not readily accepted by regulators anymore (US Army Environmental Center, USAEC, 2003). The process of incineration requires the use of fossil fuels, a nonrenewable resource, and produces a toxic ash that must be disposed of as a hazardous waste (Environmental Protection Agency, 1997). In addition the ash that is produced cannot be used for anything because of the high concentrations of contaminants is contains.

3. COMPOSTING

3.1 Description of Composting Process

Composting was the first biological treatment process to be tested, approved, and selected for use in the remediation of military sites with soil contaminated with explosives (Lewis et al. 2004). Composting is the process in which contaminants in soils, sediments, sludge, or soil-like material are biodegraded or transformed to produce innocuous or stabilized by products. During composting micro-organisms are stimulated to grow and transform the contaminants. There are a few basic parameters that must be monitored in order for this method to be effective (U.S. Army Corps of Engineers, 2003).

- Mixing
- Moisture Content (controlled by irrigation)
- Oxygen Level (controlled by mixing)
- Nutrients (nitrogen and phosphorus are provided by adding organic substances)
- PH (soil and other added substances usually buffer themselves to maintain the pH)
- Soil Bulking (controlled by adding other substances)
- Temperature (controlled by mixing, and moisture content)

When using the composting technique, it is imperative that organic additives such as, wood chips, manure, hay and vegetable wastes are added to the contaminated soil. Adding these organics increases the microbial activity and elevates temperatures producing the thermophilic conditions that are required for composting (U.S. Army Corps of Engineers, 2003). These thermophilic conditions must be maintained in order to successfully degrade the contaminants present in the soil. Additionally, organics are also added to improve texture, workability and the carbon to nitrogen ratio of the compost (Craig, H.D. et al., 1995).

Once the composting process is complete the waste must be disposed of properly. The most common wastes produced are the wastewater and the composted soil itself. The wastewater produced may be reused in other composting applications. The wastewater may be utilized as irrigation water for instance. If the wastewater is not going to be reused it must be disposed of in accordance with any and all regulations that may apply. The remediated soil may be returned to the site it was excavated from and used as fill material. The soil may only be used for this purpose, if it is determined that there have been satisfactory reductions in the contaminant and toxicity levels, and must have regulatory approval (Lewis et al., 2004). Unlike the ash created by incineration, composted material can support vegetation, thus making it a desirable site fill material.

3.2 Different Composting Methods

There are three recognized styles of composting:

1. ***Aerated Static Pile Composting-*** Compost is formed into piles and aerated with blowers or vacuum pumps in this technique. This technique requires the use of expensive blowers; aerators or vacuum pumps therefore may not be as cost effective as some of the other methods (U.S. Army Corps of Engineers, 2003).

2. ***Mechanically-Agitated In-Vessel Composting-*** This method used reactor vessels. Compost is placed into the vessels where it is then mixed and aerated. Once again this method uses expensive reactor vessels which make it more costly than other styles of composting (U.S. Army Corps of Engineers, 2003).
3. ***Windrow Composting-*** This is the most common method of composting. Compost is placed into long windrows. The long piles are turned using tractors, rotary tillers, as well as employing irrigation devices. The periodic turning provides the aeration that is required. This method has been thought of as the most cost-effective (U.S. Army Corps of Engineers, 2003).

Figure 1 illustrates the typical windrow composting process (U.S. Army Corps of Engineers, 2003).

TYPICAL COMPOSTING PROCESS

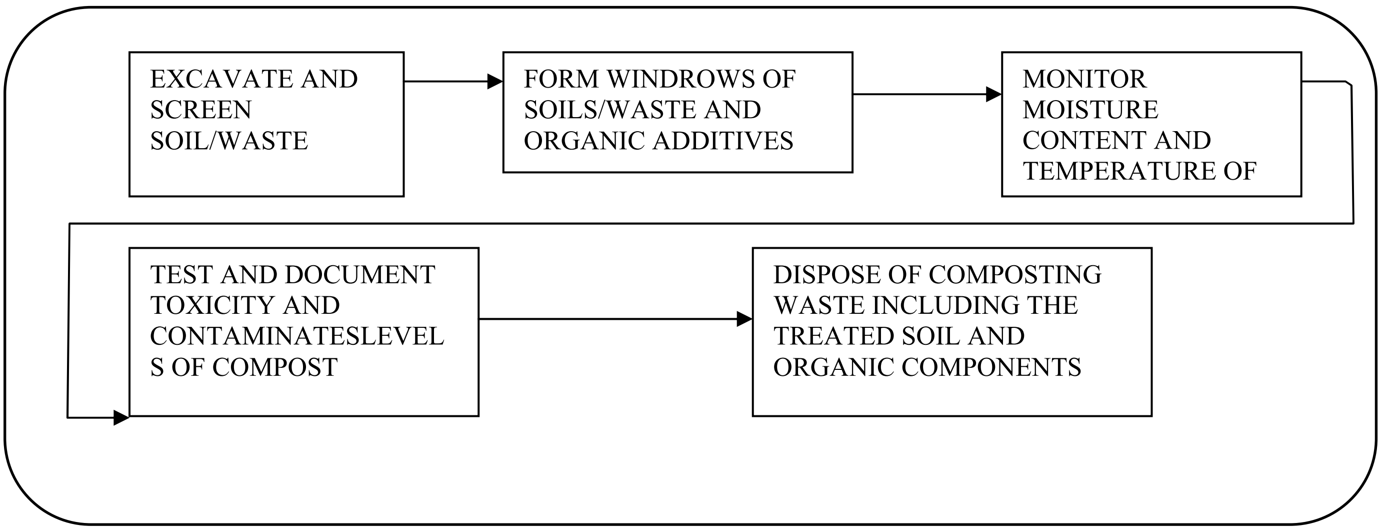


FIGURE 1

3.3 Composting Costs

There are different costs associated with composting. Some of the expenses to be considered are the construction of the treatment facility, the cost of organic additives required, the cost of equipment used in maintaining and turning the piles, the cost of transporting the soil to an from the composting facility and soil excavation costs (Lewis et al., 2004). It is estimated that the cost of composting can be anywhere form $206-$766 per ton for windrow composting (Lewis et al., 2004). Composting produces a 40-50% savings, per ton, over the average cost of incineration (Lewis et al., 2004).

3.4 Compost Application: Umatilla Army Depot in Hermiston, Oregon

Umatilla Army Depot used water and steam to clean TNT, RDX, and other explosives out of decommissioned bombs over a 15 year periods during the 1950s and 1960s (Environmental Protection Agency, 1997).The cleaning of these bombs produced over 80 million gallons of explosive-contaminated water (pink-water). This "pink-water" was placed into two 10,000 squarefoot lagoons. As time passed the water evaporated leaving behind tons of soil contaminated with explosives. In 1987, Umatilla was placed on the Superfund cleanup list due to the TNT and RDX levels, which were recorded at levels as high as 4900 parts per million (Environmental Protection Agency, 1997).

The method of composting was selected to remediate 15,000 tons of contaminated soil at the Umatilla Army Depot (Environmental Protection Agency, 1997). The clean-up goals of the project were to achieve concentrations of 2, 4, 6-Trinitrotoluene (TNT) and Royal Demolition Explosives (RDX) of 30 milligrams per liter or less. The results exceeded the expectations and as there were non-detectable levels of explosives present in the soil after the composting process was complete. There were also no traces of contaminant byproducts (Environmental Protection Agency, 1997).

3.4.1 Umatilla Composting Process

Extensive testing was performed before the appropriate mix of organics and soil was determined to use for this massive composting. The final composting mix contained 30 percent contaminated soil, 21 percent cattle manure, 18 percent sawdust, 18 percent alfalfa, 10 percent potato waste and 3 percent chicken manure (Environmental Protection Agency, 1997). Next, large temporary buildings were constructed to house the composting operations. The temporary structures were constructed to control fumes produced as well as to ensure optimal conditions for the composting process were maintained. The compost piles were turned, using large machinery, three times per day. The purpose of turning the compost was, to ensure that the compost received sufficient oxygen, to release excess heat, water vapor and gases, as well as to break up large clumps of material. Accomplishing all of this helps to accelerate the composting process (Environmental Protection Agency, 1997). The treatment time, for this particular mixture and operation was 10-12 days for a batch of 2700 cubic yards of compost (Environmental Protection Agency, 1997).

3.4.2 Umatilla Army Depot Clean-Up Cost

By using the bioremediation technique of composting, as apposed to the method of incineration, at the Umatilla Army Depot, an estimated $2.6 million dollars were saved(Environmental Protection Agency, 1997). The cost of incineration was estimated to be $527 per ton and the cost for composting per ton was $176 (Environmental Protection Agency, 1997). The end-product, or composting, was able to be sold because it was hummus-rich. The price per ton of the hummus-rich soil was estimated to be worth $10 per ton. By using composting at the Umatilla Army Depot they saved approximately $150,000. The following graph, figure 2, compares the cost of incineration and composting (Environmental Protection Agency, 1997).

COST COMPARISON: COMPOSTING VERSUS INCINERATION

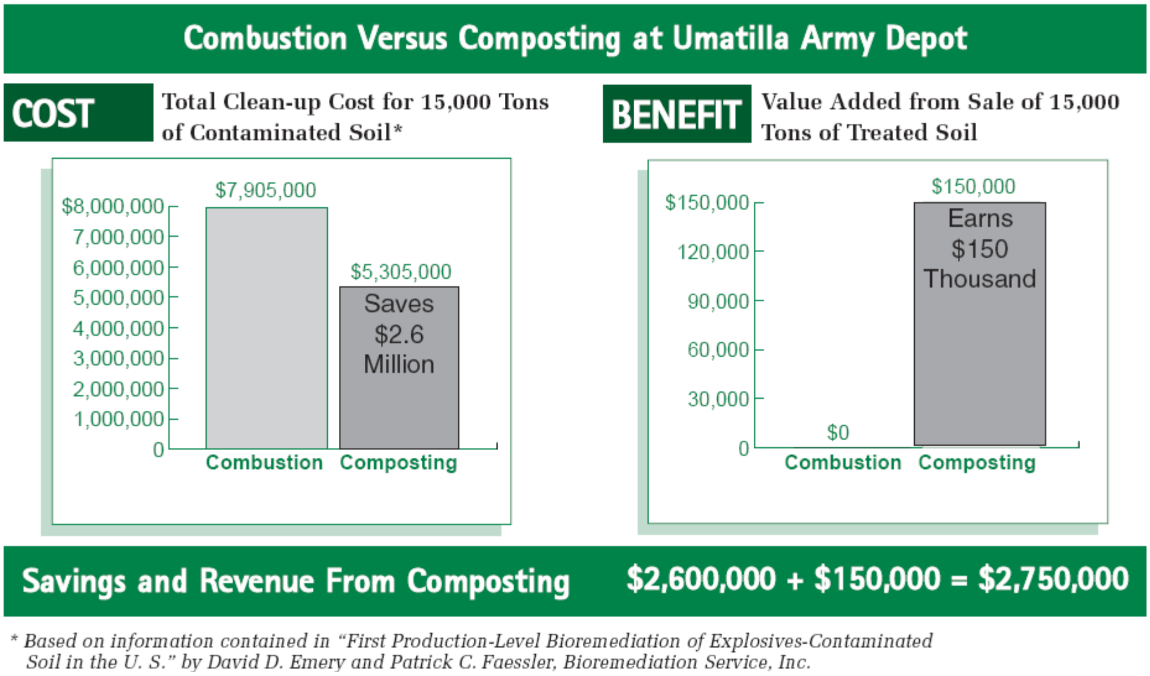


FIGURE 2

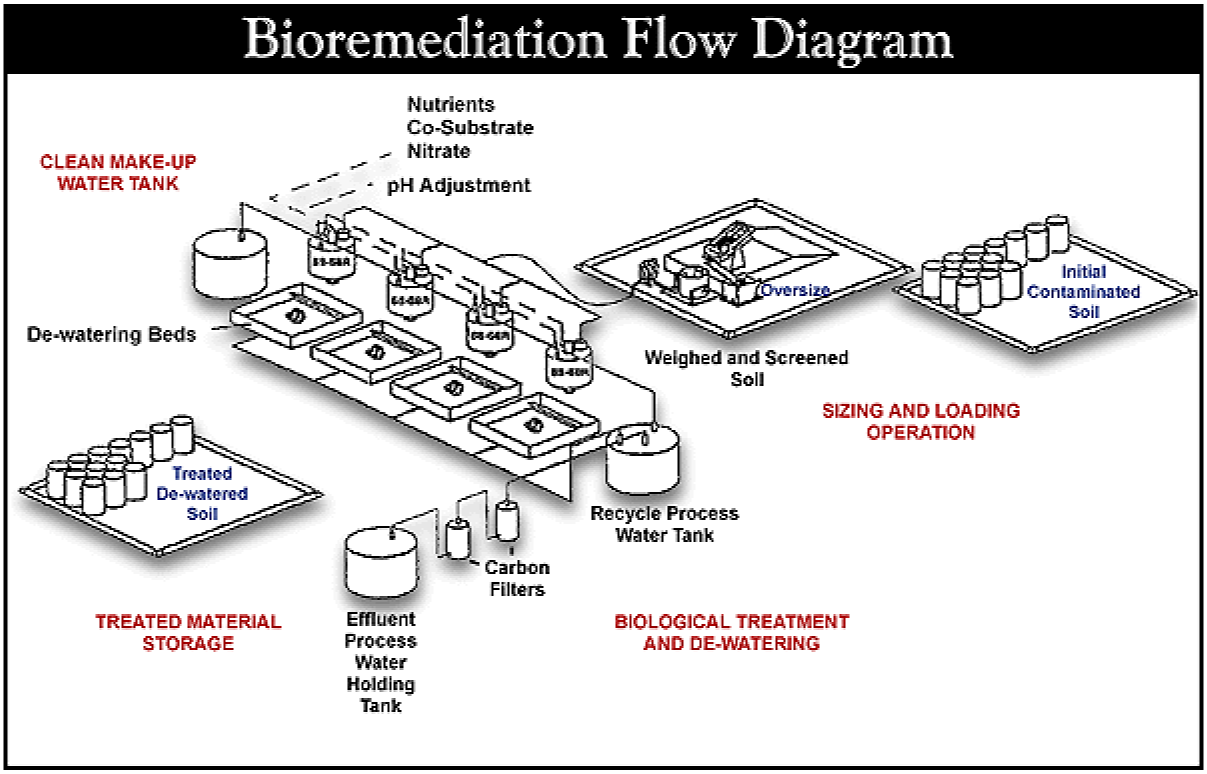
The U.S. Army Corps of Engineers have estimated that if the method of composting were used, instead of incineration, to clean-up the remaining munitions sites $200 million could be saved (Environmental Protection Agency, 1997).

4. BIOSLURRY REACTORS

4.1 Brief Description of the Bioslurry Reactor Method

Bioslurry reactors operate on the same basic principles of composting. The first step is to excavate and filter the soil to remove any large particles, or debris that may be present. Next the contaminated soils are mixed with water in large tanks or lagoons to produce "slurry." The slurry is then mechanically agitated in large reactors. The temperature, pH, oxygen levels, and nutrient amounts are monitored to ensure favorable microbial growing conditions are maintained (Craig, H.D. et al. 1995). These conditions promote the growth of the microorganisms already in the soil. The increase in microbial activity causes the explosives to degrade into by-products that are no longer harmful to life forms (US Army Environmental Center, USAEC, 2003). The soil is then separated from the slurry. This separation may occur by gravity or chemical dewatering methods may be used. The reactor water is recycled and reused in the reactor. Figure 3 shows a flow-diagram of the bioremediation process. It should be noted that in field-scale applications large lagoons with mixing equipment may be used instead of several actual reacting tanks. Pilot studies have shown that the water treated by this process meet drinking water standards (Lewis et al., 2004).

FLOW DIAGRAM OF BIOREMEDIATION PROCESS



USAEC

FIGURE 3

During field-scale operations it is a common practice to operate the reactors in a sequencing batch as opposed to a batch mode. During a sequencing batch operation the initial amount of contaminated slurry is loaded into the reactor and the process is allowed to be carried out. Once the toxicity and contamination levels have been reduce to the desirable range a portion of the batch is removed. The removed amount is replaced by the same amount of contaminated slurry. In using this method the lag time that is required for the microbial populations to grow and begin to degrade the contaminants is reduced. My eliminating the lag time between batches the overall remediation time of the project is reduced thus reducing the cost (Fuller, Mark E. et al., 2003).

4.2 Bioslurry Reactor Cost

Like any remediation technique there is a cost that must be assessed and compared to the benefit of the process. Bioslurry costs are determined by two factors, process time and the ultimate disposal of the soil. Expenses of the bioslurry method include soil excavation, soil sieving or screening to remove large particles, construction of and installation of holding tanks and reactors, as well as the installation of the required mixing equipment (Lewis et al., 2004). The cost for treating 500 cubic yards of soil is estimated to be $147 per cubic yard, this equates to

$200-$600 per ton (Lewis et al., 2004). The treated water from the system may be able to be released in to vegetated areas where it can infiltrate thought the ground. This is because often the wastewater meets drinking water standards, and if it does not meet the standards required, the disposal of the wastewater becomes an added expense. The efficiency of bioslurry remediation has been determined to be approximately 99.9% (Fuller, Mark E. et al., 2003).

4.3 Bioslurry Reactor Application: Joliet Army Ammunition Plant, Joliet Illinois

The Joliet Army Ammunition Plant was built during World War II, in 1940. The purpose of this plant was to produce ammunition and explosives for the U.S. Military. From the early 1940s through 1977 more than 4 billion pounds of explosives, composed primarily of TNT, were manufactured. The plant utilized a TNT ditch, where process wash water and waste waters were disposed; it also has a Red Water Area consisting of storage tanks, incinerators, evaporator, and a lined lagoon. The site also had several incinerator ash piles, and landfills. A part of the plant was known as the Flashing Grounds where flash burning of material took place to remove explosive residues. The site has been declared a Superfund site and is on the National Priorities List. Remediation of the site has been in progress for several years, and the several bioremediation methods have been employed. It has been shown in testing that the bio-slurry method is effective in removing 99% of the contaminants in the soil from the Joliet Army Ammunition Plant (Boopathy, R., 2000).

4.3.1 Bioslurry Test on Soil from the Joliet Army Ammunition Plant

Contaminated soil was used from the Joliet Army Ammunition Plant. The concentrations of the contaminants are shown is figure 4. The TNT concentrations in the soil ranged form 4000 to 12000 mg/kg (Boopathy, R., 2000). The organic content of the soil was 4-5% which included the contaminants, and the nitrate levels varied from 6-12 mg/kg of soil (Boopathy, R., 2000).

EXPLOSIVE CONCENTRATIONS IN THE CONTAMINATED SOIL

Table 1
Explosives concentrations in the contaminated soil

Explosive[a]	Concentration range (mg/kg of soil)
TNT	4000–12,000
TNB	175–300
2,4-DNT	50–200
RDX	50–125
HMX	50–100

[a] Abbreviations: TNT, 2,4,6-trinitrotoluene; TNB, trinitrobenzene; 2,4-DNT, 2,4-dinitrotoluene; RDX, hexahydro-1,3,5-trinitro-1,3,5-triazine; HMX, octahydro-1,3,5,7-tetranitro-1,3,5,7-tetraazocine.

FIGURE 4

4.3.1.1 Reactor Setup

The laboratory set-up of the reactor for this experiment utilized the aerobic process of degradation. Two 0.5 liter bioslurry reactors were assembled. The reactors were operated at 20-20°C. To begin operation the soil was mixed to provide a 15% ratio of water to contaminated soil slurry. After the slurry was made molasses was added to serve as carbon source for the operation (Boopathy, R., 2000). A diffuser supplied oxygen to the reactors for 10 minutes per day. The slurry was constantly stirred using a magnetic stirring bar at a rate of 50-60 rpm. The reactor required a two week lag time for the reactor to stabilize (Boopathy, R., 2000). Once the reactor had stabilized 10% of the contaminated soil was replaced weekly and more molasses was added. The TNT and other contaminant concentration, bacterial growth, pH, oxygen uptake, nitrate and ammonia levels were monitored in both reactors. The results of this testing was presented as a average between the two reactors (Boopathy, R., 2000).

4.3.1.2 Study Results

This particular study showed that bioslurry reactors can effectively be used to remediate soil contaminated with explosives. Over 200 days the reactors showed a 100% removal of TNT (Boopathy, R., 2000). The reactors required a two week stabilization period before more soil slurry could be loaded into the reactor. This particular study also recognizes that the bioslurry method could become very expensive on a full-scale basis depending on factors such as soil excavation and operation costs. The results of this study show that the bioslurry method is an effective and efficient method of explosive contaminant removal (Boopathy, R., 2000).

5. COMPARISON OF REMEDIATION TECHNIQUES

In this paper three methods have been presented as means remediation soil contaminated with explosives.

1. Incineration
2. Composting
3. Bioslurry Reactor

Incineration has been the most common technique used to treat the contaminated soil. However, with the increasing biological technology there has been an overwhelming push to use biological means of degrading the soil instead. Incineration leaves behind ash that is still high in contaminants. The ash must be disposed of as hazardous waste in many instances, this means added cost. Incineration was shown cost more than composting.

Composting is the most common biological treatment method used to date. It produces a hummus-rich mixture that can support vegetation. Since the end-product of composting is able to be sold and or replaced the disposal cost is greatly reduced. Composting is a cost-effective, environmental friendly and most important effective means of degrading explosives in soil.

Bioslurry reactors are a fairly new and developing technology. There has not been a lot of field scale use of this method that is documented to date, however, several laboratory tests have produced impressive results. This method has been shown to produce 99% removal of contaminants in a shorter period of time that composting (US Army Environmental Center, USAEC, 2003). The costs, because there has not been many field applications is only a rough estimate. It is estimated that the cost would be comparable to that of composting. Bioslurry reactors could be used in place of composting if the project required a more controlled treatment of the soil. Overall, this is an up and coming technology that will be useful in the future.

6. CONCLUSION/DISCUSSION

After reviewing several different literary pieces I have found it hard to distinguish a “winner” as far as best bioremediation technique. The cost analysis of composting and bioslurry reactors resulted in similar dollar values. However, I could not find any field-scale applications of the bioslurry reactor method therefore; the cost is a rough estimate.

In conclusion, I feel that with further research the method of bioslurry reactors could become a useful technique to remediate soil contaminated with explosives. A Bioslurry reactor produces results in a shorter time frame that is required for composting to be effective. If large amounts of contaminated soil I feel that bioslurry reactors would become the most cost effective solution. This is due to the fact that it is a quicker method and time is money. Also to remediate large amounts of soil using the composting method, a large amount of land area would be required.

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