AN EVALUATION OF ALTERNATIVES FOR THE REMOVAL/
DESTRUCTION OF KEPONE RESIDUALS IN THE ENVIRONMENT

GW DAWSON, JA McNEESE AND DC CHRISTENSEN

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AN EVALUATION OF ALTERNATIVES FOR THE REMOVAL/DESTRUCTION OF KEPONE RESIDUALS IN THE ENVIRONMENT

G. W. Dawson, J. A. McNeese and D. C. Christensen

INTRODUCTION

A series of incidents starting with the discovery of mercury pollution at Minimata Bay, Japan, in the 1950's(1) and including cadmium pollution in the mining district of Japan in the 1960's(2) and PCB contamination of the Hudson River in New York(3) has focused public attention on the problem of in-place toxics. These environmental contaminants are persistent in nature and pose an insidious threat through their tendency to accumulate to concentrations that are damaging to higher trophic levels. A lack of operative degradation mechanisms means that reduction to safe levels is dependent on natural dispersive processes. These are typically slow. Hence, in-place toxics offer opportunity for major gains if effective means of mitigation can be identified.

One of the most well publicized incidents in the United States was first reported in 1975 when it was disclosed that up to 70 miles of the James River had been contaminated with as much as 100,000 lbs of chlorinated pesticide: Kepone.(8) Subsequent studies sponsored by the State of Virginia and the U.S. Environmental Protection Agency revealed that the widespread contamination could have a significant impact on aquatic organisms. Man could be affected if contaminated fish were consumed in large quantities. In the ensuing years, numerous court cases have been filed against the various parties involved. One resulted in the largest fine ever levied under Public Law 92-500. The State has closed the James River to the taking of blue crab and other commercial species. A similar ban has been placed on male blue crabs taken from the Southern portion of Chesapeake Bay.

In February of 1977, the U. S. EPA initiated a feasibility study to evaluate the effectiveness, costs, and impacts associated with alternatives for removing and/or degrading Kepone in the river. The following narrative discusses results of that work and their implications to other in-place toxic problems.

BACKGROUND

Kepone is a registered tradename for Decachlorooctahydro-1,3,4-metheno-2H-cyclobuta (cd) pentalen-2-one, one of several derivatives of hexachlorocyclopentadine (HEX), Kepone is soluble at 1-3 ppm in acid waters and undergoes an almost exponential increase in solubility as the solution pH is raised above 9. In other respects, Kepone is very similar to the other chlorohydrocarbons:

- Kepone is persistent in the environment -- it resists photo and biochemical degradation;
- Kepone has a strong affinity for organic particles -- it associates with sediments;
- Kepone bioconcentrates;
• Kepone is acutely toxic, but its potential long-term effects are of greatest concern; and

• Kepone residuals require extreme thermal conditions for complete incineration due to the formation of toxic by-products.

It is these properties that have in great part perpetuated the current situation in the James River. Kepone from production discharges and bulk disposal of bad batches of product was released into the environment over the years between 1967 and mid-1975. During that time it is estimated that up to 200,000 lbs may have been discharged. It is further estimated that up to one quarter of that amount currently resides in the sediments of the James River.

Ecological studies have indicated that nearly all of the tidal area of the James, over 70 miles, will require amelioration. Researchers at the U.S. Environmental Protection Agency's Environmental Research Laboratory at Gulf Breeze, Florida, have recommended that water levels be maintained at or below 0.004 ppb and sediment levels below 0.015 ppm to protect aquatic life. Hence, if the impact of Kepone in the James River is to be eliminated, over 200 square miles of river bottom may require restoration. It is against this backdrop that the EPA feasibility study was conducted. The investigation covered biological, physical, and chemical alternatives for both restoration of the river and disposal of dredge spoils. The results of that work are summarized in the following sections.

DREDGE SPOIL STABILIZATION

Various materials have been identified as stabilization or fixation agents which can be applied to wastes or spoils to solidify the deposit and in so doing reduce the active surface area and subsequent leaching. This approach has been particularly effective on heavy metal bearing materials and other inorganic substances. Little has been done with persistent organic contaminants such as Kepone. Consequently, a broad screening study was required to identify candidate stabilization agents and characterize them for potential use. Each agent was employed to fix a standard size sample of Kepone contaminated sediment from the James River. The solidified mass was then subjected to both an elutriate and a leachate test as outlined below:

Elutriate Test Procedures

1. All samples were held at 4°C prior to testing.
2. Fixed sediments were ground to pass through a 10 mesh screen.
3. Distilled water at pH 4.5 was added to the ground sediment at 19 parts water to 1 part sediment (5%).
4. The slurry was mixed vigorously for 30 minutes on a horizontal displacement mechanical mixer.
5. Mixtures were allowed to settle for one hour.
6. Settled slurries were centrifuged at 3,500 rpm for 30 minutes and centrate filtered through an 0.7-2μ Gelman glass fiber filter.
7. Finally the filtrate was analyzed for Kepone and compared to results obtained with unfixed sediments.
Leachate Test Procedures

1. All samples were held at 4°C prior to testing.
2. Blocks of fixed sediments were weighed and reduced in size to the diameter of pea gravel or less.
3. Approximately 70 g of particles were placed in sealed leaching bottles and 500 ml of distilled water at pH 4.5 was added.
4. At each sampling interval the water was removed from the vessel and a new pH 4.5 500 ml aliquot was added.
5. Removed aliquots were split. Half were sent for Kepone analysis, and half were collected as a composite to assess total Kepone losses.
6. Sample intervals were selected included 1, 7, 14, 28, and 84 days.

Only commercially available materials were tested. These included silicate based agents (Portland cement derivatives), organic based polymers, a sulfur-silicate blend, a gypsum based material, and molten sulfur. Results of elutriate and leachate testing are summarized in Table 1.

In general, the silicate based agents did not effectively reduce leachate Kepone levels below those of the unfixed sediments. Many times they increased the Kepone concentration. This is believed to be the result of the reliance on Portland cement and the associated high pH of the reagents. Since Kepone solubility is greatly increased at higher pH levels, the silicate based agents release Kepone otherwise bound to the sediments.

The organic polymers were quite effective in reducing leachate Kepone content by an order of magnitude. However, the sealant relies on a film like coating. When this was broken for the elutriate test, the Kepone became more readily available. Hence, the sealant is more appropriate as a soil amendment while the grout would function well for spoil stabilization.

The molten sulfur was effective in reducing Kepone availability below that of untreated sediments. The sulfur-cement proprietary blend performed at a level intermediate between the molten sulfur and the silicate based materials. The gypsum based material was ineffective.

As a result of these evaluations, it was determined that the organic grout and the molten sulfur hold the greatest promise as stabilization agents for Kepone contaminated spoils. The grout is a commercial product which must be applied at 14.5 gal/ton of sediment and costs $14.41 per gallon. This implies a unit cost of $12.53 per ft³ of sediment. Molten sulfur can be purchased by the tank car at $38-42 per ton. If it is mixed in equal volumes with the spoils and allowed to cool, it will cost $1.30 per ft³ treated. Consequently, molten sulfur is the preferred option for stabilization.

Spoils and Elutriate Treatment

Numerous means of concentration and/or destruction were attempted with Kepone solutions to evaluate their potential for use on contaminated sediments, surface waters, and leachate. The latter included both biological and physical-chemical approaches.
TABLE 1: Summary of Test Results for Stabilization Processes

<table>
<thead>
<tr>
<th>Agent Type</th>
<th>Elutriate (µg/l)</th>
<th>24 hr</th>
<th>160 hr</th>
<th>336 hr</th>
<th>6672 hr</th>
<th>1344 hr</th>
<th>2016 hr</th>
<th>Composite of All Leachate Periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicate Base</td>
<td>0.012-3.52</td>
<td>0.059-3.55</td>
<td>0.065-3.58</td>
<td>0.306-3.58</td>
<td>0.033-3.58</td>
<td>0.11-43.9</td>
<td>0.15-2.90</td>
<td>0.17-2.90</td>
</tr>
<tr>
<td>Organic Grout</td>
<td>&lt;0.037</td>
<td>0.021</td>
<td>&lt;0.055</td>
<td>0.034</td>
<td>0.057</td>
<td>0.021</td>
<td>&lt;0.049</td>
<td></td>
</tr>
<tr>
<td>Organic Sealant</td>
<td>29.3</td>
<td>0.018</td>
<td>0.053</td>
<td>0.095</td>
<td>0.21</td>
<td>0.28</td>
<td>0.093</td>
<td>0.074</td>
</tr>
<tr>
<td>Sulfur-Cement</td>
<td>0.14</td>
<td>0.095</td>
<td>0.20</td>
<td>0.28</td>
<td>0.31</td>
<td>0.29</td>
<td>0.074</td>
<td>0.45</td>
</tr>
<tr>
<td>Gypsum</td>
<td>Decomposed</td>
<td>0.52</td>
<td>0.91</td>
<td>0.82</td>
<td>0.80</td>
<td>1.01</td>
<td>0.74</td>
<td>0.99</td>
</tr>
<tr>
<td>Holten Sulfur</td>
<td></td>
<td>0.017</td>
<td>0.010</td>
<td>0.050</td>
<td>0.029</td>
<td>0.032</td>
<td>0.15</td>
<td>0.17</td>
</tr>
<tr>
<td>Blank</td>
<td>0.042</td>
<td>0.076-0.104</td>
<td>0.058-0.081</td>
<td>0.050-0.11</td>
<td>0.22-2.30</td>
<td>0.14-1.04</td>
<td>0.10-0.26</td>
<td></td>
</tr>
</tbody>
</table>
Biological approaches to Kepone degradation have shown little promise to date. Kepone's resistance to dechlorination and breakage of the ring allow it to persist in both aerobic and anaerobic cultures for long periods of time. Attempts at cometabolism in bacteria also have failed. The single area of success has been work at Atlantic Research with fungi and mold. This group maintains an inventory of specialized cultures for degradation of persistent materials. According to Dr. Ralph Valentine of that organization, out of 40 isolates tested, 5 were found to grow utilizing Kepone as a sole carbon source. One organism yielded 41 percent reduction in Kepone after 31 days. The strains are not aggressive, however, and could not compete with bacteria in the environment. They may require presterilization of materials to be treated.

Attempts at photochemical degradation have also been unsuccessful for the most part. Kepone and the closely related compound Mirex are highly resistant to wavelengths in the range of sunlight. No measureable decrease in Kepone content could be attained with extended exposure of solutions and dry sediments to sunlight, photoflood light, or ultraviolet light. However, earlier work with Mirex had indicated that the presence of amines sensitizes the pesticide to photochemical attack.

To test the applicability of amines to Kepone degradation, 100 and 10 percent solutions of ethanolamine, triethylamine, and ethylenediamine were placed in quartz tubes, spiked with Kepone, and exposed to a photoflood light for one hour or direct sunlight for 23 hours as illustrated in Figure 1. Resultant levels of residual Kepone are presented in Table 2. The amine, apparently interfered with analysis such that absolute values are not as important as relative numbers in determining Kepone degradation. On this basis, the ethylenediamine demonstrates what appears to be a marked trend towards degradation.

Subsequently, a fourth solution using tert-butylamine was tested. Tert-butylamine is a large molecule which will resist the formation of complexes and any complications associated with complexation. With the "landfarm" apparatus (Figure 2), the presence of tert-butylamine was found to sponsor photochemical degradation leaving residual Kepone levels of 0.86µg/g (ppm) from an initial sediment level of 1.27µg/g (ppm). This constitutes a 32 percent reduction.

In a related test, a solution of ethylene diamine was sprayed on dry sediments contaminated at 0.95µg/g (ppm) with Kepone and allowed to stand in the direct sun in an open beaker. After 10 days, the sediment was found to contain only 0.21µg/g (ppm). This constitutes 78 percent destruction. Previous investigations revealed that volatilization does not occur to any measureable extent.

Due to the reliance on photolytic action, the approach here is limited to action at or very near the surface. It, therefore, may be of little use in the large volumes of contaminated spoils associated with dredging activity. Continual tilling could circumvent some of these difficulties, but land area requirements would still be massive. It is estimated that such an approach would cost $4,000 per acre treated. Information is not available on the effective depth to which degradation could be achieved.
FIGURE 1. Experimental Setup for Testing Amine Sensitized Photodegradation of Solutions.

TABLE 2. Effects of Sunlamp Irradiation on Amine Solutions

<table>
<thead>
<tr>
<th>Solvent System</th>
<th>Strength of Solvent (%)</th>
<th>Kepone Concentration in PPB After</th>
<th>Photoflood 1 Hour</th>
<th>Sunlight 23 Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hexane</td>
<td>10</td>
<td>1,640</td>
<td>6,040</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>3,700</td>
<td>530</td>
<td></td>
</tr>
<tr>
<td>Ethanolamine</td>
<td>10</td>
<td>2,230</td>
<td>7,970</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>6,520</td>
<td>2,530</td>
<td></td>
</tr>
<tr>
<td>Triethylamine</td>
<td>10</td>
<td>54.4</td>
<td>18,620</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>2,240</td>
<td>477</td>
<td></td>
</tr>
<tr>
<td>Ethylenediamine</td>
<td>10</td>
<td>1.715</td>
<td>117</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>&lt;22.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tests with the direct application of the oxidizing agents chlorine dioxide and ozone were not promising. No measureable degradation was noted with solutions or sediments in the laboratory or in direct sunlight. Success was obtained, however, with a combination of ozone and ultraviolet radiation.

Research on combined ozonation and ultraviolet irradiation has been most fully explored by Westgate Research Corporation in West Los Angeles. This organization has produced a small facility capable of treating solutions with the two oxidation processes in tandem. To test its applicability to the treatment of Kepone, a solution of 4.172 mg/l (ppm) Kepone was submitted for treatment. Subsequent effluent samples were found to contain 20.9 µg/l (ppb) after a batch exposure period of 1.5 hrs.

As noted previously, ultraviolet irradiation processes are limited in that degradation can occur only at exposed surfaces receiving direct irradiation. Hence, these results will not necessarily translate to solids or slurry systems. This is illustrated by results presented in Table 3. The addition of carbon particles to synthetic scrubber waters reduced removal in the 1 and 2 hour exposure periods.

In studies with wastewater effluent from the Hopewell sewage treatment plant, UV-ozonation was found quite effective for reduction of Kepone levels as noted in Table 4.
### TABLE 3. Effect of Westgate Process on Synthetic Scrubber Water

<table>
<thead>
<tr>
<th>Exposure Period, hr - Residuals Level, µg/l</th>
<th>Removal, hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear Solution</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>11,415</td>
</tr>
<tr>
<td>Solution with Carbon Particles</td>
<td>10,300</td>
</tr>
</tbody>
</table>

### TABLE 4. The Effect of UV-Ozonalysis on the Kepone Level in Wastewater Effluent from the Hopewell Sewage Treatment Plant

<table>
<thead>
<tr>
<th>Exposure Period, Minutes</th>
<th>Kepone Concentration, µg/l (ppb)</th>
<th>Removal, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.77</td>
<td>--</td>
</tr>
<tr>
<td>15</td>
<td>0.66</td>
<td>14</td>
</tr>
<tr>
<td>30</td>
<td>0.24</td>
<td>69</td>
</tr>
<tr>
<td>45</td>
<td>0.11</td>
<td>86</td>
</tr>
<tr>
<td>60</td>
<td>0.096</td>
<td>88</td>
</tr>
</tbody>
</table>

Based on these data, it is concluded that the Westgate process is effective in reducing Kepone levels in aqueous media and could be an effective means of treatment for elutriate, wastewater, and contaminated natural waters.

Cost projections developed by Westgate Research indicate a capital cost of $125-140,000 per MGD capacity and operating and maintenance costs (including amortization) of $0.11-0.12 per 1000 gallons treated.

If a small capacity elutriate treatment plant were constructed, unit costs would increase considerably. For a 3 MGD plant, the capital costs are $2,100,000 ($706,000 per MGD treated) and the operating costs are $0.47 per 1000 gallons ($0.23/1000 gal amortization, $0.097/1000 gal maintenance).
During decontamination efforts at the former Life Science Products Plant in early 1976, the EPA mobile spill treatment trailer was brought to Hopewell to purify washwaters and liquid wastes. At that time it was noted that carbon adsorption was effective in removing Kepone from solution. Because of this prior work, no specific laboratory studies were conducted on activated carbon applications to elutriate waters. However, adsorption isotherms produced during related work confirm the efficacy of this approach. Therefore, this option is considered viable if treatment facilities are to be constructed. Specific data on carbon capacity for Kepone are given in Table 5. Capital costs for a 50 MGD plant are estimated at $29 million without pretreatment and $43 million with pretreatment. Operating costs run $0.05 per 1000 gallons without pretreatment and exclusive of amortization. Pretreatment adds $0.12 per 1000 gallons in operating costs.

IN SITU PROCESSES

In situ processes as a category are the newest of the approaches to removal/mitigation of in-place toxic materials. As such, they are understandably less fully developed than other approaches, and may offer benefits as yet unmeasured. Several of the more promising options were selected for testing in the laboratory.

Biological options were dismissed early in the effort. As noted previously, degradation does not proceed with naturally occurring bacteria and fungi and mold isolates capable of degradation cannot survive in the natural sediment. However, biological organisms can be used to concentrate Kepone in a form which can be more readily harvested than the sediments themselves. While algae and fish are capable of such concentration, they uptake the Kepone from the water. The bulk of the Kepone residuals lie in the sediments. Accumulation from the water would only stimulate desorption from sediments and years would be required to remove substantial amounts. Consequently, attention was focused on organisms which could extract and concentrate Kepone from sediments. In subsequent studies with rooted plants, it was determined that any uptake which occurred was related to sorption on root tissue. No transport to the stem and leafy parts was observed. Hence, the approach was deemed ineffective.

Previous work with buoyant media (4-6) has produced promising results on soluble contaminants. This stimulated interest in using heavier than water sorbents to extract Kepone from sediments and thereby reduce availability to the water column. The media can be placed on the bottom as a permanent addition to the sediment, or it can be made retrievable so that Kepone (or other contaminants) can be physically removed from the waterbody. Retrievable media was produced by incorporating magnetite particles in the matrix of synthetic macroreticular resins. The resultant particles are readily picked up with a magnetic device leaving the cleansed sediments behind.

To screen media for application in areas where sediments are contaminated with Kepone, candidate sorbents were employed in batch adsorption evaluations. The latter were conducted using dilutions mixed from a stock. Kepone solution in distilled water and concentrated HCl for
<table>
<thead>
<tr>
<th>Sorbent</th>
<th>Residual Con. in Water; (ppb)</th>
<th>% Removal</th>
<th>Partition Con. in Water; Con. in Sorbent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blank</td>
<td>3374</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>ES 863 (a)</td>
<td>2.86</td>
<td>99.9</td>
<td>$4.2 \times 10^{-6}$</td>
</tr>
<tr>
<td>C 464 (a)</td>
<td>705</td>
<td>79.1</td>
<td>$1.3 \times 10^{-3}$</td>
</tr>
<tr>
<td>S 37 (a)</td>
<td>812</td>
<td>75.9</td>
<td>$1.5 \times 10^{-3}$</td>
</tr>
<tr>
<td>S 761 (a)</td>
<td>1071</td>
<td>68.3</td>
<td>$2.3 \times 10^{-3}$</td>
</tr>
<tr>
<td>XAD-7 (b)</td>
<td>50.2</td>
<td>98.5</td>
<td>$7.5 \times 10^{-5}$</td>
</tr>
<tr>
<td>XAD-4 (b)</td>
<td>3.15</td>
<td>99.9</td>
<td>$4.7 \times 10^{-6}$</td>
</tr>
<tr>
<td>XAD-2 (b)</td>
<td>4.99</td>
<td>99.8</td>
<td>$7.4 \times 10^{-6}$</td>
</tr>
<tr>
<td>Carbon Microballoons (c)</td>
<td>1283</td>
<td>61.9</td>
<td>$3.1 \times 10^{-3}$</td>
</tr>
<tr>
<td>Filtrasorb 3000 (d)</td>
<td>3.21</td>
<td>99.9</td>
<td>$4.8 \times 10^{-6}$</td>
</tr>
<tr>
<td>Magnetic ES 863</td>
<td>18.0</td>
<td>99.5</td>
<td>$2.7 \times 10^{-5}$</td>
</tr>
<tr>
<td>Blank II</td>
<td>2400</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Anthracite</td>
<td>1515</td>
<td>37</td>
<td>$8.5 \times 10^{-3}$</td>
</tr>
<tr>
<td>Hi Volatile Bituminous</td>
<td>2010</td>
<td>16</td>
<td>$2.6 \times 10^{-2}$</td>
</tr>
<tr>
<td>Subbituminous</td>
<td>1520</td>
<td>37</td>
<td>$3.6 \times 10^{-3}$</td>
</tr>
<tr>
<td>Lignite</td>
<td>607</td>
<td>75</td>
<td>$1.7 \times 10^{-3}$</td>
</tr>
<tr>
<td>Blank III</td>
<td>765</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Ambersorb XE</td>
<td>17.9</td>
<td>98</td>
<td>$1.2 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

(a) Product of Diamond Shamrock  
(b) Product of Rohm and Haas  
(c) Product of Bently Laboratories  
(d) Product of Calgon
adjustment to pH 7. One gram of media was applied to each 200 ml sample and placed on a horizontal displacement shaker for 24 hours. Results of subsequent analysis are provided in Table 5. For reference, the partition coefficient for standard sediments was found to be 2-3 x 10^-4.

Based on these results, ES863, XAD-4, XAD-2, and Filtrasorb 300 were selected for further study. The three proprietary products are synthetic sorbents produced commercially. The Filtrasorb 300 is a commercial activated carbon.

Further testing was conducted through the use of a series of test aquariums. A 500 ml (0.232 gal) sample of "standard" Bailey Bay sediment (1.17 mg/l ppm Kepone) was placed in each 200 ml beaker and covered with 1000 ml of water. A set of beakers was designated for each sorbent and for control purposes so that a discrete group of beakers could be sacrificed at the end of each observation period. Each sorbent beaker received 5 grams of sorbent and was allowed to sit for two weeks. At that time, the first group of beakers (a control and one for each of the sorbents) was sacrificed for analysis. Sorbents were then mixed down into the sediment in the remaining beakers for 4, 8, and 12 week analyses. Results of sediment analysis after sacrifice and removal of sorbents are presented in Table 6. The transfer of Kepone from sediments to sorbents was verified through analysis of regenerate solutions for each sorbent.

Insufficient time was available to prepare magnetically retrievable sorbents other than the one magnetic carbon and the ES863. Consequently, other means of separation were needed to proceed with the analysis of sediments and sorbent regenerate solutions. The magnetic carbon and resin were removed with electromagnets. Filtrasorb was removed by visual inspection.

Based on data obtained in these studies, it is estimated that use of activated carbon for in situ mitigation can be done on a throwaway basis (no retrieval). This will reduce the availability of the contaminate but not remove or destroy it. Such an approach would cost $0.52 per ft^2 of sediment treated. If removal is desired, the preferred approach is use of retrievable synthetic sorbents. Assuming losses of 25 percent and use of two applications, it is estimated that this approach would cost $0.90 per ft^2 of sediment treated.

The use of polymer films was also investigated as a means of preventing Kepone from moving into the water column. This approach has been discussed previously for application to mercury contaminated sediments. Because Kepone has not been shown to degrade in the environment, such an action would be interim in nature. Further, the need to perforate the film to allow for release of degradation gases formed in the sediments jeopardizes the integrity of the seal. Consequently, the approach was not judged appropriate for use on Kepone contaminated sediments.

APPRAISAL

Based on the work summarized here, it was concluded that the most effective means of mitigating Kepone contamination in the James River would be the use of sorbents or dredging technology and associated spoils.
TABLE 6. Results of Aquarium Studies with Sorbents

<table>
<thead>
<tr>
<th>Sorbent</th>
<th>2 wk</th>
<th>4 wk</th>
<th>8 wk</th>
<th>12 wk</th>
<th>Maximum Removal %</th>
</tr>
</thead>
<tbody>
<tr>
<td>XAD-2(a)</td>
<td>0.80</td>
<td>0.53</td>
<td>1.19</td>
<td></td>
<td>65</td>
</tr>
<tr>
<td>XAD-4(a)</td>
<td>1.18</td>
<td>1.06</td>
<td>0.99</td>
<td></td>
<td>32</td>
</tr>
<tr>
<td>863(b)</td>
<td>0.89</td>
<td>0.72</td>
<td>1.21</td>
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<td>54</td>
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<tr>
<td>FILTRASORB(c)</td>
<td>1.21</td>
<td>1.06</td>
<td>1.00</td>
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<tr>
<td>Magnetic Carbon</td>
<td>1.56</td>
<td>1.23</td>
<td>1.24</td>
<td>1.04(d)</td>
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<td>1.16</td>
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<td>0.82</td>
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<td>0.92</td>
<td>1.18</td>
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</tbody>
</table>

(a) Product of Rohm and Haas
(b) Product of Diamond Shamrock
(c) Product of Calgon
(d) Analysis of the spent carbon revealed 1.07 µg/g Kepone disposal.

Unit costs for related alternatives are presented in Table 7. The competitiveness of the retrievable media approach suggest that this option deserves further development efforts.

This work was performed with funds provided by the Environmental Protection Agency through an interagency agreement with the Department of Energy.
<table>
<thead>
<tr>
<th>Collection Technique</th>
<th>Disposal Alternatives</th>
<th>Cost ($/ft³)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throw Away Activated Carbon</td>
<td>Incineration of Regenerate</td>
<td>0.52</td>
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<tr>
<td>Retrievable Sorbents</td>
<td>Ocean Dumping</td>
<td>0.90</td>
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<td>Ocean Dumping</td>
<td>1.02</td>
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<td>Ocean Dumping</td>
<td>1.07</td>
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<td>Molten Sulfur Stabilization</td>
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<td>Incineration</td>
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<tr>
<td>Dragline Dredge</td>
<td>Molten Sulfur Stabilization</td>
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<td>Dragline Dredge</td>
<td>Ocean Dumping</td>
<td>1.81</td>
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</table>

*Assumes contamination is one foot deep.
REFERENCES


