
**REMEDIAL TECHNOLOGY REVIEW FOR
HUDSON RIVER REMNANT DEPOSITS**

FOR:

GENERAL ELECTRIC COMPANY
GE Corporate Environmental Programs
Albany, New York

December 1992

BY:
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December 28, 1992

Mr. Douglas J. Tomchuk
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26 Federal Plaza
New York, New York 10278

RE: HUDSON RIVER REMNANT DEPOSITS
REMEDIAL TECHNOLOGY REVIEW REPORT

Dear Mr. Tomchuk:

Please find enclosed the report entitled "Remedial Technology Review for Hudson River Remnant Deposits". This report was developed pursuant to the requirements of the September 1989 Administrative Consent Order between EPA Region II and GE (Index No. II, CERCLA-90224) and the approved Scope of Work dated August 1992.

This report does not constitute a Feasibility Study (FS) within the context of the Federal Superfund program. General Electric firmly believes that the capping remedy implemented at the Hudson River remnant deposits was the correct remedy to select. The review of potentially applicable technologies and the evaluation of technologies contained in the attached report is only of a theoretical nature and should in no way be construed to mean or suggest any other remedy than capping at the remnant deposits is necessary.

Please let me know if you have any questions or concerns with the report.

Yours very truly,

John G. Haggard
Engineering Project Manager

Enclosure

cc: Remnant Deposits Distribution

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EXECUTIVE SUMMARY

This Remedial Technology Review (RTR) report has been prepared by Applied Environmental Management, Inc. (AEM) for General Electric Company in compliance with the September 1989 Consent Order (Consent Index No. II CERCLA-90224) between General Electric and the U.S. EPA. This RTR report presents (1) a description of current site conditions at four of the Hudson River remnant deposit sites and (2) an evaluation of remedial technologies that could be applicable to the remnant deposit materials. The remnant deposits are four separate sediment areas on the banks of the Hudson River, which became exposed when a 150-year old dam at the Town of Fort Edward was removed in 1973, causing the water level in the dam pool to drop. The four remnant deposits, designated No. 2, 3, 4, and 5 in a north-to-south orientation, are located along a one and one-half mile reach of the river in Saratoga and Washington Counties, New York. The four remnant deposits were capped in 1990-91. The cap is an in-place containment remedy implemented by General Electric in accordance with the Consent Order.

The remnant deposits beneath the cap consist of unconsolidated deposits of silty sand, gravel, sawdust, and wood chips which originated from the once extensive lumber industry located upstream. The remnant deposits also contain elevated levels of polychlorinated biphenyls (PCBs) and heavy metals, notably cadmium, chromium, and lead. The cap system consists of, in ascending order, subgrade fill material, a sand fill bedding layer, an impervious geosynthetic Claymax liner, a sand drainage layer, topsoil, and vegetative cover. The subgrade fill material and cap averages four to six and one-half feet in depth, and totals (for all four remnant deposits) an estimated 425,000 cubic yards.

A soil boring and sampling analysis program was undertaken and completed in 1990 to provide PCB and heavy metals characterization data for the remnant deposits, prior to cap installation. The program resulted in installation of 288 boreholes and collection and analysis of associated two-foot split spoon samples. Using these characterization data, AEM

has estimated that roughly 300,000 cubic yards (500,000 tons) of remnant deposit materials beneath the cap contain greater than 5 ppm PCBs. Approximately ninety percent of this volume is contained within the first six feet below the pre-cap ground surface.

Fourteen remedial technologies potentially applicable for (1) reduction of PCB levels in the remnant deposits by treatment or removal or (2) immobilizing or containing PCBs in-place, were identified and evaluated. The evaluation is qualitative in nature consistent with (1) the technology review objective of this report and (2) the uncertainties regarding the full-scale capabilities, constraints, and costs for many of the remedial technologies.

The fourteen potentially applicable remedial technologies/approaches included:

- Capping (already implemented)
- Total Containment with Barriers
- In-Situ Solidification/Stabilization
- In-Situ Vitrification
- In-Situ Natural Biodegradation
- In-Situ Enhanced Biodegradation
- Ex-Situ Solidification/Stabilization
- Solvent Extraction
- Soil Washing
- Thermal Desorption
- Dechlorination
- Onsite Incineration
- Disposal Offsite at a Permitted Landfill
- Disposal Offsite at a Permitted Incinerator

These technologies were qualitatively evaluated using three comparison criteria: effectiveness, implementability, and cost. Major difficulties associated with implementability of each of these remedial technologies at the remnant deposits were identified. The extent of these major difficulties, coupled with the fact that the majority of the remedial technologies have not been demonstrated on a large-scale for PCB-contaminated soils or sediments, suggest that the already implemented in-place containment remedy (cap) may represent the most practical, effective, and least intrusive remedial technology for remnant deposit PCBs.

REMEDIAL TECHNOLOGY REVIEW FOR HUDSON RIVER REMNANT DEPOSITS

SECTION 1

INTRODUCTION

1.1 PURPOSE

This Remedial Technology Review (RTR) report presents (1) a description of current site conditions at four of the Hudson River remnant deposit sites and (2) an evaluation of remedial technologies that could be applicable to the media which comprise the remnant deposits.

1.2 BACKGROUND¹

The remnant deposits are located along a one and one-half mile reach of the Hudson River, in Saratoga and Washington Counties, New York. These deposits are exposed sediment and debris which accumulated immediately upstream of a former dam at the Town of Fort Edward. When the dam (originally built in 1822) was removed in 1973, the water level in the dam pool dropped, exposing five separate remnant deposit areas (designated Remnant No. 1 through 5 inclusive, in a north to south orientation). Two of the remnant deposit areas (Nos. 2 and 4) are located on the west bank of the Hudson River in Saratoga County, two (Nos. 3 and 5) are located on the east bank in Washington County, and one (No. 1) is an island in the middle of the river. Remnant No. 1 is a small island in the river which has been substantially altered by the river flow since the dam removal.

Figure 1 (located at the end of this document) illustrates the location of Remnant No. 1 and the location and configuration of Remnants No. 2 through 5.

¹ Information in this background section is derived from References A through G.

The remnants consist generally of unconsolidated deposits of silty sand, gravel, sawdust, and wood chips and extend from the river bank to the former dam pool elevations. The sawdust, wood chips, and other related debris originated from the once extensive lumber industry located upstream. The remnant deposits also contain areas with elevated concentrations of polychlorinated biphenyls (PCBs). Upstream industrial discharges over the years also have contributed substantial quantities of metals to the remnant deposits, most notably cadmium, chromium, and lead.

Several remedial activities were performed on the remnant deposits between 1974 and 1978 by the New York State Department of Transportation in response to concerns associated with the elevated PCB concentrations, including:

- Grading and stabilizing (with stone riprap) the banks of Remnants No. 3 and 5;
- Cutting back the bank at Remnant No. 2 to a more shallow slope to limit erosion, and placement of the removed material on higher ground at the edge of the former dam pool; and
- Excavating a shallow volume of sediments "highly contaminated with PCBs" from the northeast area of Remnant No. 3. This area was designated 3A; the volume has been variously reported as 9700, 14,000, or 17,000 cubic yards. This excavated volume was placed in the New Moreau containment cell in the nearby Town of Moreau.

In September 1984, the "Hudson River PCBs Site" was placed on the National Priority List by the U. S. Environmental Protection Agency (EPA). Subsequently, the EPA issued a Record of Decision (Reference B) which, among other things, recommended an "in-place containment remedy," to include in-place containment of the remnant deposits by application of a soil covering, and vegetation, and stabilization of banks. In March 1989, General Electric Company assumed responsibility for the implementation of the in-place containment remedy, an agreement which is documented in a September 1989 Consent

Order (Consent Index No. II CERCLA-90224) (Reference D) between General Electric and EPA and in a 1990 Consent Decree (Reference E) between the same two parties.

The in-place containment ("capping") of Remnant Deposits No. 2, 3, 4, and 5 was accomplished during the period July 1990 through April 1991. Seeding (revegetation) was completed by October 1991. Remnant Deposit No. 1 was not included in this program due to its in-river location and its typically underwater condition. The cap system for each of the four remnant deposits consisted of, in ascending order, subgrade fill material, a sand fill bedding layer, an impervious geosynthetic composite liner called Claymax consisting of bentonite sandwiched between geotextile fabric, a sand drainage layer, topsoil, and vegetative cover. A typical cross-section of the cap is shown on Figure 1. The horizontal limits of the cap on the inland boundaries were, in all but a few isolated instances, extended to at least five feet beyond the 5 ppm PCB boundary (as determined by a soil boring and sampling program at each of the four remnant areas prior to installation of the cap). The few isolated instances where this was not accomplished were as a result of the presence of physical obstructions or steep topography.

One of the provisions in the 1989 Consent Order (paragraphs 33 through 39) requires that General Electric prepare a report to evaluate remedial technologies which may be available for use on the remnant deposits. This activity is referred to as the remedial technology review (RTR) and is the subject of this document.

By letter dated September 6, 1991, General Electric submitted to EPA, in response to EPA's formal request, a scope of work for performing the RTR. By letter of August 3, 1992, EPA provided review comments on the RTR Scope of Work. These comments were addressed by General Electric and a revised, final RTR Scope of Work was issued on August 20, 1992 which designated November 21, 1992 as the due date for this RTR document. The due date was subsequently extended to December 31, 1992.

1.3 APPROACH

This RTR does not constitute a feasibility study (FS) as defined by the EPA Superfund Program although some of its elements are similar. Rather, it is an evaluation of remedial technologies that could be applicable to the media which comprise the remnant deposits.

This document contains the results of the RTR and comprises the following three major topics:

- Description of the current site conditions at Remnants No. 2, 3, 4, and 5;
- Identification, description, and summary of potentially applicable remedial technologies; and
- Comparison and relative assessment of the remedial technologies.

SECTION 2

SITE CONDITIONS

2.1 ACCESS AND SURROUNDINGS

The immediate surroundings on the inland side of Remnants No. 2, 3, and 4 are generally wooded and undeveloped. The north side of Remnant No. 5 abuts a sharply sloping (upward) fifty-foot wide wooded corridor, which in turn abuts residences and commercial properties in the Town of Fort Edward. The east side of Remnant No. 5 abuts the Scott Paper Company property.

To support the capping program, a system of unpaved roads was constructed on the west side of the Hudson River to provide access from town roads to Remnants No. 2, 3, and 4, and to a local borrow pit. The roads were supplemented by erection of a temporary steel pier bridge across the Hudson River to allow access to Remnant No. 3 from the west side of the river. The roads are continuing to be maintained for current and future use. The bridge system has been dismantled and removed. The only parts of the bridge still in place are the concrete abutments at each river bank.

Remnant No. 3 also can be accessed from the east side of the river via an existing unpaved access road which traverses pasture land on top of a bluff overlooking the river and then descends sharply through a wooded area to the remnant deposit. Remnant No. 5 is accessed from a public road northwest of the Scott Paper Company facility.

2.2 CHARACTERIZATION DATA (PRE-CONSTRUCTION)

2.2.1 Overview of Data

The descriptions of pre-construction site conditions contained in this section were derived from boring logs and sample analytical data presented in Reference F and survey data and As-Built Drawings presented in Reference G. The Reference F program was conducted in

August and September of 1990, prior to the in-place containment ("capping") work, to provide PCB and metals characterization data for the overall remnant deposits and PCB characterization data at the inland boundaries to define the limits for capping (5 ppm PCBs).

As part of the Reference F overall remnant deposit characterization, a total of 59 boreholes were advanced at Remnants Nos. 2 through 5 (12 boreholes at No. 2, 19 at No. 3, 17 at No. 4, and 11 at No. 5). Boring depths ranged from six to 32 feet. A total of 426 two-foot split-spoon samples were collected and analyzed for PCBs. A total of 129 of these split-spoon samples were also analyzed for cadmium, chromium, and lead. Blow counts (USCS Standard Penetration Test Procedure) were recorded during installation of all 59 boreholes.

An additional 229 four-foot deep boreholes were advanced and split-spoon samples were analyzed at two-foot intervals for PCBs to define the inland cap boundaries of Remnants No. 2 through 5.

These characterization data are assumed representative of the soil² conditions and the concentrations and locations of PCB and metal contamination in the soils beneath the cap at each remnant deposit. It must be recognized, however, that this assumption is not strictly valid since some of the cut and fill activities which occurred in preparation of the sub-grade prior to cap placement most likely redistributed and repositioned some of the existing shallow surface soils. Nonetheless, no soil materials were removed from the remnant areas during the cut and fill activities.

2.2.2 Remnant No. 2

Soil conditions beneath the cap at Remnant No. 2 are summarized in the soil descriptions on Figure 2. Tables 2 and 6 summarize the PCB concentrations and selected metals

²Although Remnants No. 2 through 5 consist of sediment deposits which became exposed above the river level following removal of a dam at the Town of Fort Edward in 1973, the term soil is used to avoid confusion with in-river sediments.

concentrations, respectively, at different depth intervals. (Tables 2 through 9 are on pages 10 through 17.)

The volume of soil containing PCBs at greater than 5 ppm (dry weight) is estimated at 22,000 cubic yards, extending down to ten feet below pre-construction grade in at least one region of the site. Ninety percent of these 22,000 cubic yards is contained within the first six feet below the pre-construction ground surface.

2.2.3 Remnant No. 3

Soil conditions beneath the cap at Remnant No. 3 are summarized in the soil descriptions on Figure 3. Tables 3 and 7 summarize the PCB concentrations and selected metals concentrations, respectively, at different depth intervals.

The volume of soil containing PCBs at greater than 5 ppm (dry weight) is estimated at 135,000 cubic yards, extending down to ten feet below pre-construction grade in at least two separate regions of the site. Ninety percent of these 135,000 cubic yards is contained within the first six feet below the pre-construction ground surface.

2.2.4 Remnant No. 4

Soil conditions beneath the cap at Remnant No. 4 are summarized in the soil descriptions on Figure 4. Tables 4 and 8 summarize the PCB concentrations and selected metals concentrations, respectively, at different depth intervals.

The volume of soil containing PCBs at greater than 5 ppm (dry weight) is estimated at 89,000 cubic yards, extending down only to a maximum of six feet below pre-construction grade.

2.2.5 Remnant No. 5

Soil conditions beneath the cap at Remnant No. 5 are summarized in the soil descriptions on Figure 5. Tables 5 and 9 summarize the PCB concentrations and selected metals

concentrations, respectively, at different depth intervals.

The volume of soil containing PCBs at greater than 5 ppm (dry weight) is estimated at 46,000 cubic yards, extending down 12 to 14 feet below pre-construction grade in at least one region (east-central) of the site. Seventy percent of these 46,000 cubic yards is contained within the first six feet below the pre-construction ground surface.

2.2.6 Comparison of Remnants

Table 1 summarizes the remnant characteristics described above. Based on a review of the characterization data presented herein, it appears that no one of the four remnants has dramatically different characteristics than the others. Accordingly, a remedial technology judged applicable for one site is likely applicable for all four sites.

Overall, 262,000 (ninety percent) of the estimated 292,000 cubic yards which contain PCBs at greater than 5 ppm are within the first six feet below the pre-construction ground surface. However, PCB concentrations of greater than 5 ppm extend to ten to 14 feet below the pre-construction grade in localized regions at three of the four remnant deposit sites.

Pertinent comparisons of the remnant deposits follow.

- All four remnants show PCB, cadmium, chromium, and lead concentrations of similar orders of magnitude and at similar depth intervals (Tables 2 through 9).
- Remnant No. 5 shows some localized PCB concentrations in excess of 5 ppm at a greater depth than the other three remnant sites. Also, Remnant No. 5 samples showed a consistently higher weight percent moisture (average³ of 38 - 57% across

³ Moisture percent in all samples at each two-foot depth interval were averaged. The range of averages presented above represents the lowest average across any depth interval and the highest average across any depth interval. For example, for Remnant No. 5, all split-spoon samples across the 0 to 2 foot depth interval averaged 38% moisture and across the 14 to 16 foot depth interval averaged 57% moisture.

TABLE 1
REMNANT DEPOSIT SUMMARY

<u>REMNANT DEPOSIT</u>	<u>SURFACE AREA (acres)¹</u>	<u>VOLUME² WITH >5 ppm PCBs (cy)</u>	<u>COVER³ VOLUME (cy)</u>
2	3.4	22,000	23,000
3	19.6	135,000	205,000
4	22.9	89,000	148,000
5	5.7	46,000	49,000
<hr/>			
TOTALS	51.6	292,000	425,000
ROUNDED TOTAL		300,000	
NOTES: 1. Surface area is measured to the boundaries of the geosynthetic Claymax liner (reference As-Built Drawings in Reference G for boundary locations).			
2. This volume is beneath the pre-construction ground surface, i.e. beneath the cover volume.			
3. In-place (i.e. compacted) cover volumes are calculated from the difference in pre-construction surface elevations (from Reference F soil boring logs) and post-construction surface elevations (from As-Built Drawings in Reference G).			

TABLE 2
REMNANT No. 2 PCBs¹

Depth Interval (feet)	No. of Sample Locations ²	PCB Average (ppm) ³	PCB Median (ppm) ⁴	PCB Range (ppm)	% Moisture Range ⁵
0-2	12	112 J	26 - 37.2 J	0.99 - 490 J	14-42
2-4	12	11.7 J	5.2 J - 10.6	0.50 - 61 J	12-38
4-6	12	10.4 J	0.72 J - 0.75	ND - 51	8-42
6-8	12	1.4 J	0.27 - 0.29 J	ND - 12.1 J	14-51
8-10	10	8.2 J	0.49 J - 0.61	ND - 75.2 J	18-50
10-12	11	0.47 J	0.39	ND - 1.2	18-50
12-14	10	0.05 J	ND	ND - 0.27	18-74
14-16	9	0.28	ND	ND - 1.7	25-47
16-18	6	ND	ND	ND	30-66
18-20	3	0.83	ND	ND - 2.5 ⁶	23-31

REMNANT No. 2 SURFACE AREA⁷: 3.4 acres

- NOTES:**
1. All PCB results are reported as Aroclor 1242 in ppm, dry weight basis. "J" means quantitation is approximate. The depth interval (first column) is measured from the pre-construction ground surface (i.e. prior to capping).
 2. Non-boundary samples only. Locations with duplicate results are counted as one sample location. All sample results are counted in the range. However, when determining average and median, an individual result is ascribed to each location by first averaging duplicate results.
 3. A "J" indicates that the average included one or more individual "J" values. ND's are counted as "zero" for calculating averages.
 4. A "J" indicates that the median value is a "J" value.
 5. Weight percent moisture values are listed in the August 1990 boring logs (Reference F).
 6. Interval 19-21 feet.
 7. Surface area is measured to the boundaries of the geosynthetic Claymax liner.

TABLE 3
REMNANT No. 3 PCBs¹

<u>Depth Interval (feet)</u>	<u>No. of Sample Locations²</u>	<u>PCB Average (ppm)³</u>	<u>PCB Median (ppm)⁴</u>	<u>PCB Range (ppm)</u>	<u>% Moisture Range⁵</u>
0-2	19	168 J	28	ND - 1600	10-43
2-4	18	34.8 J	2.1 - 8.0 J	ND - 220	11-51
4-6	18	9.6 J	3.7 J - 4.7 J	ND - 64	13-66
6-8	16	8.4 J	1.8 - 2.3 J	ND - 81	20-59
8-10	15	6.8 J	0.79 J	ND - 72	15-60
10-12	10	0.68 J	ND - 0.21 J	ND - 5.7	16-46
12-14	6	0.16 J	ND	ND - 0.96 J ⁶	15-30
14-16	3	0.10	ND	ND - 0.29	26-30

REMNANT No. 3 SURFACE AREA⁷: 19.6 acres

- NOTES:**
1. All PCB results are reported as Aroclor 1242 in ppm, dry weight basis. "J" means quantitation is approximate. The depth interval (first column) is measured from the pre-construction ground surface (i.e. prior to capping).
 2. Non-boundary samples only. Locations with duplicate results are counted as one sample location. All sample results are counted in the range. However, when determining average and median, an individual result is ascribed to each location by first averaging duplicate results.
 3. A "J" indicates that the average included one or more individual "J" values. ND's are counted as "zero" for calculating averages.
 4. A "J" indicates that the median value is a "J" value.
 5. Weight percent moisture values are listed in the August 1990 boring logs (Reference F).
 6. Interval 13-15 feet.
 7. Surface area is measured to the boundaries of the geosynthetic Claymax liner.

TABLE 4
REMNANT No. 4 PCBs¹

<u>Depth Interval (feet)</u>	<u>No. of Sample Locations²</u>	<u>PCB Average (ppm)³</u>	<u>PCB Median (ppm)⁴</u>	<u>PCB Range (ppm)</u>	<u>% Moisture Range⁵</u>
0-2	16	37.0 J	5.7 - 6.4 J	0.37 J - 140	14-54
2-4	17	25.9 J	1.4	0.07 J - 480 J	10-65
4-6	16	4.6 J	0.80 - 1.5	ND - 28 J	9-51
6-8	16	0.35 J	ND - 0.09	ND - 2.1	11-62
8-10	17	0.53 J	ND	ND - 3.5 J	5-55
10-12	13	0.22 J	ND	ND - 0.97	17-48
12-14	10	0.09 J	ND	ND - 0.54 J	15-44
14-16	6	0.20	ND	ND - 1.2	17-47
16-18	4	ND	ND	ND	15-32
18-20	2	ND	ND	ND	16-19

REMNANT No. 4 SURFACE AREA⁶: 22.9 acres

- NOTES:**
1. All PCB results are reported as Aroclor 1242 in ppm, dry weight basis. "J" means quantitation is approximate. The depth interval (first column) is measured from the pre-construction ground surface (i.e. prior to capping).
 2. Non-boundary samples only. Locations with duplicate results are counted as one sample location. All sample results are counted in the range. However, when determining average and median, an individual result is ascribed to each location by first averaging duplicate results.
 3. A "J" indicates that the average included one or more individual "J" values. ND's are counted as "zero" for calculating averages.
 4. A "J" indicates that the median value is a "J" value.
 5. Weight percent moisture values are listed in the September 1990 boring logs (Reference F).
 6. Surface area is measured to the boundaries of the geosynthetic Claymax liner.

TABLE 5
REMNANT No. 5 PCBs¹

Depth Interval (feet)	No. of Sample Locations ²	PCB Average (ppm) ³	PCB Median (ppm) ⁴	PCB Range (ppm)	% Moisture Range ⁵
0-2	11	118 J	57 J	0.19 - 356	25-65
2-4	10	31.9 J	5.5 - 8.1 J	ND - 170 J	19-68
4-6	11	9.0 J	1.8 J	ND - 37 J	15-60
6-8	9	6.0 J	0.71 J	0.23 - 20.5	17-66
8-10	11	0.95 J	0.49 J	ND - 2.9 J	22-72
10-12	9	1.6 J	0.2 J	ND - 8.5 J	23-64
12-14	10	2.8 J	0.46 J - 0.59 J	ND - 18 J	23-68
14-16	8	0.6 J	0.17 J - 0.2 J	ND - 3.4 J	29-70
16-18	6	0.96 J	0.14 J - 1.5	ND - 2.1	26-72
18-20	3	0.43	ND	ND - 1.3	16-75
20-22	1	ND	---	ND	12
22-24	2	ND	ND	ND	14-20
24-26	1	ND	---	ND	21
26-28	1	ND	---	ND	22

REMNANT No. 5 SURFACE AREA⁶: 5.7 acres

- NOTES:**
1. All PCB results are reported as Aroclor 1242 in ppm, dry weight basis. "J" means quantitation is approximate. The depth interval (first column) is measured from the pre-construction ground surface (i.e. prior to capping).
 2. Non-boundary samples only. Locations with duplicate results are counted as one sample location. All sample results are counted in the range. However, when determining average and median, an individual result is ascribed to each location by first averaging duplicate results.
 3. A "J" indicates that the average included one or more individual "J" values. ND's are counted as "zero" for calculating averages.
 4. A "J" indicates that the median value is a "J" value.
 5. Weight percent moisture values are listed in the September 1990 boring logs (Reference F).
 6. Surface area is measured to the boundaries of the geosynthetic Claymax liner.

TABLE 6
REM NANT No. 2 SELECTED METALS ¹

Depth Interval (feet)	No. of Sample Locations ²	Cadmium		
		Average (ppm) ³	Median (ppm) ⁴	Range (ppm)
0-2	9	6.9 J	5.3	1.2 J - 16
2-4	8	3.0 J	1.7 J - 4.0	ND - 6.1
4-6	9	4.4 J	4.0	ND - 9.6
		Chromium		
		Average (ppm) ³	Median (ppm) ⁴	Range (ppm)
0-2	9	137 J	126 J	34 - 225
2-4	8	52 J	33 - 35	9.1 - 102 J
4-6	9	29 J	29	3.5 - 56
		Lead		
		Average (ppm) ³	Median (ppm) ⁴	Range (ppm)
0-2	9	129 J	112	32 J - 224
2-4	8	51 J	39 J - 43 J	13 - 93
4-6	9	45 J	44	9.8 - 74

NOTES:

1. All results are reported in ppm, dry weight basis. "J" means quantitation is approximate. The depth interval (first column) is measured from the pre-construction ground surface (i.e. prior to capping).
2. Non-boundary samples only. Locations with duplicate results are counted as one sample location. All sample results are counted in the range. However, when determining average and median, an individual result is ascribed to each location by first averaging duplicate results.
3. A "J" indicates that the average included one or more individual "J" values. ND's are counted as "zero" for calculating averages.
4. A "J" indicates that the median value is a J-value.

TABLE 7
REM NANT No. 3 SELECTED METALS ¹

<u>Depth Interval (feet)</u>	<u>No. of Sample Locations²</u>	<u>Cadmium</u>		
		<u>Average (ppm)³</u>	<u>Median (ppm)⁴</u>	<u>Range (ppm)</u>
0-2	14	10.2 J	5.7 J - 5.9	ND - 42
2-4	13	4.5 J	4.8 J	ND - 11 J
4-6	12	4.1 J	3.3 J - 3.7	ND - 13 J
		<u>Chromium</u>		
		<u>Average (ppm)³</u>	<u>Median (ppm)⁴</u>	<u>Range (ppm)</u>
0-2	14	40.2 J	30 - 31 J	7.9 J - 124 J
2-4	13	30.5 J	14	6.9 J - 86 J
4-6	12	31.8 J	13 J - 14 J	6.7 - 115 J
		<u>Lead</u>		
		<u>Average (ppm)³</u>	<u>Median (ppm)⁴</u>	<u>Range (ppm)</u>
0-2	14	43.3 J	36 - 41	6 - 104
2-4	13	50.5 J	29	ND - 296
4-6	12	31 J	13 J - 18 J	ND - 103

NOTES:

1. All results are reported in ppm, dry weight basis. "J" means quantitation is approximate. The depth interval (first column) is measured from the pre-construction ground surface (i.e. prior to capping).
2. Non-boundary samples only. Locations with duplicate results are counted as one sample location. All sample results are counted in the range. However, when determining average and median, an individual result is ascribed to each location by first averaging duplicate results.
3. A "J" indicates that the average included one or more individual "J" values. ND's are counted as "zero" for calculating averages.
4. A "J" indicates that the median value is a J-value.

TABLE 8
REM NANT No. 4 SELECTED METALS ¹

Depth Interval (feet)	No. of Sample Locations ²	Cadmium		
		<u>Average (ppm)³</u>	<u>Median (ppm)⁴</u>	<u>Range (ppm)</u>
0-2	13	12 J	11	5.5 - 38
2-4	12	9.2 J	8.2 J - 8.8 J	4.5 J - 17 J
4-6	12	8.1 J	6.8 J - 6.9	3.6 - 17 J
		Chromium		
		<u>Average (ppm)³</u>	<u>Median (ppm)⁴</u>	<u>Range (ppm)</u>
0-2	13	139 J	114 J	13 - 375 J
2-4	12	54.5 J	26 J - 37 J	10 J - 155
4-6	12	26.5 J	19	3.2 J - 100 J
		Lead		
		<u>Average (ppm)³</u>	<u>Median (ppm)⁴</u>	<u>Range (ppm)</u>
0-2	13	139 J	109 J	16 - 311 J
2-4	12	58 J	43 J	11 J - 120
4-6	12	39 J	29 J	5.6 J - 127

NOTES:

1. All results are reported in ppm, dry weight basis. "J" means quantitation is approximate. The depth interval (first column) is measured from the pre-construction ground surface (i.e. prior to capping).
2. Non-boundary samples only. Locations with duplicate results are counted as one sample location. All sample results are counted in the range. However, when determining average and median, an individual result is ascribed to each location by first averaging duplicate results.
3. A "J" indicates that the average included one or more individual "J" values. ND's are counted as "zero" for calculating averages.
4. A "J" indicates that the median value is a J-value.

TABLE 9
REMNANT No. 5 SELECTED METALS ¹

<u>Depth Interval (feet)</u>	<u>No. of Sample Locations²</u>	<u>Cadmium</u>		
		<u>Average (ppm)³</u>	<u>Median (ppm)⁴</u>	<u>Range (ppm)</u>
0-2	7	1.8	1.1	ND - 5.8
2-4	5	0.16	ND	ND - 0.79
4-6	7	0.30	ND	ND - 0.85
		<u>Chromium</u>		
		<u>Average (ppm)³</u>	<u>Median (ppm)⁴</u>	<u>Range (ppm)</u>
0-2	7	137 J	104	9.9 J - 510
2-4	5	18	12	9.1 - 46
4-6	7	9.2 J	9.9	ND - 17
		<u>Lead</u>		
		<u>Average (ppm)³</u>	<u>Median (ppm)⁴</u>	<u>Range (ppm)</u>
0-2	7	207 J	132	29 J - 653
2-4	5	52	37	14 - 132
4-6	7	17 J	11	ND - 32

NOTES:

1. All results are reported in ppm, dry weight basis. "J" means quantitation is approximate. The depth interval (first column) is measured from the pre-construction ground surface (i.e. prior to capping).
2. Non-boundary samples only. Locations with duplicate results are counted as one sample location. All sample results are counted in the range. However, when determining average and median, an individual result is ascribed to each location by first averaging duplicate results.
3. A "J" indicates that the average included one or more individual "J" values. ND's are counted as "zero" for calculating averages.
4. A "J" indicates that the median value is a J-value.

each two-foot depth interval, from Reference F) as compared to the other three remnant sites (average of 21 - 40%).

- Surface water collection, diversion, and disposal were necessitated to varying degrees during construction of the caps.
- Variations in groundwater levels in the remnant deposits will be seasonal and are likely influenced by water levels in the river and precipitation events, however, these variations have not been quantified.

2.2.7 Additional Pre-Construction Characterization Data

Additional pre-construction characterization data important for assessing the condition of the remnant deposit sediments below the cap and the applicability of remedial technologies have been collected and are summarized below. These additional characterization data are reported in Reference F and are from the analysis of a split-spoon sample obtained from the two to four foot interval of one borehole advanced at each remnant deposit before installation of the cap.

- Target Analyte List (TAL) metals, in addition to cadmium, chromium, and lead, and either Total Organic Carbon (TOC) or Total Volatile Solids (TVS) results are listed in Table 10.
- No volatile organic compounds or pesticides were detected.
- Only ten of the 64 semi-volatile organic compounds analyzed were detected, and these ten were present only at low levels (maximum, fluoranthene at an estimated 3.3 ppm at Remnant No. 2). None of these ten compounds normally influence remedial actions.

TABLE 10
TAL METALS (ppm) AND TOTAL ORGANIC CARBON (TOC, in weight %)

Analyte	Remnant No. 2 ¹	Remnant No. 3 ¹	Remnant No. 3 ¹ (duplicate)	Remnant No. 4 ¹	Remnant No. 5 ¹
Aluminum	8230	3010 J	4540 J	----	7620
Antimony	ND	1.2 J	1.3 J	----	ND
Arsenic	1.9 J	1.2 J	2.1 J	----	1.3 J
Barium	26.1 J	55.1 J	71.0 J	----	88
Beryllium	ND	ND	ND	----	ND
Cadmium	--	4.5 J	4.7 J	----	5.3
Calcium	1610	1660 J	1990 J	----	4860
Chromium	27.2	56 J	66.9 J	----	20
Cobalt	11.6 J	3.8 J	4.5 J	----	6.2
Copper	25.2 J	22.9 J	25.2 J	----	26
Cyanide	0.52 J	ND	ND	----	ND
Iron	21,900 J	5020 J	5870 J	----	9140
Lead	18.6	51.7 J	54.3 J	----	41
Magnesium	4980	890 J	1060 J	----	1870
Manganese	387	37.6 J	46 J	----	74
Mercury	ND	0.15 J	0.17 J	----	0.23
Nickel	28.2 J	8.4 J	9.6 J	----	11
Potassium	906	559 J	719 J	----	543
Selenium	ND	ND	ND	----	ND
Silver	ND	ND	ND	----	3.4
Sodium	259	226	229	----	332
Thallium	ND	ND	ND	----	ND
Vanadium	25.6 J	10.1 J	16.6 J	----	22
Zinc	--	44.2 J	48.1 J	----	124
TOC	--	--	--	0.044%	--
TVS ²	8.8%	77.8%	76.8%	----	12.4%

- NOTES:**
- Results are from one split spoon sample at each remnant site, obtained at the 2-4 foot depth interval prior to capping. The TOC value and the TVS value in each instance is from a different sample location than the TAL metals. "J" means quantitation is approximate. No metal results are available for Remnant No. 4.
 - Total volatile solids (TVS), in weight %.

- Toxicity Characteristic Leaching Procedure (TCLP) analysis of the one split-spoon sample from each remnant deposit showed measurable concentrations of five of the TCLP metals (barium, cadmium, chromium, lead, and selenium) in certain of the extracts, but none that exceeded (or approached) TCLP regulatory limits. The maximum extract concentration measured was barium at 0.8 ppm in the Remnant No. 3 sample (vs. a TCLP limit of 100 ppm).
- Heat of combustion of each split-spoon soil sample was reported as "less than 1000 Btu/lb."

2.3 IN-PLACE CONTAINMENT CONDITION (POST-CONSTRUCTION)

As reported in Reference G, a total of approximately 351,000 cubic yards of fill was removed from three nearby borrow areas and placed on the four remnant deposits to implement the in-place containment remedy. The fill was used for subgrade material (to elevate and level the grade at each remnant deposit prior to constructing the cap), for the sand fill bedding layer (immediately below the geosynthetic Claymax liner) and for the sand drainage layer (immediately above the geosynthetic Claymax liner). Additionally, a total of approximately 66,000 cubic yards of topsoil was placed on top of the sand drainage layer, resulting in a total, unconsolidated fill volume of 417,000 cubic yards.

A rough estimate of the total in-place (i.e. compacted) cover volume at each of the four remnant deposit sites has been made by dividing each remnant area into sub-areas; assigning an average cover thickness to each sub-area based on the difference in post-construction surface elevation (from Reference G As-Built Cap Drawings) and pre-construction surface elevation (recorded in Reference F boring logs); calculating the volume of cover for each sub-area using surface area and average cover thickness; and summing the resultant sub-area cover volumes for each remnant deposit. The calculated in-place cover volumes for each remnant deposit are listed in Table 1. The calculated total in-place cover volume of 425,000 cubic yards compares reasonably with the total unconsolidated fill volume of 417,000 cubic

yards noted above, given the limitations in the estimating method for in-place volumes described above.

Although the in-place multi-layer caps have effectively mitigated potential PCB release mechanisms from the remnant deposits, the caps have substantially increased the total volume of material in place at each remnant deposit. The caps are, therefore, a factor to be considered and dealt with when evaluating the applicability of remedial technologies.

Additional changes to each of the four remnant deposits as part of the implementation of the in-place containment remedy included construction of:

- River bank stabilization consisting of a three layer composite of filter fabric, filter stone (12-inch thickness minimum) and stone riprap (18-inch thickness minimum) placed on a typically 2:1 slope;
- Perimeter drainage channels at the inland boundaries to direct surface run-on around the remnant areas or across the remnant surface area to the river via stream transfer channels. The perimeter channels are typically grass-lined (grass on top of a minimum of six inches of topsoil and 20 inches of sand). Stream transfer channels typically consist (from top to bottom) of 18 inches of stone riprap and an HDPE (60-mil) liner placed over (and sloped into) the multi-layer cap; and
- Venting systems to vent methane and other gases generated by the decomposition of the underlying organic material, consisting of vertical, 3-inch diameter, Schedule 40 PVC pipes spaced at regular intervals. The PVC vent pipes penetrate to approximately 18 inches below the geosynthetic Claymax liner; the lower 18 inches of the pipes are perforated.

The post-construction characteristics of each of the four remnant deposits are as follows:

- Remnant No. 2, located on the west side of the Hudson River, has approximately 1200 feet of shoreline and has a maximum capped width (north end) of 200 feet. The capped surface area is 3.4 acres. Figure 2 is the As-Built Cap Drawing for Remnant No. 2.
- Remnant No. 3, located on the east side of the Hudson River, has approximately 3375 feet of shoreline, 725 feet of which bounds an uncapped "island" area on the remnant's northwest side. Remnant No. 3 has a maximum capped width of 370 feet (south central area) and a capped surface area of 19.6 acres. Figure 3 is the As-Built Cap Drawing for Remnant No. 3.
- Remnant No. 4, located on the west side of the river, is crescent-shaped with approximately 2850 feet of shoreline and a maximum capped width of 575 feet. The capped surface area is 22.9 acres. Figure 4 is the As-Built Cap Drawing for Remnant No. 4.
- Remnant No. 5, located at a 90 degree bend on the east side of the river, has approximately 1300 feet of shoreline which runs from the former dam location on the east side of the remnant to the bend in the river on the remnant's west side. Remnant No. 5 has a maximum capped width of 240 feet (west end) and a capped surface area of 5.7 acres. Figure 5 is the As-Built Cap Drawing for Remnant No. 5.

The "in-place containment remedy" at each of the four remnant deposits has mitigated six potential PCB release mechanisms; namely (1) reduction of scour during high river flows (reduced by bank stabilization), (2) elimination of surface water infiltration into the remnant deposits and subsequent desorption of PCBs to the river, (3) elimination of surface runoff of PCB-contaminated soil to the river, caused by precipitation and water runoff from the surrounding terrain, (4) elimination of volatilization of PCBs from the surface soil to the ambient air, (5) elimination of soil particulate (dust) transport to the ambient air, and (6) elimination of potential animal or human uptake by direct contact. Only regional

groundwater movement through the remnant deposits to the river with the potential desorption of PCBs remains as a potential release mechanism. In this regard, it is appropriate to note that the presence of both fine (clay and silt) particles and wood debris in the remnant deposits will enhance the natural fixation of PCBs to the remnant deposit matrix, substantially decreasing the desorption potential (References OO and PP).

SECTION 3

POTENTIALLY APPLICABLE REMEDIAL TECHNOLOGIES

3.1 SITE CHARACTERISTICS AND CONSTRAINTS

To identify and evaluate remedial technologies that may realistically be applicable to the remnant deposits, it is necessary to be cognizant of the major characteristics and constraints associated with the four remnant deposit sites. These major characteristics and constraints are summarized below for the four remnant deposit sites as a group.

- The remnant deposits are now covered by a cap. The estimated volumes of cover for each remnant deposit are listed in Table 1. As a result, ground surface at the remnant deposits averages 4 to 6.5 feet higher than the original (pre-cap) ground surface. Essentially all of the PCB contamination in the remnant deposits lies below this cover material. Application of any ex-situ remedial technology will, as a first step, require the removal and stockpiling of the cover material (estimated at 425,000 cubic yards, Table 1). Further, the differentiation between the bottom of the sub-grade soil and the top of the PCB-contaminated soil may be difficult to establish. Accordingly, the deepest portions of this 425,000 cubic yards may have to be handled and included with the PCB-contaminated soil, in effect increasing¹ the contaminated volume requiring remediation.
- The remnant deposits are characterized by elevated moisture content and the presence of numerous wood chips and wood debris (including intact logs). These characteristics result in a low bearing capacity for the remnant deposit materials which in turn makes them difficult to access with conventional earth moving equipment and difficult to excavate. These same characteristics will also dictate the

¹If, for example, the lowest one foot layer of cover material becomes indistinguishable from the remnant deposits, this, in effect, increases the volume to be remediated by 83,000 cubic yards (one foot across 51.6 acres), or roughly 30 percent.

necessity of pretreatment (wood debris removal, dewatering, size reduction, or particle classification) prior to application of ex-situ remedial technologies. Pretreatment will produce PCB-contaminated sidestreams (water, debris and oversized particles) requiring controlled handling and disposition.

- The proximity of the Hudson River presents two constraints for remedial activities, namely, (1) the river is an environmentally sensitive receptor and (2) excavation of the deposits to an appreciable depth may have to include provisions to preclude intrusion of the river onto the excavated area.
- Applicable remedial technologies will be required to handle and treat a large volume of material containing low-level (typically <100 ppm) concentrations of PCBs. For example, an estimated total of 300,000 cubic yards² of material contains greater than 5 ppm PCBs (Table 1). This same material is also characterized by elevated metals concentrations, notably cadmium, chromium, and lead (Tables 6-10), and elevated organic content (primarily from the wood fragments and debris).
- There are no extensive, readily available areas at or adjacent to the remnant deposits suitable for stockpiling of large volumes of excavated material, for spreading excavated material for treatment, or for erection of treatment facilities. Also, except at Remnant No. 5, no utilities are readily available at or near the remnant deposits.

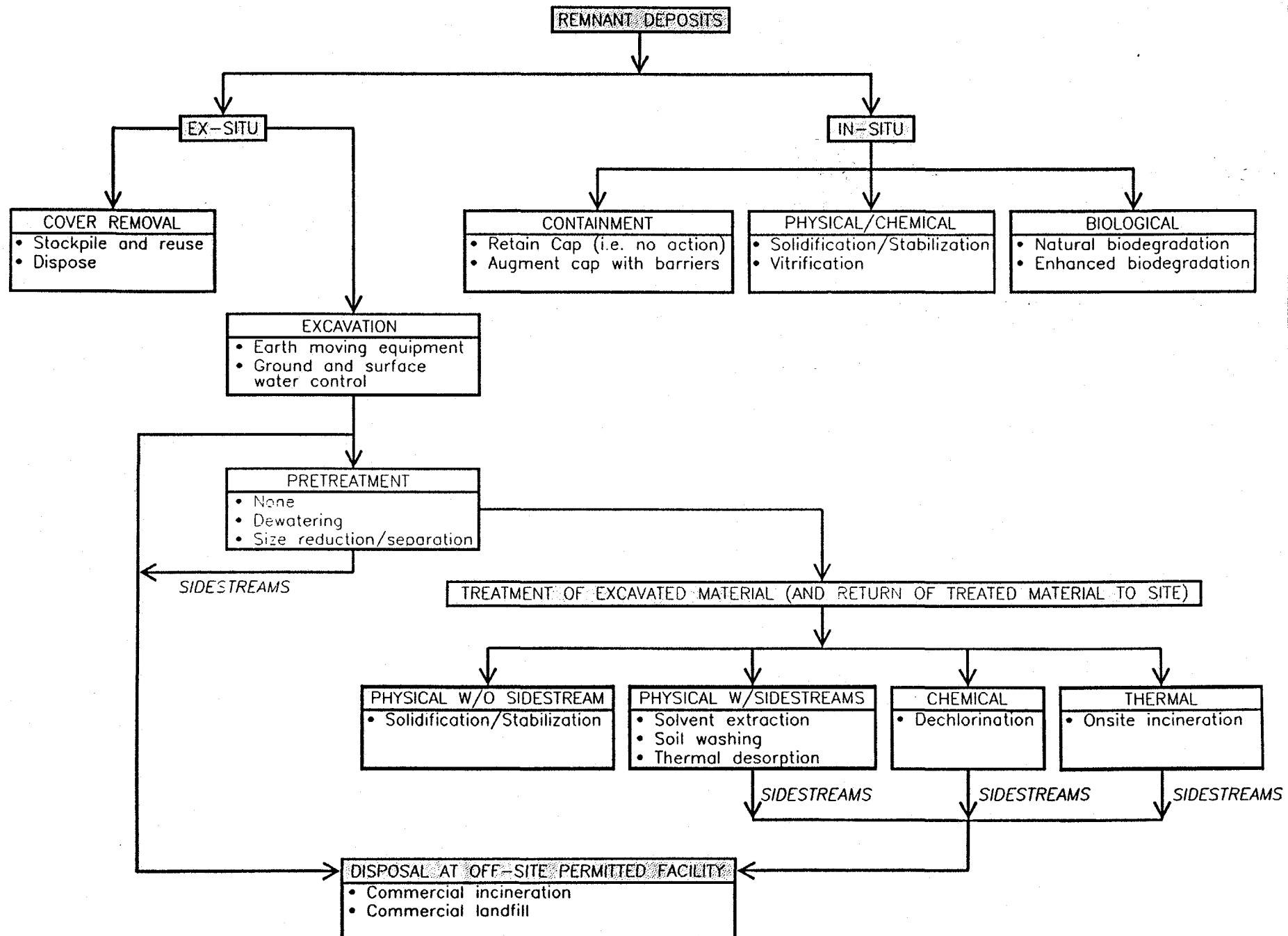
3.2 INITIAL SCREENING OF TECHNOLOGIES

Based on available reference material and documented technology screening efforts for sites with PCB contaminated sediments, an initial screened list of potentially applicable generic remedial technologies has been prepared and is presented in Figure 6. References H, I, J, and K have been consulted for the preparation of Figure 6.

²The 300,000 cubic yards represents roughly 500,000 tons, based on an in-situ soil density of 125 pounds per cubic foot (reference: file information from Canonic Environmental).

FIGURE 6

POTENTIALLY APPLICABLE GENERIC REMEDIAL TECHNOLOGIES (FOR REMNANT DEPOSITS)



3.3 DESCRIPTION AND QUALITATIVE COMPARISON OF REMEDIAL TECHNOLOGIES

This section contains a description of each of the potentially applicable generic remedial technologies shown in Figure 6 and describes representative technologies and vendors. References I, J, K, and N through NN document the sources relied upon for information regarding availability, capability, and performance record for the representative technologies.

Additionally, a brief qualitative comparison of the remedial technologies described in this section has been included with the narrative descriptions. The three comparison criteria include:

- Effectiveness: This criterion considers the degree to which a remedial technology reduces the toxicity, mobility, or volume of the contaminants through treatment; minimizes short-term impacts to the environment during implementation; and how quickly it achieves protection.
- Implementability: This criterion considers the technical feasibility of applying a remedial technology at a particular site; and the commercial availability and demonstrated full-scale performance ("track record") of a remedial technology.
- Cost: This criterion considers the costs of constructing, operating and maintaining a remedial technology.

These three criteria are similar to the initial screening criteria presented in the National Contingency Plan (CERCLA, 40 CFR Part 300) and described in Reference H.

The unit cost ranges for implementation of the remedial technologies presented in the following narrative descriptions are present day ORDER OF MAGNITUDE costs for treatment or disposal only and are derived from (1) costs presented in the published literature, (2) informal quotes from vendors, and (3) actual costs available from on-going or completed remediation projects. These unit costs are further constrained at this stage of evaluation by the absence of (1) bench-scale test data to define efficiency and pretreatment requirements for application of the remedial technologies to the remnant deposits, (2) long-term performance records and resultant defined construction and O&M costs for the remedial technologies, (3) details regarding pretreatment equipment requirements and sidestream volumes and characteristics, and (4) costs for the excavation and disposition of the cover material (i.e. stockpile and reuse, or dispose) and for the excavation and handling of the remnant deposit soils.

3.3.1 Excavation

Excavation followed by off-site disposal of excavated material at a permitted disposal facility is an obvious and often-used remedial technology. However, off-site disposal of excavated material is undesirable from three major standpoints, namely (1) high cost, (2) the risks associated with off-site transportation of contaminated material, and (3) if landfilled, no treatment will occur to permanently and significantly reduce the toxicity, volume, or mobility of the contaminants. The cost of off-site disposal will be greatly influenced by the amount of moisture in the excavated material (more moisture translates into less solids per truckload) and the distance to the selected permitted facility.

Excavation is a necessary first component of any ex-situ remedial technology. Excavation of the remnant deposits presents numerous difficulties in implementation, which would substantially increase the cost and potential environmental impact, as compared to a more typical remedial excavation. These difficulties include:

- The need to first excavate the cap and associated sub-grade materials at each remnant deposit and either dispose of the material or stockpile it for reuse;

- The low bearing capacity of the remnant deposits due primarily to their high moisture content, making access and operation of earth-moving equipment difficult;
- The possible destruction of wetlands areas;
- The presence of the Hudson River which precludes access to the remnant deposits from one side, and which dictates the need for stringent controls during excavation to prevent transport of remnant material into the river;
- The need to divert surface water and groundwater away from the excavated areas, and to prevent intrusion of river water into the excavated areas;
- The need for special handling and treatment of water removed from the excavated areas due to potential PCB or heavy metals contamination; and
- The general absence of adjacent areas suitable for use for erecting facilities, or for the stockpiling of equipment or excavated material.

Although excavation to support ex-situ treatment and excavation followed by off-site disposal are proven and available remedial technologies, excavation of the remnant deposits and the associated cap material would be a complex and costly undertaking. The effectiveness of excavation of the remnant deposits would be limited by short-term impacts to the environment during implementation. The effectiveness of off-site landfill disposal is limited in that there is no reduction of toxicity, mobility, or volume by treatment. No firm statement regarding the implementability or cost for excavation of the remnant deposits is possible at this stage of evaluation.

For off-site disposal, the PCB-contaminated soil would have to be transported by truck, or by truck and then by rail, and disposed-of at the most cost-competitive permitted landfill or commercial incinerator. The truck traffic and associated transportation risks would be

substantial. For example, to transport 300,000 cubic yards (500,000 tons), approximately 20,000 to 25,000 truck trips (22 tons per truck) would be required. An all inclusive (transportation and disposal) cost range for landfilling is estimated at 200 to 250 dollars per ton, based on available competitively bid prices for large-scale PCB remediation projects. The cost range for disposal of large volumes of bulk PCB soils at a permitted commercial incinerator is estimated at 1200 to 1900 dollars per ton.

3.3.2 Total Containment

The currently installed cap at each remnant deposit is intended to eliminate direct contact with and volatilization from the PCB contamination at the remnant deposits (Reference B). The cap also minimizes transport and release of PCB-contaminated material into the river by erosion, and minimizes surface water infiltration into the remnant deposits.

The Reference B Record of Decision concluded that "complete isolation of the remnant deposits by construction of impermeable walls or barriers" in conjunction with an impermeable cap "is neither feasible nor practical at these sites." The reasoning behind this statement was that it was not considered possible to hydrologically seal the bottom of the remnant deposits using impermeable materials.

Side sealing of the remnant deposits may be feasible. Vertical barriers such as slurry walls and metal sheeting are proven and available remedial technologies used to mitigate the transport of contaminants through the sidewalls of containment areas or contaminated soil areas. To-date, slurry walls have been built as containments at approximately 20 National Priority List sites. A combination of vertical barriers to control side transport and hydrologic methods (e.g. pumping) to mitigate or redirect vertical transport may be effective and implementable at the remnant deposits, but no firm statement in this regard is possible at this stage of evaluation.

Currently, there is still no demonstrated technology available for bottom-sealing the remnant deposits using impermeable materials. There is also not enough known regarding either the

mechanism for or the importance of side or bottom transport of PCBs from the remnant deposits and which, if any, of these pathways is important.

3.3.3 Physical/Chemical Technologies

Solidification/Stabilization: Solidification/stabilization (S/S) technologies use additives to immobilize the PCBs within the soil³ matrix. The resultant solidified/stabilized matrix has better handling characteristics, has a decreased surface area from which contaminant transport can occur, and limits the mobility of a contaminant exposed to leaching fluids. Solidification involves hardening or encapsulation to prevent leaching, whereas stabilization involves a chemical reaction or bonding to prevent leaching. Because heavy metal contaminants cannot be readily destroyed and because extraction of heavy metals from soils is complex, S/S is most often used for remediation of soils contaminated with heavy metals. S/S is not as often successfully applied to organic contaminants, although it has been successfully demonstrated for PCBs.

Solidification of PCBs and metals in a soils matrix can be accomplished by use of pozzolanic materials such as cement or lime. Stabilization may be accomplished using a modified clay, inorganic polymer, or other binder to bond to the contaminant. The PCB (or other contaminant) migration potential is reduced but PCB destruction does not occur.

S/S can be performed either in-situ or ex-situ. The application of in-situ methods typically requires two basic components, (1) a means for additive injection and deep soil mixing and (2) a batch mixing plant to supply the additive(s). An ex-situ S/S process would include (1) excavation of the contaminated material, (2) possible debris removal, size reduction and particle classification, (3) an additive application and mixing area where additives are introduced into and mixed with the excavated material, (4) a curing area where the treated material is allowed to solidify/stabilize before reapplication onto the site or disposal off-site,

³In the discussion of remedial technologies in this section, the terms "soil" and "sediment" are used interchangeably.

and (5) a batch mixing plant to supply the additives. Transport of additive reagents to the sites would be a feature common to either an in-situ or ex-situ S/S operation.

S/S is a commercially-available technology. There are a number of vendors and processes, many of them proprietary, for ex-situ application of S/S. However, the in-situ processes have a very limited vendor base. The applicability of a particular S/S technology to a given site is heavily site-dependent. Extensive bench-scale and probably pilot-scale evaluations would be required to assess the effectiveness of particular S/S technologies for use on the remnant deposits. Factors that would make in-situ application of S/S at the remnant deposits difficult include (1) the large volume to be treated, (2) the high moisture content, (3) the amount of wood and wood debris present, and (4) the wide particle size-distribution range. Also, the cap material would have to be removed down to and including the Claymax liner, since both the granular drainage layer material and the Claymax liner would be detrimental to operation of the soil mixing equipment. Removal of, or leaving in place, the remainder of the cover and sub-grade material (as much as 275,000 cubic yards is in place below the Claymax liner) is a trade-off that would have to be evaluated. If left in place, this remaining cover material would have to be incorporated into the S/S process, essentially doubling the volume requiring treatment.

Proving the effectiveness of an in-situ S/S technology after full-scale application can be difficult, costly, and time-consuming, particularly at depth. Evaluations are usually accomplished by means of unconfined compressive strength tests and leaching tests. Leaching tests can be insensitive and inconclusive due to the already low mobility of PCBs in soil, often resulting in PCBs being undetected in both pre-S/S and post-S/S leaching tests.

International Waste Technologies (KS) and Geo-Con, Inc. (PA) have successfully demonstrated an in-situ stabilization technology which immobilizes organic and inorganic compounds in wet or dry soils, using reagents to produce a cement-like mass. The basic components of this technology are: (1) Geo-Con's deep soil mixing system, an auger system which is applied in an over-lapping pattern and delivers and mixes the chemicals with the

soil in-situ, and (2) a batch mixing plant to supply IWTs proprietary treatment chemicals. The proprietary additives generate a crystalline, bonded network of inorganic polymers. The process involves a two-phased reaction in which the contaminants are first complexed in a rapid reaction, and then in a slow-acting reaction in which the building of macromolecules continues over a long period of time. For each type of soil, the amount of additives used varies. Large-scale in-situ application for PCBs has not yet been demonstrated

S.M.W. Seiko, Inc. (CA) has developed a "soil-cement mixing wall" technology for in-situ S/S of contaminated soils. The associated augering equipment and batch mixing plant are equipment developed from a technology used for years on construction applications involving soil mixing and chemical grouting. No full-scale demonstration on contaminated soil has been completed.

STC Silicate Technology Corporation (AZ) has developed a series of silicate compounds shown to be effective for stabilization of both organic and inorganic contaminants in soil. These additives need to be extensively bench and pilot-scale tested on the contaminated soil in question to establish the optimum formulation and to demonstrate effectiveness. Most of STC's applications have been ex-situ to-date.

Despite the difficulties in implementation enumerated above, the prevalence of vendors and processes along with some demonstrated (although limited) full-scale applications makes S/S a potentially applicable remedial technology for the remnant deposits. S/S does not rate as highly on effectiveness as the majority of the other remedial technologies evaluated, since S/S does not reduce either the toxicity or volume of PCB or heavy metal contamination, only the mobility. The estimated cost range for in-situ S/S treatment is 30 to 60 dollars per ton.

Vitrification: In-situ vitrification is a process for achieving the concurrent destruction of PCBs and the solidification of inorganic contaminants. This process raises the soil temperature to the melting point and converts the soil into a glass-like crystalline mass by

application of electrical energy, applied from electrodes inserted into the soil. Organic contaminants are destroyed or volatilized and inorganic contaminants are bound-up in the glass-like mass that is created. In-situ vitrification works best in sandy soils, but can be effectively applied to any soils containing enough silica and aluminum oxides (the mineral constituents in glass) to support the process. Because the process results in nearly complete pyrolysis of the PCBs in the treated area, it is considered equivalent to incineration. However, to verify this, the perimeter of the treated area must be evaluated using leaching tests or analytical techniques to determine if less efficient PCB destruction occurred in the perimeter region due, for example, to gradations in temperature.

The in-situ vitrification process is typically applied as follows:

- Four molybdenum or graphite electrodes are vertically inserted into the soil to form a square array within the treatment area. The spacing of the electrodes will vary depending on site conditions. A conductive mixture of graphite and glass frit is placed on the surface of the soil between the electrodes to provide a "starter path" for current flow.
- The current flows through the mixture, heating the adjacent soil to the melting point. Typical treatment temperatures are in the range of 3000 to 3500°F. As the surrounding soil melts, it becomes electrically conductive and completes the electrical circuit. The applied voltage is periodically reduced during the process to compensate for the increasing conductivity of the growing melt.
- The molten soil zone expands vertically and horizontally encompassing the volume of soil within the electrodes. As the soil melts, organic contaminants are pyrolyzed. The resulting gases migrate to the surface and are combusted when they come in contact with air and the high temperatures at the surface. Constituents that do not volatilize, such as most heavy metals, remain in the molten soil and are incorporated into the glass-like crystalline product after cooling.

- An off-gas hood is placed over the treatment zone to capture emissions and combustion gases. The off-gas collection and treatment system forms a major portion of the equipment necessary for the in-situ vitrification process and can include quenching, venturi scrubbing, mist elimination, humidity control, filtration, carbon adsorption units, and coolers. Solids collected from the off-gas treatment units can be recycled back to the vitrification process, significantly decreasing the amount of waste that requires further treatment or offsite disposal.
- The vitrification process eliminates the void space in the treated soil, thereby reducing its volume by 20 to 40 percent for typical soils, causing subsidence, and necessitating application of clean backfill to restore the original grade.

It has been claimed that the resultant vitrified mass will resist leaching, will withstand environmental degradation for geologic time periods, that it is up to ten times stronger than unreinforced concrete, and that it is not susceptible to seasonal cycles (wet/dry and freeze/thaw). The process is claimed to be less energy intensive than incineration (1000 kwh/ton vs. 2000-3000 kwh/ton). The largest field tests to date have involved approximately 1000 tons of treated material. These were performed by Geosafe Corporation (WA), a company established by Battelle Memorial Institute to offer commercial in-situ vitrification services. Highest reported processing rates are four to six tons of in-situ soil per hour.

Some of these claims were called into question when a plan to apply in-situ vitrification to 12,000 cubic yards of soil at Rocky Mountain Arsenal was put on indefinite hold by EPA in December 1991. This would have been the largest application of this technology to-date. Concerns centered around (1) escalating cost projections (\$1200 per cubic yard), (2) ability of the off-gas collection and treatment system to handle the large volume of volatilized contaminants and vaporized groundwater, and (3) effectiveness of the process at depth, including the possibility of leaving partially treated soil below the vitrified mass.

In-situ vitrification is an attractive remedial technology from several standpoints, namely, it has been commercially available for about four years, it is used in-situ, and it can be used to treat (destroy or immobilize) both organic and inorganic contaminants. However, the remnant deposits present formidable obstacles to the implementation of in-situ vitrification as a remedial technology. These obstacles are summarized below.

- The remnant deposits have a high organic content, due primarily to the large amounts of wood and wood debris. Existing in-situ vitrification processes reportedly can treat material only with total organic concentrations of less than ten percent by weight. This limitation is related to the volume of off-gas that the equipment can collect and treat in any given time.
- In-situ vitrification can be applied to saturated soils. However, it cannot be applied to sites where groundwater freely recharges to replace vaporized water in the treatment zone, since, in such cases, the melt is unable to advance. Free recharge of groundwater may occur in a significant portion of the remnant deposits.
- In-situ vitrification has not been demonstrated or successfully applied to large volumes of material.
- The cap would interfere with application of in-situ vitrification, and the cap and sub-grade material would most likely need to be removed before applying vitrification. If the average four to six and one-half foot depth of cover (425,000 cubic yards) is not removed, it would interfere with application and verification of the process applied to the soil beneath the cover, and, in fact, if not removed, may have to be included as part of the treatment zone.
- Application of the vitrification process to the shoreline portion of the remnants would be difficult and could result in a discontinuous or untreated zone of soil along the shoreline.

The obstacles to implementation enumerated above along with the recently raised, unresolved questions regarding cost and effectiveness are reason enough to conclude that in-situ vitrification is not a practical remedial technology for the remnant deposits.

A similar technology called ERACE has been developed by DOE's Pacific Northwest Laboratory (PNL) (operated by Battelle Memorial Institute in Richland, WA).

In the ERACE process, electrodes are used to apply an electrical current to in-situ soil. Moisture within the soil forms steam, stripping organic contaminants from soil particles. The contaminated steam is vented, and contaminants are collected within an offgas treatment system. In addition, a specialized off-gas treatment system is being developed to destroy contaminants escaping from the soil instead of just filtering and collecting them.

Laboratory tests suggest that ERACE will be able to remove 99.99 percent of many organic soil contaminants, including PCBs.

The soil heating step is being field tested by PNL at DOE's Hanford Site in southeastern Washington state, and it will be demonstrated at DOE's Savannah River Site in South Carolina beginning next year.

The ERACE process has promise, but shows some of the same constraints as in-situ vitrification and is in an early developmental stage.

Solvent Extraction: Solvent washing/extraction processes separate PCBs from excavated soil and concentrate the PCBs in a sidestream (solvent). After extraction is performed, the PCBs in the sidestream must then be treated, disposed, or destroyed, most often by incineration. The major effectiveness of solvent extraction is that it dramatically reduces the volume of PCB-containing material requiring disposal or destruction.

One problem confronting solvent extraction processes can be interference from water in the soil, with greater than ten percent water causing agglomeration and preventing intimate contact between the solvent and PCBs. Excessive water needs to be removed either by a pretreatment dewatering step or by innovative features in the solvent extraction process.

Four prominent solvent extraction processes that have been demonstrated for treating PCB-contaminated soils are summarized below.

- The B.E.S.T.TM (Basic Extractive Sludge Treatment) Process uses triethylamine (TEA) and separates PCB-contaminated soils into effluent streams of dry soils, water, PCB oils, and solvent (TEA). Since TEA is flammable, the system is operated under a nitrogen blanket. Solvent is separated and recovered for reuse. The process was developed by Resources Conservation Co. (WA) (now owned by Haliburton).

The B.E.S.T.TM process is a two stage process. In the first (cold) stage, soils are mixed with refrigerated TEA. At the resultant 40°F mixture temperature, both water and PCB-contaminated oil fractions are soluble in the TEA and a single liquid phase forms. The treated solids are then separated from the liquid either by filtration or centrifugation and are dried to remove residual TEA. The vaporized solvent is condensed and recycled.

In the second (hot) stage, liquid from the cold stage is heated to about 130°F which, due to TEA's inverse miscibility properties, causes the water to separate from the amine/oil phase. The water phase is steam stripped to remove residual TEA and also may be routed to a carbon adsorption unit for removal of low-level PCBs. The TEA/PCB/oil phase is distilled to recover TEA for reuse. The concentrated PCB/oil fraction is disposed of by incineration, or other means.

The B.E.S.T.TM process has been successfully bench-scale tested on several occasions, including on New Bedford Harbor sediment. Reduction of soil PCB concentrations

from the 130-400 ppm range down to 3-4 ppm have been reported. The first (and only) successful full-scale application of the process to date was at the General Refining Superfund Site (GA) where a total of 3700 tons of oily sludge containing heavy metals and low-level PCB contamination was treated.

- The ENSR Process, developed by ENSR Corporation (now NuKEM Development, Houston, TX), is typical of many extraction processes except that a proprietary reagent (surfactant) is added to the solvent to counteract the effect of water in the contaminated material by minimizing agglomeration. The contaminated material is first size-reduced and is then mixed with the proprietary reagent and an organic solvent (pentane), and is then subjected to three to five stages of extraction. The process operates at ambient temperature and pressure.

The residual solvent is stripped from the decontaminated material in a solvent dryer, and water is then separated from the material in a solids settling tank. Solvent from the extraction process (as well as from the solvent dryer) is distilled and recycled. PCBs and other heavy organics are removed from the process with the distillation bottoms and are incinerated or otherwise disposed.

NuKEM Development has recently received a patent for the organic solvent and surfactant process, however, no commercial operating unit has been constructed. NuKEM Development is currently emphasizing application of the process to refinery oily wastes (e.g. sludges, which present no particle size constraints) and the first commercial-size unit will be intended for this market. Application of the technology to PCB-contaminated soil is technically feasible, however, substantial pretreatment (particle-size separation/reduction to less than one-eighth inch) will typically be required.

- The Low Energy Extraction Process (LEEP) was developed by Remediation Technology, Inc. (NJ) (now Applied Remediation Technology (ART), Int.) to remove

organics, such as PCBs, from contaminated soil or sediment. The process is operated at ambient temperature and can handle high-moisture solids. Particle size is limited to one-half inch. In the process, the contaminated material is first centrifuged to partition PCBs (reportedly greater than 98 percent) to the solids fraction. The solids are then processed in a multistage, paddle-washer extractor where a hydrophilic (water miscible) solvent, such as acetone, extracts the organics. After gravity separation, the decontaminated solids pass to a solvent recovery unit where residual solvent is recovered for reuse by indirect heating.

The hydrophilic solvent leaving the extraction unit contains large amounts of water as well as PCBs and other organics extracted from the contaminated material. This stream is processed in a countercurrent liquid/liquid extractor in which a hydrophobic (water immiscible) solvent, such as kerosene, extracts PCBs and other organic contaminants from the hydrophilic solvent. The volume of the hydrophobic solvent is relatively small and this stream can either be incinerated or chemically decontaminated and recycled.

When the hydrophilic solvent exits the liquid/liquid extractor, it still contains substantial quantities of water and is then processed in a distillation unit. Solvent leaving the distillation unit is recycled to the solids extraction unit. Water, which may contain low concentrations of PCBs, is routed to a carbon adsorption unit for final treatment.

ART Int. has successfully conducted bench-scale testing of the LEEP process on Waukegan (IL) harbor sediments. The LEEP process has the advantages of being a low-energy operation at ambient conditions and using available, traditional processes and equipment. Feed stream particle size has been identified as a limiting parameter. Also, the use of acetone and kerosene as solvents, environmentally-objectionable compounds in their own right, is of concern.

A trailer-mounted commercial unit is under construction. However, no LEEP system is yet available for full-scale application.

- CF Systems (Woburn, MA) Organics Extraction Process is a continuous process which uses a mixture of compressed (liquified) propane and butane as a solvent to extract PCBs from sediments. The process sequence includes (1) size-reduction to reduce or remove material larger than one-eighth inch diameter, (2) slurring excavated material with water to produce a pumpable mixture, (3) pH adjustment to near neutral, and temperature adjustment to greater than 60°F, (4) processing the slurry with the liquified propane/butane solvent in typically three stages of modular extraction units, (5) dewatering the resultant solids/water stream from the extraction modules by use of a gravity thickener, filter press, or centrifuge, (6) reusing some or all of the resultant water to slurry the feed solids, (7) reducing the pressure on the second stream (solvent-organics) from the extraction modules to vaporize the solvent, (8) recovering the vaporized solvent and compressing it for reuse, and (9) collecting the separated organics (concentrated PCBs) for incineration or other disposal method.

For solids treatment, up to four 250 ton per day processing units can potentially be operated in parallel. CF Systems has collected bench-scale test data and has field demonstrated pilot-scale units on a wide range of organic contaminants. The most notable pilot-scale test for PCB-contaminated sediment was on New Bedford Harbor (MA) sediments. PCB extraction efficiencies greater than 90 percent were achieved, reducing PCB sediment concentrations (350-2600 ppm range) to as low as 8 ppm. However, a number of operational problems were identified including solvent flow variability, solids retention in the process hardware and solids carryover into the extracted organic stream, and foaming. CF Systems indicates that certain of these problems may have been attributable to using only a single-pass unit.

CF Systems has been operating a commercial-scale unit to treat petroleum refinery sludge, with a capacity of 4200 gallons per day. The CF Systems organics extraction process also has been selected for ex-situ treatment of 94,000 cubic yards of contaminated soils at the United Creosoting Superfund Site in Conroe, Texas, starting in 1994.

Other solvent extraction processes still in development include (1) OHM Corporation's extraction process which uses methanol as the solvent on crushed, dried (less than five percent moisture) soil in a counter-current reactor and (2) CET Environmental Services' (Sanivan Group, Canada) Extraksol™ process which uses a proprietary solvent and multiple extractions to desorb and dissolve PCBs from dried contaminated soil.

All of the solvent extraction technologies have similar features and present similar constraints which would limit their effectiveness and make their implementation at the remnant deposits difficult. These similarities and constraints are summarized below.

- The need for removal of the cap material and excavation of the contaminated soil, for ex-situ treatment.
- No demonstrated record of performance on large volumes of contaminated material; for certain of the technologies, no full-scale, transportable process equipment is yet available.
- An insufficient record of performance for establishing typical on-line time and operating costs, which makes comparison of costs with proven technologies and projection of treatment costs difficult and uncertain.
- The need for extensive, site-specific bench and pilot-scale testing to first demonstrate the technology's applicability to the site in question.

- The use of multiple unit processes, requiring both substantial set-up area and operator attention.
- The need for pretreatment of the contaminated soil to accomplish one or more of the following: to effect particle size reduction or classification; to add water to improve pumpability; to remove water to prevent interference with the extraction process; or to increase temperature.
- Generation of concentrated sidestreams from both the pretreatment and extraction processes, which require additional handling and treatment, or disposal.
- Use of chemical reagents (solvents) which themselves may be environmentally objectionable and which present delivery, handling, and storage concerns, as well as concerns regarding residues left on the treated soil.
- Negligible removal efficiency for heavy metals, and the possibility that the extraction process may increase the mobility of the heavy metals in the PCB-decontaminated soil -- a concern if the treated soil is returned to the site.

The above factors coupled with the formidable constraints posed by the physical setting and characteristics of the remnant deposits (refer to Section 3.1) in all likelihood make solvent extraction an impractical remedial technology to apply to the remnant deposits. Reliable cost information for full-scale application of solvent extraction is not available.

Soil Washing: Soil washing is an extraction process without the use of chemical solvents. Soil washing is a water-based process for mechanically scrubbing soils ex-situ. The process removes contaminants from soils in one of two ways, namely, by dissolving or suspending them in the wash solution (which can then be treated by conventional wastewater treatment methods) or by concentrating them into a smaller volume of soil through particle size separation techniques (which reduces the volume of contaminated material requiring

disposal or further treatment). The reduction of soil contamination through particle size separation is based on the fact that organics (e.g. PCBs) and inorganics (e.g. metals) tend to bind to fine (clay and silt) particles. The fine particles tend to be physically attached to the coarser sand and gravel particles by compaction and adhesion. The soil washing process separates the fine particles (and, thus, the major portion of the contaminants) from the coarse particles.

Soil washing is a volume reduction process and, depending on the application, may be applied either as a pretreatment step or a stand-alone separation technology. At the present time, soil washing is used extensively in Europe but has had only limited use in the U.S. There are no full-scale soil washing processes in use at Superfund Sites.

Although soil washing is simple in principle, the full-scale systems tend to be complicated and heavily unit process dependent. Also, depending upon the process, a supply of large volumes of washwater can be required. A typical soil washing system requires that first the contaminated soil be screened to remove material greater than two inches in size. Then a series of conventional unit process techniques are employed, which can include wet particle classification, attrition scrubbing (e.g. rotating impellers to promote mechanical and fluid shear stress), density separation, flotation, gravity settling, and mechanical dewatering. Chemical aids can include detergents, surfactants, coagulants, flocculants, and acids/bases (for pH adjustment).

Two limitations are typically cited as a prerequisite for effective and economical soil washing, namely, that the contaminated soil contain less than 40 percent fine (clay and silt) material and less than 20 percent organic matter (such as roots, leaves, and wood debris). Remnant deposit characterization data suggest that both the percent fines and organic content are substantial. Too high a percentage of either of these components will overwhelm the soil washing process, manifested by inefficient particle-size separation, loss (adsorption) of surfactants onto clay particles, and excessive operating cycles.

Soil washing can reportedly concentrate contaminants into a residual solids fraction representing as little as ten to 30 percent of the original feed volume. Several U.S. firms are actively marketing their soils washing systems, including Biotrol, Inc. (MN), Waste-Tech Services, Inc. (formerly MTARRI), and Bergmann USA, Inc. Bergmann USA in mid-1991 demonstrated a five ton per hour soil washing unit on stockpiled sediments previously dredged from the Saginaw River in Michigan. The 40 hour test was effective for concentrating PCBs and heavy metals into a volume of organic and fine particles representing approximately 18 percent of the original sediment volume. However, no U.S.-based full-scale demonstration data for application to PCB-contaminated soil or sediments are available. Further, operational cost estimates for a Bergmann plant and for European facilities indicate that soil washing costs can be substantial, in the 75 to 150 dollars per ton range for the volume reduction steps only.

Accordingly, soil washing is a technology of interest and its development and progress in the U.S. should be monitored. However, due to the aforementioned limitations of experience and cost, and unpredictable volume reduction efficiency, the effectiveness and implementability of soil washing as either a pretreatment step or a stand-alone separation technology for the excavated remnant deposits is uncertain.

Thermal Desorption: Thermal desorption is an ex-situ process that uses either direct or indirect heat exchange to volatilize organic contaminants from soil. Thermal desorption is a physical separation (volume reduction) process and not an organic decomposition (incineration) process. Operating temperatures are in the 200 to 1000°F range. The relatively low operating temperatures tend to make thermal desorption less energy intensive and thus, less costly, than incineration. The primary technical factors affecting thermal desorption performance are the contaminant concentration, the maximum soil temperature achieved, total soil residence time, and soil moisture content. The volatilized contaminants from the thermal desorption process are typically directed to a secondary system for incineration (i.e. an afterburner), adsorption on activated carbon, or recovery by

condensation. If the volatilized contaminants are incinerated, an air emissions control system is employed to remove acid gases and particulates in the exhaust gas.

Chemical Waste Management (Oak Brook, IL) has a proprietary transportable thermal desorption system, named X*TRAX™, which is representative of the process. The X*TRAX™ unit consists of an indirectly fired rotary dryer which heats soil from 450 to 850°F and an off-gas condensation system. Nitrogen gas is used as a blanket to preclude ignition within the rotary dryer and as a carrier gas to transport vaporized organics to the condensation system. The off-gas condensation system consists of a liquid scrubber (for cooling and particulate removal), a primary condenser, and a secondary condenser. Three condensed off-gas streams result, which are gravity separated. The three condensed streams include (1) floating organics that may be reclaimed, used as fuel, or disposed; (2) dense organics (e.g. PCBs) which are disposed; and (3) water, which is recycled to the scrubber or for use in cooling, and controlling dust from, the treated soil. The X*TRAX™ system operates most efficiently on soils with less than ten percent organic contaminant concentration. The feed stream particle size limitation is two inches, to preclude jamming the screw feeder or flighting within the rotary dryer. Treatment costs increase significantly as moisture content in the contaminated soil increases.

The first full-scale, commercial X*TRAX™ unit has been constructed, following successful pilot testing on a variety of PCB-contaminated soils using a five ton per day mobile unit. This first commercial unit is rated at 100 to 150 tons of soil per day and is scheduled to treat 35,000 tons of PCB-contaminated soil at the Resolve Superfund Site (MA), starting in late 1992.

The AOSTRA Taciuk process is a high temperature thermal desorption process, operated under near-pyrolytic (anaerobic) conditions. The process was originally developed in 1975 for extracting oil from oil sands and shales under an agreement with the Alberta Oil Sands Technology and Research Authority (AOSTRA), and in 1988 was successfully demonstrated for removing PCBs from contaminated soils. SoilTech ATP Systems, Inc. (IN), a joint

venture of UMA Eng. Ltd. (Canada) and Canonie Environmental Services, has the exclusive U. S. license to use the process. Transportable, modular systems are available with capacities in the 3 to 25 tons per hour range.

The main processor is a compartmentalized, horizontal, rotating vessel, with four distinct zones. Efficient mixing and heating of the contaminated feed solids, and to some extent size reduction, is promoted by the turbulent, tumbling action of this rotating vessel. Feed solids are introduced to a preheat zone where they are indirectly heated by combustion flue gases and exiting solids. Water and light organics are driven off in this zone, and exit the processor to a condenser/separator unit. The preheated feed solids then move to the reaction zone, where the temperature is 1000 to 1200°F and the atmosphere is kept nearly oxygen-free by a proprietary sealing system. In the reaction zone, the feed solids are mixed with hot recycled solids from the third (combustion) zone. Organics are vaporized (including PCBs, which vaporize at 600 to 750°F) and extracted from the reaction zone. The heated, coke-coated solids are transferred from the reaction zone into the combustion zone through a dynamic, proprietary seal that is maintained full of solids, thereby maintaining separation of the atmospheres of the two zones.

Heat for the process is generated in the combustion zone which is an annular section around the reaction zone. Non-volatile organic material and non-condensable hydrocarbons, in conjunction with supplementary gaseous fuel (if necessary) and preheated air, are combusted in the presence of the treated solids to heat them rapidly for use as the heat carrier for the process. The combustion process also burns the coke on the solids.

As aforementioned, a portion of the hot solids from the combustion zone are recycled back into the reaction zone, while the remaining hot solids pass through a cooling zone, indirectly preheating the feed, prior to exiting the processor. After the treated solids are removed from the processor, they are further cooled and dust is suppressed by water addition.

Flue gas exiting the combustion zone passes through a flue gas treatment system consisting of cyclones to remove coarse particulates, baghouses to remove fine particulates, and a wet caustic scrubber to remove remaining fines and acid gases. Preheat vapors leaving the processor are routed to the vapor treatment system. This system consists of a condenser followed by an oil/water separator. Noncondensables are returned to the processor. Organic vapors from the reaction zone are routed to an oil recovery system. The vapor stream first passes through cyclones to remove fine solids, then to a fractionation tower. Several fractions (containing the PCBs) are drawn from the tower for further processing, destruction, or disposal. Tower vapors, which consist of light oils and water, are condensed and separated, and non-condensables are routed back to the processor. Water from this process usually requires additional conventional treatment prior to reuse or disposal. Water treatment is provided by a skid-mounted system rated at 10 gpm and utilizing oil/water separation, filtration, and UV-ozonation. The Taciuk system is a net consumer of water for feed soil moisture concentrations of 20 percent or less.

The process can be readily adapted to accept feeds having oil, water, and solids in all proportions. However, higher water content reduces the throughput capacity of a given size of processor because of the higher heat load on the fixed heat transfer capacity. High organic loading has a similar impact. Throughput capacity is also reduced with higher fines content in the feed because heat transfer capability is less than with coarser solids. Conversely, throughput capacity increases with coarse solids, up to a maximum particle size (reportedly three to six inches). Particles larger than can be processed must first be separated from the feed or size-reduced by screening or crushing. As with most thermal processes, metals in the contaminated soil are not removed, or are only removed inefficiently.

The Taciuk ten ton per hour systems have been used successfully for full-scale remediation of PCB-contaminated soils and sediments at both the Wide Beach Superfund Site (NY), where 40,000 tons of soil were treated, and the Waukegan Harbor Site (IL), where 13,000 tons of soils and sediment were treated. In the latter project, PCB concentrations in soils

and sediments averaging 11,000 ppm were reduced to less than 2 ppm. The Taciuk process was selected over solvent extraction at the Waukegan Harbor Site based, in part, on more efficient PCB removal and the absence of solvent residue on the treated soils.

Aptus, Inc. (a subsidiary of Westinghouse) is developing a full-scale thermal desorption unit, rated at ten cubic yards per hour, for treating PCB-contaminated soil. The transportable unit is a modified Shirco infrared incineration unit, operated at lower temperatures than for incineration.

Clean Berkshires, Inc. (MA) has a 50 ton per hour thermal treatment unit for processing contaminated soils. A thermal desorption process in this unit operates at temperatures of 1100 to 1400°F and is followed by an afterburner which operates at 2000 to 2200°F. The unit is awaiting a final EPA approval for use in remediating PCB-contaminated soils at the F. T. Rose Superfund Site (MA).

Thermal desorption shares many of the limitations in effectiveness and uncertainties in implementation associated with solvent extraction, listed on pages 42 and 43. However, thermal desorption ranks higher on implementability than solvent extraction since thermal desorption has fewer unit processes, may be less demanding with regard to soil pretreatment requirements, does not use chemical solvents, and has been applied more often for full-scale remediations. The estimated cost range for thermal desorption is 125 to 200 dollars per ton.

3.3.4 Chemical Technologies

Dechlorination: Chemical dechlorination processes destroy PCBs by removing the chlorine atoms from the PCB molecule. The reaction products are environmentally acceptable, and more water soluble than PCBs, which allows for their dissolution from soil.

The dechlorination technologies which have been developed to treat PCB-contaminated soil rely on the use of potassium hydroxide in polyethylene glycol (PEG) or in polyethylene

glycol methyl ether (PEGME). One process reacts potassium hydroxide (KOH) in PEG to form an alkali metal hydroxide and water, and is called the KPEG process. The alkali metal hydroxide then reacts with one of the chlorine atoms on the PCB biphenyl ring to produce PEG ether and potassium chloride. Both of these products are water soluble and are readily separable from the contaminated soil. Ultimately, however, the KPEG process produces an increased final volume of material.

GRC Environmental (NY) (formerly Galson Remediation) has developed the APEG-PLUS™ process, which is a KPEG process using dimethyl sulfoxide (DMSO) as a solvent and catalyst in the dechlorination process. A hot volume (300°F) of reagent is mixed with contaminated soil using a rotating mixer (reactor). After reaction, the reagent is decanted from the soil and the soil is washed to remove residual reagent and dechlorinated reaction products. The wash fluid is passed through an activated carbon treatment unit. The residual reagent is recycled.

GRC has conducted successful pilot tests of its APEG-PLUS™ process at the Wide Beach Superfund Site (NY), followed by recent operation of a 50-ton per day test unit, demonstrating reduction of 150 ppm PCBs in soil to less than 2 ppm.

General Electric has a KPEG process (called the GETEK process) which is similar to GRC's process, but does not use DMSO as a solvent/catalyst. General Electric operates a mobile treatment unit for decontaminating transformer oils. The unit reportedly can process 6000 gallons per day of PCB-contaminated oil. Potential use of the unit for PCB-contaminated soils treatment is being investigated.

Chemical Waste Management, Inc. (IL) is developing a dechlorination process that uses potassium glycol methyl etherate (KGME) instead of KPEG. Since KGME is about one-quarter of the molecular weight of KPEG, and stoichiometric quantities of KGME are used in the dechlorination process, much less KGME is required on a weight basis and, accordingly, reagent and ultimate disposal costs are reduced. Chemical Waste Management

intends to apply the KGME process in conjunction with their X*TRAX™ process (described in Section 3.3.3). In the first step, contaminated soil is thermally treated in an X*TRAX™ system to volatilize the PCBs and recover them in liquid form. In the second step, the PCB liquid is mixed with KGME to induce dechlorination. Pilot testing has been performed at the Resolve Superfund Site (MA).

Chemical Waste Management conducted laboratory tests to compare the effectiveness of the KGME and KPEG processes. Generally, both KGME and KPEG were able to reduce the concentration of highly chlorinated PCB products (e.g. Aroclor 1260 and 1254) in the condensed liquid from the X*TRAX™ process from initial levels in excess of 100,000 ppm to final concentrations of less than 10 ppm. The KGME was more effective than KPEG on an "equal weight of reagent" basis. However, neither reagent reacted as efficiently with the less chlorinated PCB products (e.g. Aroclors 1016 and 1242). Treatment of the latter typically required large amounts of reagent, longer reaction times, and higher temperatures. It is also noteworthy that the testing was conducted on PCBs in a concentrated liquid phase, such as would result from a solvent extraction process, and not directly on PCB-contaminated soil.

The AOSTRA Taciuk process (described under "Thermal Desorption" in Section 3.3.3) has also been used for dechlorination, at the Wide Beach Superfund Site (NY). In this mode, KPEG dechlorination was accomplished in the first (preheat) zone. The thermal desorption process in the second (reaction) zone then desorbed unreacted PCBs and reagent, which were recovered and recycled for re-treatment. Although this combined mode of operation was successful, the remediation results indicated that the Taciuk process, without dechlorination, would have met the remediation goal.

Some operational concerns with the KPEG and KGME dechlorination processes that must be resolved for full-scale application to PCB-contaminated soil include (1) the requirement that the contaminated soil have a low moisture content, typically less than ten percent, (2) problems with obtaining efficient mixing, (3) maximizing reagent recovery and reuse,

further treatment or other means of qualifying the reaction products remaining in the treated soil as environmentally acceptable, and (5) the presence of either a high humic content in the contaminated soil (which increases reaction time) or alkaline-reactive metals (which compete for reagent).

Other dechlorination processes, which are still in the research stage include (1) photochemical dechlorination (using a chemical dechlorination reagent, a sensitizer dye, propane gas, and incandescent light); (2) the LARC™ process (similar to photochemical dechlorination, but using ultraviolet radiation and hydrogen gas), patented by ARCTECH, Inc. (VA); (3) radiolytic dechlorination (using radiation to irradiate PCBs in an alkaline isopropanol solution); and (4) ultrasonic detoxification (utilizing high-frequency sound waves to destroy PCBs in PCB-contaminated material slurried with a caustic solution), developed by Trinity Environmental Technologies, Inc. (KS). All of these processes have, thus far, been applied to PCBs in liquid mixtures (slurries).

The KPEG dechlorination processes can be considered more effective than solvent extraction in that they are PCB-destruction processes, while solvent extraction is a physical separation process (with the separated PCB stream requiring additional treatment, or disposal). However, KPEG dechlorination shares the same limitations in effectiveness and uncertainties in implementation associated with solvent extraction, listed on pages 42 and 43. As with solvent extraction, these limitations and uncertainties in all likelihood make dechlorination an impractical remedial technology to apply to the remnant deposits. Reliable cost information for full-scale application of chemical dechlorination is not available.

3.3.5 Thermal Destruction Technologies

Onsite Incineration: Incineration is thermal destruction of organic contaminants by use of high temperatures. The contaminants are converted to carbon dioxide, water, and other combustion products. Incineration of PCB-contaminated waste pursuant to the Toxic Substances Control Act (TSCA), 40 CFR 761.70, requires that PCBs be maintained at a temperature of 2200°F for at least two seconds and that a destruction removal efficiency in

temperature of 2200°F for at least two seconds and that a destruction removal efficiency in the gaseous emissions of at least 99.9999% be achieved (i.e. emissions from the incinerator stack shall not contain greater than 0.001 grams of PCBs per kilogram of PCB-contaminated material fed into the incinerator). Residuals (ash) from incineration must contain no more than 2 ppm PCBs.

Incineration systems can be mobile, transportable, or permanent (fixed-base). Mobile systems are transported essentially intact to a site and are then relocated to another site at the conclusion of the remediation. They normally are vehicular-mounted and include all of the equipment and sub-systems necessary for operation of the facility, such as electric power generation equipment, a fuel supply, and equipment to collect and dispose of wastewater. These systems, in order to be mobile, are limited in capacity to approximately two to three tons per hour.

Transportable equipment differs from mobile equipment in that it is provided in modular components and requires a significant erection, installation and interconnection effort. Transportable incineration systems are designed so that they can be dismantled, removed and re-installed at another site. However, for remediation by incineration at multiple and geographically close sites, like the remnant deposits, it would be appropriate for a transportable system to be erected at only one of the sites, or at a nearby central location, remain at that location, and perform the incineration of sediments from all of the remnant deposit sites at that central location. To do otherwise would require four costly and time-consuming erections and removals, would require support utilities to be provided at four separate locations, and would require separate approvals for four locations.

Commercial, fixed-based incinerators permitted to incinerate PCBs in bulk solids at greater than 50 ppm (of which there are four currently operating in the U.S.) are proven and in wide-spread use. However, these are more appropriately a part of the "excavation and off-site disposal" remedial alternative described in Section 3.3.1. Accordingly, transportable

incinerators will be the only type of incinerator evaluated, and a transportable system will be referred to as an "onsite incinerator."

Numerous types of incineration systems for contaminated materials, including PCBs, are in various stages of development; performance claims vary; and determination of which systems are commercially viable, available, and performance-worthy is difficult. All commercial fixed-base incinerators permitted for incinerating PCBs are of the rotary kiln type. Onsite incineration systems identified as commercially available and generally considered viable for remediation of high-moisture soils use rotary kiln, circulating bed, or infrared incinerators. Features of each type incinerator and a description of at least one representative, commercially-available, example system follow.

- Rotary Kiln Incineration: A rotary kiln incinerator is a cylindrical, refractory-lined steel shell that is fueled by natural gas, oil, or pulverized coal. The kiln rotates to create turbulence and, thus, improve combustion efficiency. Contaminated material, typically no greater than two inches in diameter, is deposited in the kiln at one end and is reduced to an ash by the time it reaches the opposite end. A rotary kiln is capable of handling a wide variety of solid wastes, with residence times ranging from a few seconds to hours for bulk solids. Combustion temperatures range from 1200 to 3000°F.

A source of heat is required to bring the kiln to operating temperature and to maintain its temperature during incineration of the feed. Supplemental fuel is normally fed into the kiln through a conventional burner. The kiln dries and burns solids and volatilizes organic material, including PCBs. All organics may not be incinerated in the kiln and, in such instances, they are fed into a high temperature afterburner for a residence time sufficient to complete destruction.

A rotary kiln system used for the incineration of PCB-contaminated material (feed) includes the kiln, feed pretreatment components (possibly dewatering and size

classification/reduction), equipment for conveying the feed, supplemental fuel injection, an afterburner, an ash collection system, and an air emissions control system. Air emissions controls can be extensive and can include such components as coolers, wet scrubbers, demisters, carbon adsorption beds, and high efficiency particulate filters.

Feed characteristics that are not suited for rotary kiln systems include elevated inorganic salt content which causes degradation of the refractory and slagging of the ash, and elevated heavy metal content which can result in emissions of heavy metals which are difficult to collect with air emissions control equipment.

Environmental Systems Co. (ENSCO, Little Rock, AR) has developed a transportable rotary kiln incinerator, the MP-2000, consisting of a rotary kiln, secondary combustor, heat recovery system and air emissions control system. A conveyor belt and screw feeder in series move the feed into the kiln. The rated capacity is six tons of soil per hour.

The ENSCO rotary kiln operates between 1400 and 2000°F with typically 30 to 40 minutes solids residence time, which is sufficient to vaporize and partially destroy PCBs. After incineration, residual ash is discharged into a water-sealed receiving tank. Gases produced in the kiln pass through a dual parallel cyclone for initial particulate removal. Gases then flow to a secondary combustion chamber, where PCB destruction is completed. Combustion products and kiln off-gas flow from the secondary combustor to a fire-tube boiler used for heat recovery. Once the off-gas leaves the boiler, it passes through a quenching chamber, which also provides the first stage of acid-gas removal.

A lime solution from an effluent neutralization tank is used as the quenching fluid to saturate the off-gas and remove hydrogen chloride. The solution is also used as a scrubbing medium in the second stage of the acid-gas scrubbing system, which

consists of a counter-current flow, packed tower. A steam ejector, using 20,000 pounds per hour of 250 psig steam from the heat recovery boiler, removes particulates and residual acid gases, and serves as the prime mover for the off-gas (in lieu of an induced draft fan).

The ENSCO transportable incinerator has been demonstrated effective for PCB destruction in a trial burn of three combinations of PCB-contaminated soils at a one to two ton per hour feed rate.

Weston Services (West Chester, PA) has two transportable rotary kiln incinerator systems, similar from a component standpoint to ENSCO's, each with a nationwide TSCA permit allowing such systems to operate in all ten EPA regions. The smaller of Weston's two systems has a capacity of seven tons of soil per hour, was successfully demonstrated in 1988, and ultimately was used to treat 8500 tons of PCB-contaminated soil at the demonstration site. Since that time, the system has successfully completed two additional full-scale projects for incinerating PCB-contaminated material. It is scheduled next for use at The University of Minnesota (Rosemount Research Center) Superfund Site, and subsequently for use on New Bedford Harbor sediments in the Spring of 1993. Weston's larger system is rated at 20 tons of soil per hour and has successfully completed a trial burn on soils at the Savanna Army Ammunition Depot (IL).

- Circulating Bed Incinerator: The circulating bed incinerator is an outgrowth of conventional fluidized bed incineration, which is primarily applicable to homogeneous sludges and slurries. A fluidized bed is, basically, a sand bed on a supporting structure contained within a cylindrical, refractory-lined shell. A high degree of turbulence is created in the sand bed by controlled passage of an air stream through the bed, giving the top of the bed a fluid appearance.

In the circulating bed concept, a 15 to 20 foot per second air velocity is introduced into a fluid bed by a combustion air fan. This high velocity, which is ten times the velocity in a conventional fluid bed incinerator, elutriates both the bed and the combustible feed. Circulating material rises through a reaction zone to the top of a combustion chamber and passes through a hot cyclone. Hot gas passes through the cyclone, while the majority of solids drop to the bottom of the cyclone and are re-injected into the bed. The hot flue gases are cooled and then pass to a conventional exhaust gas treatment system for removal of particulate and other contaminants.

Feed material needs to be sized to less than a one inch nominal particle size and is conveyed into the leg between the cyclone and the bed. The feed rate is automatically adjusted to maintain a pre-set oxygen concentration in the flue gas. Lime can be added to the feed or to the bed through a lime metering system to neutralize acid gas-generating constituents, and eliminate the need for wet scrubbers for the exhaust gases.

This technology is well-suited for materials with relatively low heating values. The design operating temperature is normally 1600°F, although some systems can withstand temperatures up to 2000°F on a continuous basis. Retention times within the system are controlled by monitoring the discharge from the ash cooler, and can range from a few seconds for gases to up to 30 minutes for solid feed materials. The cyclone bottom ash either discharges back to the reaction zone or is removed from the system through a water-cooled ash conveyor. By changing the speed of this conveyor, the rate of material removal from the system and, likewise, the residence time within the system is controlled. This ability to control (particularly, lengthen) residence time is a major feature of the circulating bed incinerator and can generally lead to destruction of organics, including PCBs, at system temperatures at or even below 1600°F.

Ogden Environmental Services (NJ) has developed and successfully demonstrated a circulating bed incinerator system. Ogden has constructed four five ton per hour transportable incineration systems, all identical circulating bed systems. The systems are TSCA-permitted to operate in all ten EPA regions. The largest application has been the successful incineration of 120,000 tons of PCB-contaminated soils and sediments from the Swanson River Oil Field in Alaska.

- Infrared Incineration: A typical infrared incineration system consists of a rectangular carbon steel chamber lined with layers of a light-weight, ceramic fiber. Infrared energy, provided by silicon carbide resistance heating elements, is used to bring the PCB-contaminated feed material to combustion temperature (500 to 1850°F) for residence times of ten to 180 minutes. The remaining organics are destroyed in a gas-fired afterburner at temperatures of 1000 to 2300°F and at residence times of approximately two seconds. Primary advantages of infrared incineration, as compared to a rotary kiln, are reportedly precise control of soil residence times and reduced off-gas flows due to the indirect heating.

Full-scale tests of an infrared incineration system were originally conducted by Shirco Infrared Systems, Inc. (Dallas, TX) on lagoon sludges from the Peak Oil Superfund Site in Brandon (FL) and subsequently on soils at the Rose Township Dump Superfund Site (MI). The materials were contaminated with metals, PCBs, and other organics. All organic compounds in the ash were below regulatory limits. Available data suggest that this process is suitable for solid materials containing particles up to two inches in diameter and having up to a 50 percent moisture content. The particle size limitation is due to feed equipment limitations and to the fact that feed material is spread in an approximately two-inch thick bed as it is conveyed through the infrared section. Shirco has since been merged with Ecova Corporation (WA); patents on the Shirco equipment have expired and their equipment is being modified for use by other firms.

OHM Corporation (OH) has a transportable infrared incineration system which now has a national TSCA permit to incinerate PCB wastes. The incinerator is a modified Shirco unit. The system achieved processing rates of up to 210 tons of contaminated soil per day when the first full-scale operation occurred in 1987-88. The system has been used successfully at three Superfund sites (Indiantown, FL; Twin Cities AAP, MN; Syncon Resins, NJ) and one DOD site in Labrador, and has been selected for use at the Rose Township Dump Superfund Site (MI). The largest of these projects (FL) involved incineration of 18,000 tons of PCB-contaminated soil and sediments.

Incineration is the most widely used remedial technology for PCB-contaminated materials and ranks highly in effectiveness, since PCBs are destroyed efficiently, consistent with TSCA requirements. Transportable systems are commercially available for onsite incineration.

Constraints in both effectiveness and implementation common to all three of these types of onsite incineration systems if utilized for remediation of the remnant deposit soils are summarized below.

- Onsite incineration is an ex-situ treatment, requiring excavation of the cap materials and the contaminated soils. Some or all of the contaminated soil would have to be transported offsite by truck to a central location or to the one remnant deposit site at which the incineration system is erected.
- Pretreatment of the excavated contaminated soil would likely be required, including dewatering and particle size reduction.
- The approval process for an onsite incineration system is difficult and lengthy. Also, public opposition to onsite incineration as a remedial technology is often intense.

- Onsite incineration is one of the most expensive of the various remedial technologies, due primarily to the high energy requirements, the stringent air emissions limits imposed, and also handling/disposal requirements for the bottom ash and other residues.
- Incineration will not destroy metals, which generally remain in the incinerator ash or, in the case of the more volatile metals (e.g. cadmium and lead), may be entrained in the off-gas and accumulate in the sidestreams from the wet scrubbers and filters/precipitators. In either event, both bottom ash and off-gas particulates would have to be tested for metals leachability and, in the extreme, may have to be handled and disposed as a RCRA-hazardous waste. (Recent testing in this regard was done during pilot-scale incineration of New Bedford Harbor sediments, which contained cadmium, chromium, and lead at concentrations of up to several hundred ppm. The testing demonstrated that there was little change in the leachability of these three metals in the bottom ash as compared to the sediment feed stream, however, the lead content of the wet scrubber liquids approached the toxicity characteristic concentration level).
- The apparently high total volatile solids content of the remnant deposits, in the form of organic matter (wood debris) and moisture, would have to be evaluated in sufficient detail to determine the effect on energy requirements, required residence time to achieve efficient combustion, and the amount of inert residue and ash generated. Careful pilot testing would be essential to establish pretreatment requirements and required operating parameters, and to predict expected throughput rates for the contaminated soil.

Although onsite incineration is a proven and available remedial technology, its effectiveness and implementation for remediation of the remnant deposits will be constrained by the

factors enumerated above. The estimated cost range for onsite incineration is 175 to 250 dollars per ton.

One innovative approach for onsite incineration which warrants continued evaluation is the use of oxygen-enriched combustion, which potentially increases the processing rate by up to 50 percent and reduces unit costs. The benefits of substituting pure oxygen for air are all derived from the elimination of the inert nitrogen gas which is present in air in the amount of 78 percent, by volume. The benefits include:

- Higher flame temperatures associated with the oxygen enrichment, which increases both the heat transfer to the feed and the feed processing (throughput) rate. (Nitrogen acts as a diluent, which reduces the flame temperature. Nitrogen also carries sensible heat out of the combustion zone and into the exhaust.)
- Reduction of the exhaust gas volumetric flow rate, due to the absence of nitrogen gas. This, in turn, reduces the size of the emissions control equipment required; decreases exhaust gas velocity, which allows longer residence times in the combustion zone; and minimizes the entrainment of particulates in the exhaust gas.

In short, application of oxygen-enriched combustion to onsite incineration systems offers the potential for (1) increased incinerator throughput, which is normally limited by residence time requirements and capacity of the emissions control equipment, (2) little or no need for supplemental fuel, because of the decreased sensible heat loss, (3) improved PCB destruction and removal efficiencies, because of longer residence times and higher flame temperatures, and (4) smaller emissions control units.

Vesta Technology, Ltd. (FL) has three rotary kiln onsite incineration systems. To-date, Vesta Technology has completed eight onsite incineration projects, with the most recent three projects using oxygen-enriched combustion.

Williams Environmental Services (AL) used oxygen-enriched combustion in their 20 ton per hour onsite incineration system for the incineration of 25,000 tons of soil containing volatile organic compounds at the Bog Creek Farm Superfund Site (NJ). Oxygen-enriched combustion was selected for the Bog Creek site to reduce particulate carryover in order to meet a rigorous particulate emission limit imposed by the New Jersey Department of Environmental Protection.

3.3.6 Biological Technologies

Contrary to popular opinion, PCBs are biodegradable. Biodegradation of PCBs can occur under both anaerobic and aerobic conditions. PCB-degrading microorganisms under anaerobic conditions have shown the ability to partially dechlorinate the more highly-chlorinated PCB congeners. This partial dechlorination does not appreciably change the concentration of PCBs, only the degree of chlorination of the resultant biphenyl biodegradation products. However, the dechlorination is important environmentally in that the less chlorinated congeners are generally considered as less toxic and less likely to bioaccumulate in fish than the higher chlorinated congeners. Further, PCB-degrading microorganisms under aerobic conditions will preferentially degrade the less chlorinated PCB congeners, cleaving the chlorines from the biphenyl ring, and in essence accomplishing PCB destruction. The complementary nature of the anaerobic and aerobic degradation processes offers the potential for a sequentially applied remedial technology that can biodegrade PCBs to a chlorinated benzoic acid (one phenyl ring) intermediate and ultimately to carbon dioxide, water, and chloride ion.

General Electric has determined that widespread naturally-occurring anaerobic PCB dechlorination has already resulted in a significant reduction of the more highly chlorinated PCB congeners throughout the in-situ sediments of the Upper Hudson River (Appendix A-2 in Reference L). Further, General Electric has evidence from the Reference L study along with data from 1984 and 1990 Hudson River sediment investigations that (1) suggest that indigenous microorganisms are causing some aerobic PCB destruction to occur naturally and (2) demonstrate that aerobic PCB destruction can be accelerated in Hudson River sediments

in-situ by the addition of nutrients and supplemental oxygen. The importance of these findings is that, obviously, the remnant deposits are also Hudson River sediments (although in an out-of-water condition since 1973) and it is reasonable to assume that these biodegradation processes have been and continue to be at work naturally within the remnant deposits. The current presence of an impermeable cap on each of the four remnant deposits may serve to enhance the rate of in-situ anaerobic degradation of PCBs. The extensive wood debris present in the remnant deposits may be helpful as a source of organic material for naturally-occurring PCB-degrading organisms.

In-situ destruction of PCBs in the remnant deposits by biodegradation must rely on indigenous or introduced PCB-degrading microorganisms. Introduction of PCB-degrading microorganisms implies the ability either to identify and cultivate naturally occurring microorganisms for this purpose, or genetically engineer a group of complementary microorganisms. General Electric, in Table 1-1 of Reference L, identified twenty-five indigenous bacterial strains that had been isolated from PCB-contaminated areas and that displayed a wide range of PCB-degrading capabilities under aerobic conditions. General Electric, also in Reference L (page 179), noted that indigenous microorganisms capable of degrading PCBs under anaerobic conditions had been identified at numerous PCB-contaminated sediment sites (including New Bedford Harbor, MA; Sheboygan River, WI; and Waukegan Harbor, IL).

DeTox Industries (TX) has demonstrated enhanced aerobic degradation of PCBs using naturally occurring microorganisms in an enhanced (conducive for growth) environment. A successful ex-situ field demonstration on PCB-contaminated sludge was performed in 1983. Financial difficulties slowed progress until recently. New field tests are planned. Separately, Envirogen, Inc. (NJ) has completed extensive laboratory testing of both anaerobic and aerobic naturally-occurring PCB-degrading microorganisms, but no field-scale testing has been done to-date. Environmental Remediation, Inc. (LA) has performed a two-year ex-situ pilot scale field test on PCB-contaminated soil using both enhanced naturally-occurring microorganisms and also white rot fungus, which secretes an enzyme that degrades

PCBs. Results are not yet available. Sybron Chemicals (NJ) (Bio-Chem Division) develops complementary naturally-occurring anaerobic/aerobic microorganisms for PCB degradation, but all work is still in the laboratory phase. They have been more successful to date with, and have made wider application of, selectively adapting naturally-occurring organisms for the biodegradation of petroleum contamination.

In a related development, INNOVA Corporation (Denver, CO) has developed a stable, porous ceramic soil additive called ISOLITE, made of diatomaceous earth and natural binders that are rotary kiln fired at 1800°F. ISOLITE, which has up to 75 percent pore space, is incorporated into soil by tilling or soil injection and is claimed to enhance microbial activity by providing a growth matrix, improving retention of soil moisture and nutrients, and promoting microbial/soil contact. ISOLITE is being used in conjunction with ex-situ bioremediation pilot testing by Griffin Remedial Services (Ontario, Canada).

As is apparent from the preceding, the work to-date on in-situ bioremediation of PCBs has been limited to the laboratory and small pilot-scale demonstrations. Full-scale in-situ bioremediation of PCBs is yet to be demonstrated, and will have to be accomplished by one of three approaches, namely:

- Enhancement of the effectiveness of indigenous microorganisms by optimizing the in-situ conditions;
- Introduction of suitable exogenous microorganisms and establishment of optimum in-situ conditions for their distribution and growth; or
- A combination of the two approaches.

Prior to introduction of exogenous microorganisms, determinations would have to be made regarding the ability of the microorganisms to survive in a new environment; to migrate

throughout the targeted environment; to retain their biodegradation qualities; and not to pose a threat to human health or the ecosystem.

Optimizing the in-situ conditions can involve (1) neutralizing or eliminating inhibitory aspects of the environment, (2) maximizing the bioavailability of the PCBs to the microorganisms, and vice versa, and (3) introducing nutrients (e.g. nitrogen and phosphorous) and a carbon source or oxygen to accelerate the degradation process. In most cases, accomplishing these optimizations requires either intrusive introduction of materials to, or intrusive manipulation of, the in-situ environment which, in turn, poses engineering difficulties yet to be resolved on a full-scale basis.

A passive approach for in-situ bioremediation of PCB-contaminated sediments is in progress at the Sheboygan Harbor and River Superfund Site (WI) whereby a 15,000 square foot area of PCB-contaminated sediments in the river bed has been capped. The capping is expected to prevent transport of the sediments and increase anaerobic conditions, thereby enhancing the anaerobic dechlorination already observed to be in progress.

At the Queen City Farms Superfund Site (WA), part of the selected remedy is to install vent wells through an existing multi-layer cap, for providing oxygen so that indigenous bacteria can degrade in-situ contaminants, which include PCBs.

Implementation of enhanced in-situ bioremediation of PCBs in the remnant deposits to reduce PCB concentrations to low levels faces the following difficulties:

- The absence, for comparison purposes, of any demonstrated, full-scale, enhanced bioremediation project to-date on in-situ PCB-contaminated material;
- The absence of isomer-specific baseline PCB data in the remnant deposits against which the progress and efficiency of natural or enhanced in-situ bioremediation can be measured;

- The need for extensive site-specific bench and pilot scale testing to demonstrate the effectiveness of enhanced PCB bioremediation;
- The presence of potentially inhibitory concentrations of heavy metals (e.g. cadmium, chromium, and lead);
- The potentially long remediation time-frame for in-situ bioremediation unless highly effective enhancements are identified and implemented. (Studies to-date do not provide sufficient data for reliable estimation of natural PCB degradation rates. Reference M suggests that the half-life of highly-chlorinated PCBs undergoing natural anaerobic biodegradation (partial dechlorination) may range from seven to 50 years.)
- The depth of the PCBs (for example, elevated concentrations have been identified as much as 14 feet below the cap at Remnant No. 5) and the volume of material potentially requiring remediation, which will make delivery of enhancement agents to targeted regions and periodic monitoring of such regions both logistically difficult and costly; and
- The presence of an impermeable cap on each remnant deposit which presents an obstacle to the delivery of nutrients, oxygen, or microorganisms to the PCB-contaminated regions and presents an obstacle to collection of baseline in-situ data as well as subsequent data needed to monitor in-situ conditions and to measure the rate and extent of PCB degradation.

With regard to the delivery of microorganisms or other agents into the PCB-contaminated sediments, discussions with J & L Engineering, designers of the geosynthetic Claymax liner, indicate that the Claymax is self-sealing for punctures up to one inch in diameter. This offers the possibility of penetrating the Claymax with small diameter probes without

compromising the cap integrity, which would allow delivery of enhancement agents or collection of samples or other data.

Methods of supplying oxygen to the in-situ PCB-contaminated material for enhancing biodegradation might include:

- Injection of hydrogen peroxide solution at closely spaced intervals through the cap into the sub-surface, or via the groundwater. Hydrogen peroxide rapidly decomposes to form water and free oxygen. The effectiveness of this approach, however, can be dramatically reduced in soils containing elevated iron or manganese levels, which produce loss of available oxygen by metal catalysis.
- Injection and vacuum withdrawal of air through the sub-surface via appropriately-spaced wells (effective only in unsaturated soils). Controls and treatment may be required on the discharged vapor.

Although natural PCB degradation has undoubtedly occurred within the remnant deposits, the extent is not known at this time. It is also not known whether substantial natural PCB degradation will occur in the future and in a reasonable time-period. However, the favorable aspects of natural PCB degradation as a remedial process for the remnant deposits are apparent. If effectiveness can be verified, natural degradation rates highest from an implementation and cost standpoint. Implementation would be non-intrusive and would occur by naturally-occurring processes. Cost would be relatively low and would involve monitoring procedures only.

Enhancing the in-situ bioremediation process to increase the rate and efficiency of PCB biodegradation is feasible, and such an approach offers substantial advantages in implementation as compared to the other generic remedial technologies reviewed. However, enhanced in-situ PCB bioremediation is a technology which is still in its infancy

and which requires engineering development in order to be demonstrated effective at full-scale. As a result, cost data for full-scale enhanced PCB bioremediation are not available.

Ex-situ biodegradation obviously greatly simplifies the delivery of microorganisms, nutrients, and oxygen to the PCB-contaminated soil. However, it is not considered a realistic option for the remnant deposits due to the extensive excavation required, the absence of available area for stockpiling and distributing soils into treatment plots, and the likely increased time period (as compared to other ex-situ treatment technologies) of weeks or months for completing biodegradation of any unit volume of contaminated soil.

3.3.7 Summary of Remedial Technologies

Representative vendors and processes for the remedial technologies discussed in this section are listed in Table 11.

TABLE 11

REPRESENTATIVE¹ VENDORS/PROCESSES FOR REMEDIAL TECHNOLOGIES

- **Pretreatment** (to support all ex-situ remedial technologies)
 - Size Reduction (screening, crushing, classification, soil washing)
 - Dewatering (filtration, centrifugation, drying)
- **In-Situ Vitrification**
 - Geosafe Corporation
- **In-Situ Solidification/Stabilization**
 - International Waste Technologies and Geo-Con Inc.
 - S.M.W. Seiko, Inc.
 - STC Silicate Technology Corporation
- **Biodegradation** (all developmental)
 - DeTox Industries, Inc.
 - Envirogen, Inc.
 - Environmental Remediation, Inc.
 - Sybron Chemicals (Bio-Chem Division)
- **Solvent Extraction**
 - CET Environmental Services (Sanivan Group) (Ektraksol™ Process)
 - CF Systems Corporation (Morrison Knudsen)
 - NuKEM Development (formerly ENSR Corporation)
 - ART International, Inc. (Low Energy Extraction Process)
 - OHM Corporation (methanol extraction)
 - Resources Conservation Company (Haliburton) (B.E.S.T.™ Process)
- **Soil Washing**
 - Biotrol, Inc.
 - Waste-Tech Services, Inc.
 - Bergmann USA, Inc.

¹Only representative processes/vendors (discussed in the text) are listed. Others may be available and appropriate for consideration.

TABLE 11 (cont'd)

- **Thermal Desorption**

- Aptus, Inc. (infrared)
- Chemical Waste Management, Inc. (X*TRAX™)
- SoilTech ATP Systems, Inc. (AOSTRA Taciuk Process)
- Clean Berkshires, Inc.

- **Dechlorination**

- Chemical Waste Management, Inc. (KGME Process)
- General Electric Company (GETEK Process)
- GRC Environmental, Inc. (APEG-PLUS™ Process)
- ARCTECH, Inc. (LARC™)
- Trinity Environmental Technologies, Inc. (ultrasonic)

- **Onsite (Transportable) Incineration**

- Environmental Systems Company (ENSCO) (rotary kiln)
- Weston Services (rotary kiln)
- OHM Corporation (infrared)
- Ogden Environmental Services (circulating bed)
- Vesta Technology, Ltd. (rotary kiln, oxygen-enriched)
- Williams Environmental Services (rotary kiln, oxygen-enriched)

- **Disposal at Offsite Permitted Facility**

- Four TSCA-Permitted (>500 ppm) Commercial Incinerators (closest: Coffeyville, KS)
- Six TSCA-Permitted (>50 ppm) Landfills (closest: Model City, NY)

SECTION 4

LIMITATIONS AND MAJOR DIFFICULTIES

4.1 LIMITATIONS

The comparative discussion of remedial technologies in Section 3 is qualitative for the following reasons:

- Site Characterization Data: In addition to the available remnant deposit characterization data, additional data which would be helpful, and in certain instances required, for performing a detailed, quantitative evaluation of remedial technologies would include:
 - Additional remnant deposit physical characteristic data and test data, including in-situ moisture content and density, particle size distribution, heat of combustion, and debris distribution (all of which influence the need for and definition of pretreatment requirements);
 - Additional remnant deposit chemical data including acidity/alkalinity; oxidation-reduction potential; heavy metals concentrations (notably cadmium, chromium, lead, iron, and manganese); and total chlorides, total organic carbon, and dissolved carbon (parameters which are important for assessing the mobility/bioavailability of contaminants, the conditions conducive for or inhibitory to microbial growth, and the conditions important to thermal treatment efficiency);
 - Isomer specific PCB data, to assist in evaluating the extent of naturally-occurring PCB biodegradation in the remnant deposits; and

- Bench-scale treatability testing on PCB-contaminated sediment, to establish the viability and efficiency of remedial technologies and to define pretreatment requirements.
- Pretreatment Requirements: Ex-situ remedial technologies would require pretreatment of the excavated, PCB-contaminated sediments. Pretreatment could include dewatering, debris removal (e.g. screening), size reduction (e.g. crushing), and particle classification (e.g. soil washing). Conventional, proven equipment and systems are commercially available to accomplish pretreatment and a review and identification of such equipment/systems is not within the scope of this document. Pretreatment, nonetheless, would be a major component of any ex-situ remedial technology. Remedial technologies having too stringent standards for the sediment feed may be judged impractical for use on the remnant deposits on this basis alone. In this regard, it is instructive to be aware of the particle size limitations for incoming feed for the various remedial technologies reviewed. Table 12 summarizes these limitations. These limitations are typically dictated by either (1) limitations in the material handling equipment (e.g. conveyors, screw feeders) integral to the remedial process equipment or (2) limitations internal to the process equipment relating to process efficiency or material transport. Given the physical characteristics of the remnant deposits and the presence of wood debris, pre-screening and size reduction would be a necessity for application of ex-situ remedial technologies.

Pretreatment would also generate sidestreams, including water and rejected ("large size") particles and debris. These sidestreams are likely to contain PCBs and require special handling and disposal.

- Sidestreams and Residual (Treated) Soil: The ex-situ, onsite remedial technologies would generate sidestreams requiring special handling, additional testing, or additional treatment, and subsequent final disposition. Thermal desorption would generate several sidestreams, namely (1) either a liquid phase or solid phase

TABLE 12

FEED STREAM LIMITATIONS FOR EX-SITU REMEDIAL TECHNOLOGIES

<u>REMEDIAL TECHNOLOGY</u>	<u>MAXIMUM PARTICLE SIZE (inches)</u>	<u>MAXIMUM WEIGHT PERCENT WATER²</u>
Solvent Extraction	1/8 to 1/2	preferably < 10%
Dechlorination	1/8 to 1/2	preferably < 10%
Thermal Desorption	2	no free flowing liquids
Onsite Incineration	2	no free flowing liquids
Commercial Fixed-Based Incinerator	6 ¹	no free flowing liquids

- NOTES:
1. This value is approximate and is a material handling limitation imposed by commercial incinerators. Larger particle sizes can be accepted, but at additional cost.
 2. System efficiency decreases and cost per unit weight processed increases as weight percent moisture in the feed increases. For example, for the X*TRAXTM thermal desorption unit, an increase in feed moisture content from 20 to 50 percent will reportedly increase treatment cost by 75 percent. High moisture content will typically reduce system capacity (throughput rate), but not reduce PCB removal efficiency.

(activated carbon) in which the desorbed PCBs have been concentrated, (2) a condensed organics phase, (3) water, (4) particulates (from the air emissions control system), and (5) wet scrubber liquid (from the air emissions control system). Onsite incineration would generate sidestreams (3), (4), and (5). Predicting the volume and quality of these sidestreams, and associated handling, treatment, and disposal costs, is difficult without bench-scale treatability testing and possibly pilot testing. These sidestreams are in addition to sidestreams from pretreatment (discussed above). Costs for handling and disposition of the residual (treated) soil, or ash, are unpredictable at this stage of evaluation and are dependent on whether the treated material can be backfilled onto the site without restriction. Restrictions can result, for example, from the presence of leachable heavy metals in the treated material or ash (compliance with toxicity characteristic regulatory levels would have to be demonstrated by testing).

4.2 MAJOR DIFFICULTIES

Table 13 summarizes the major difficulties associated with application of the generic remedial technologies to the remnant deposits. These are major difficulties regarding effectiveness and implementation and are discussed in more detail in Section 3.

These major difficulties, coupled with the fact that the majority of the remedial technologies have not been demonstrated on a large-scale for PCB-contaminated soils or sediments, suggest that the already implemented in-place containment remedy (cap) may represent the most practical, effective, and least intrusive remedial technology for remnant deposit PCBs.

TABLE 13

**MAJOR DIFFICULTIES IN APPLICATION OF REMEDIAL TECHNOLOGIES
TO REMNANT DEPOSITS**

- **Total Containment with Barriers**

- No available technologies for bottom sealing with impermeable materials

- **In-Situ Vitrification**

- Not successfully demonstrated at full scale
- Technical questions relative to implementability and effectiveness are unresolved
- Difficulty with high organic content of remnant deposits and high groundwater

- **Ex-Situ Solidification/Stabilization**

- Requires extensive excavation of both the cap and remnant deposit material
- High moisture content, presence of wood debris, and wide particle size-distribution range complicates application to remnant deposits
- Substantial area required for excavated materials during additive application, mixing, and curing

- **In-Situ Solidification/Stabilization**

- Would require excavation of a portion of the in-place cap, including topsoil, drainage layer, and Claymax
- Limited vendor base
- No demonstrated large-scale application for PCB-contaminated sediments
- High moisture content, presence of wood debris, and wide particle size-distribution range complicates application to remnant deposits
- Verifying the effectiveness, particularly at depth, can be difficult, time consuming, and inconclusive

- **Solvent Extraction and Dechlorination**

- Requires extensive excavation of both the cap and remnant deposit material
- Extensive pretreatment (size reduction and dewatering) of remnant material would be required
- Not demonstrated on large volumes
- Use of multiple unit processes complicates operation and control
- Use of chemical reagents is a handling and residual contamination concern
- Negligible removal efficiency for heavy metals; possibility of increase in mobility for same in treated soil

TABLE 13 (cont'd)

• **Soil Washing**

- Requires extensive excavation of both the cap and remnant deposit material
- Not demonstrated full-scale for PCBs in sediments in U.S.
- Elevated percent fines and organic matter in remnant deposits may be limiting
- Use of multiple unit processes complicates operation and control
- Negligible removal efficiency for heavy metals; possibility of increase in mobility for same in treated soil

• **Thermal Desorption**

- Requires extensive excavation of both the cap and remnant deposit material
- Extensive pretreatment (size reduction and dewatering) of excavated remnant material would be required
- Negligible removal efficiency for heavy metals; possibility of increase in mobility for same in treated soil
- Energy intensive

• **Onsite (Transportable) Incineration**

- Requires extensive excavation of both the cap and remnant deposit material
- Extensive pretreatment (size reduction and dewatering) of excavated remnant material would be required
- Negligible removal efficiency for heavy metals; possibility of increase in mobility for same in treated soil
- Energy intensive
- Approval process is difficult and lengthy; public opposition is often intense
- Stringent air emissions limits

• **Enhanced Biodegradation**

- Developmental
- Efficient systems for delivery of microbes and nutrients in-situ not developed
- Excessive volumes of material to treat in-situ, or to excavate for ex-situ treatment
- Absence of extensive/readily-available area for ex-situ treatment plots
- Time-period for effective biodegradation to occur is uncertain

• **Disposal at Offsite Permitted Facility**

- Requires extensive excavation of both the cap and remnant deposit material
- Some pretreatment (size reduction and dewatering) of excavated remnant material may be required to meet offsite disposal restrictions
- Thousands of truck trips involved, with associated transportation risks
- Replacement of some of the excavated material with clean fill required
- Landfilling does not reduce PCB toxicity, mobility, or volume by treatment

SECTION 5

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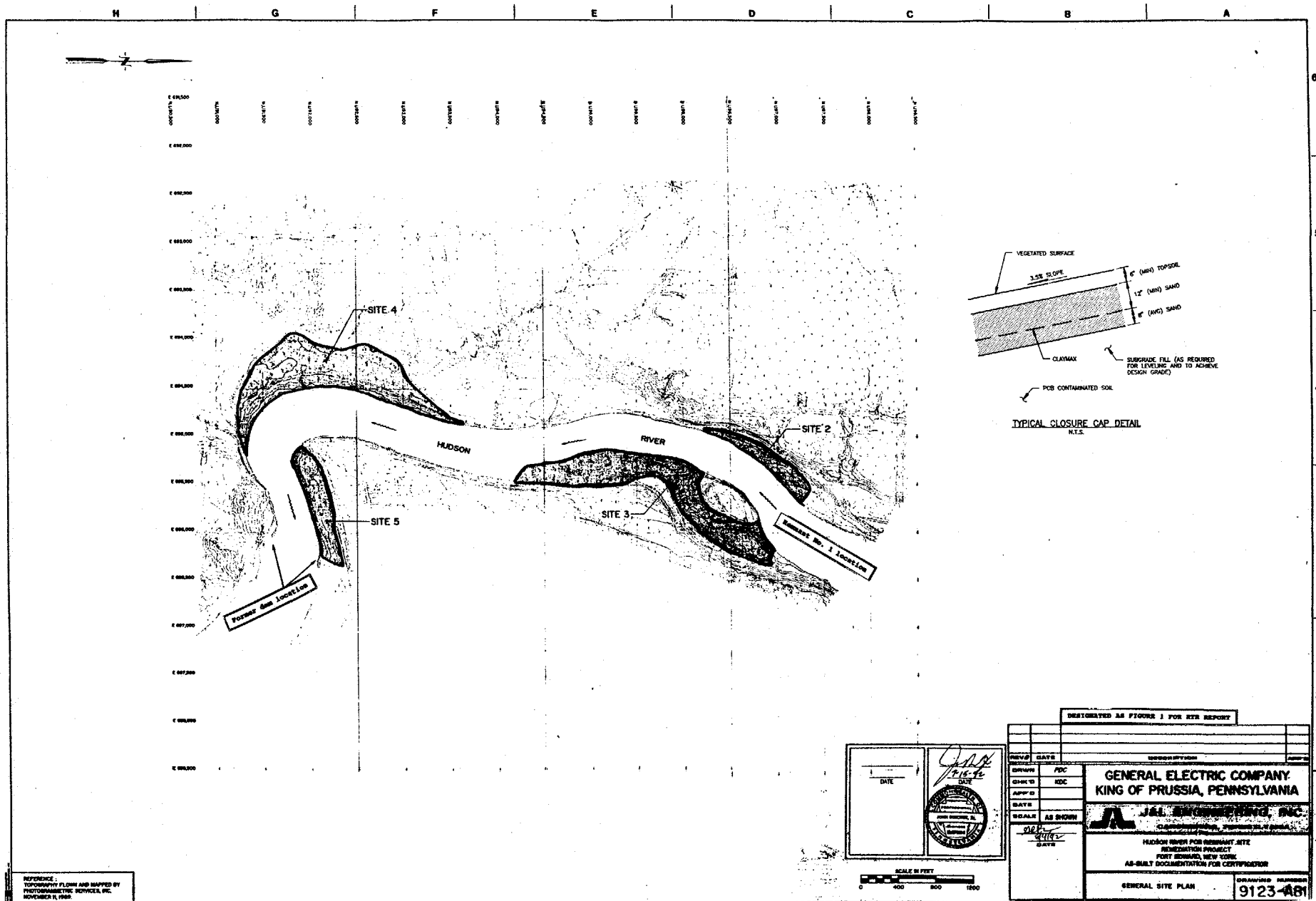
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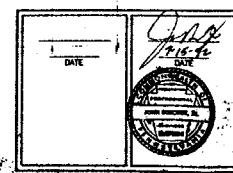
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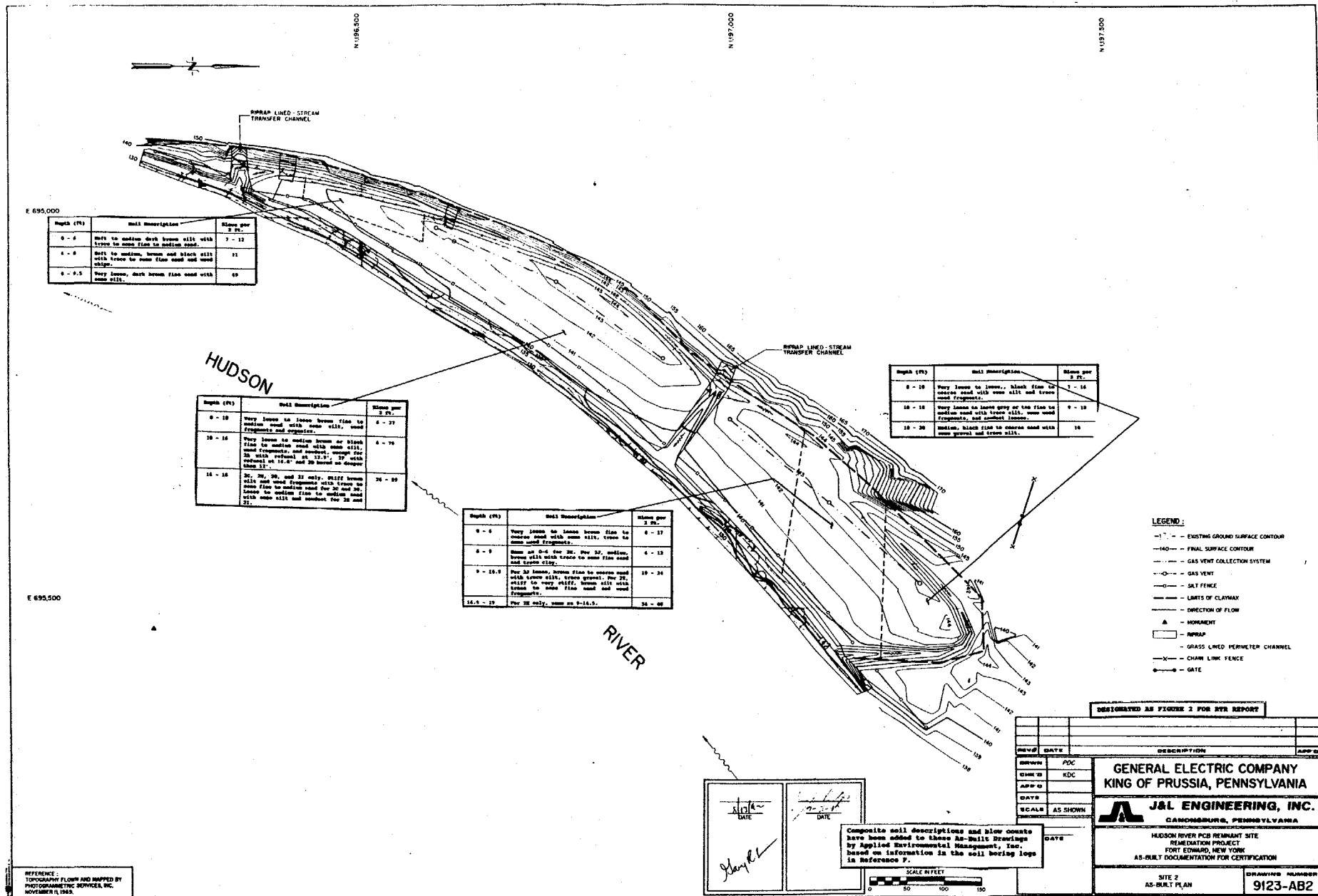
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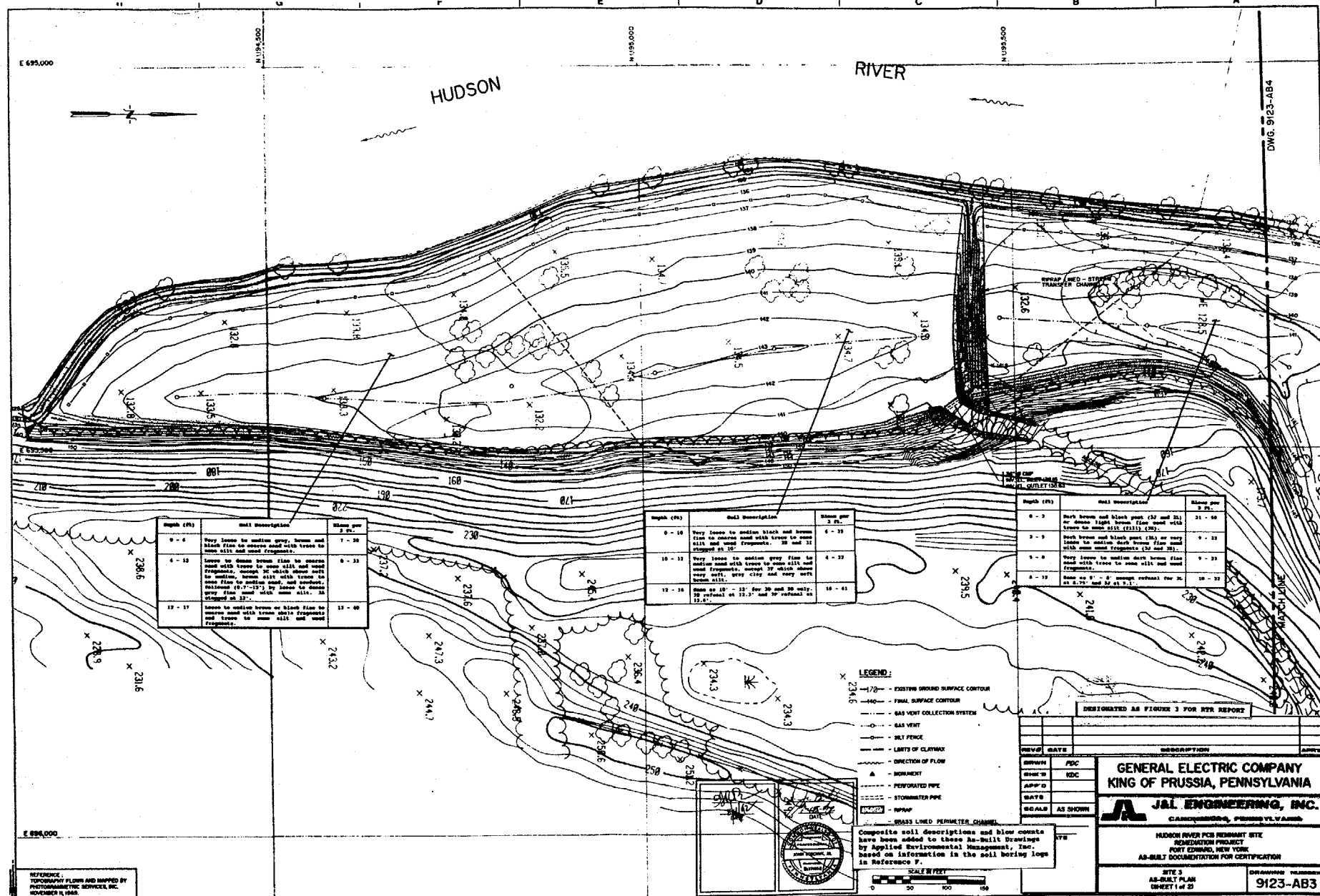
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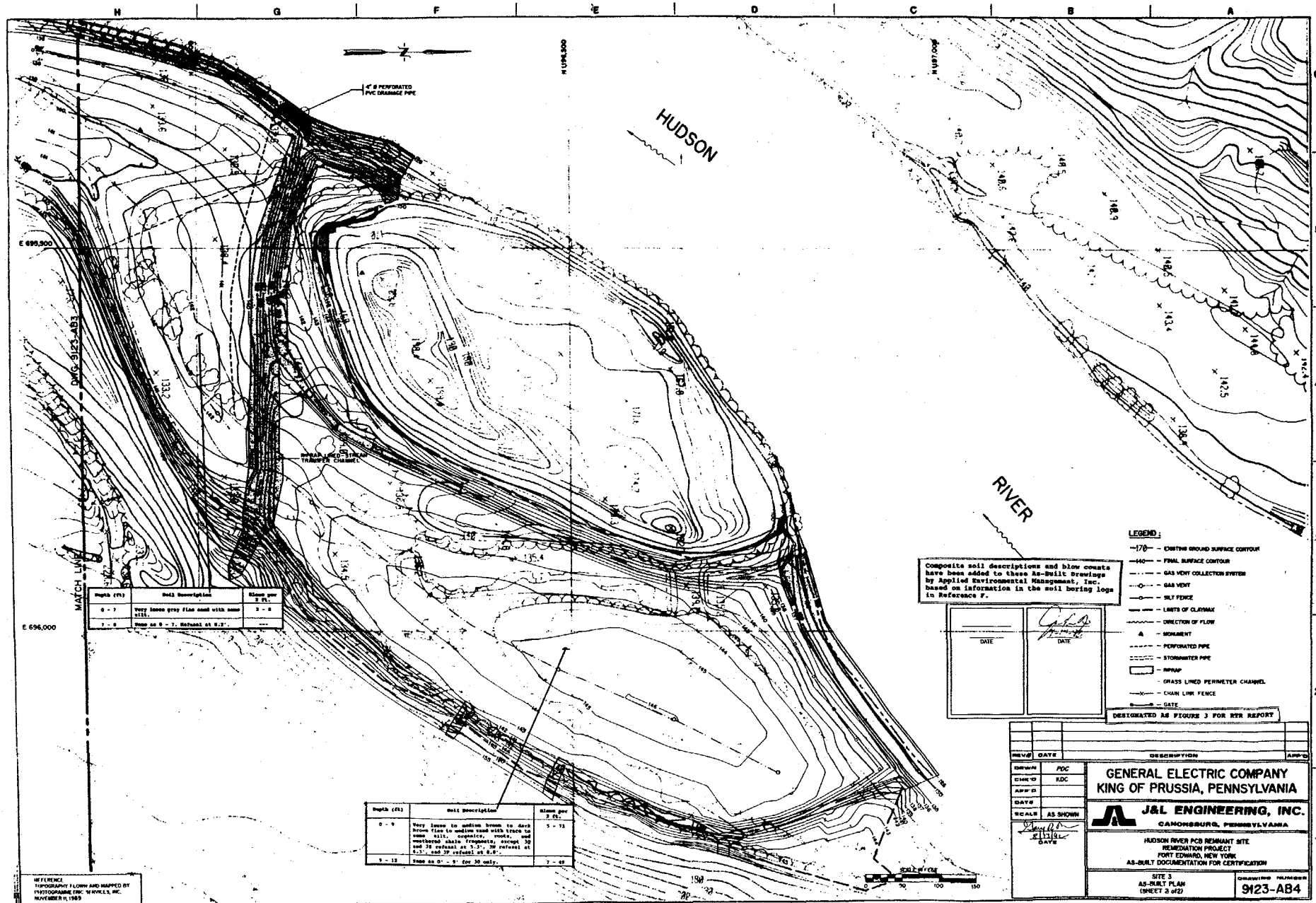
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