COST AND PERFORMANCE REPORT

EXECUTIVE SUMMARY

This report presents cost and performance data for a slurry phase bioremediation application at the Southeastern Wood Preserving Superfund site, in Canton, Mississippi. Slurry phase bioremediation was used at the Southeastern Wood site to treat soil and sludge contaminated with polynuclear aromatic hydrocarbons (PAHs), including acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(b and k)fluoranthenes, benzo(ghi)perylene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene, and pyrene.

The Southeastern Wood site was the location of a creosote wood preserving facility that operated from 1928 to 1979, and included three unlined wastewater treatment surface impoundments. Bottom sediment sludge from the impoundments was found to contain PAHs at levels of approximately 4,000 mg/kg, and was identified as a RCRA K001-listed hazardous waste. PAH concentrations measured included acenaphthene at 705 mg/kg, naphthalene at 673 mg/kg, and benzo(a)pyrene (B(a)P) at 224 mg/kg.

The application at Southeastern Wood was completed as a removal action, under an action memorandum signed in September 1990. A slurry phase bioremediation system was operated from July 1991 until 1994, and consisted of a power screen, a slurry mix tank, four slurry phase bioremediation reactors (bioreactors), and a slurry dewatering unit. The bioreactors were 38 feet in diameter and 24 feet in height, and were equipped with a blower for aeration and an impeller for mixing and keeping the slurry in suspension. Cleanup goals for this application were developed based on the results of laboratory and field pilot tests and a site-specific health-based risk analysis, and consisted of the following: total PAHs - 950 mg/kg, and B(a)P-equivalent PAHs - 180 mg/kg. These goals were provided in an LDR treatability variance for this application.

The bioreactors were operated on a batch basis, and each batch was monitored during treatment to evaluate performance with respect to the cleanup goals. Treatment performance data are available for 13 of the 61 bioreactor batches, and show that the average total PAH concentration was reduced from 8,545 to 634 mg/kg, which corresponds to a treatment efficiency of 93 percent. The average B(a)P-equivalent concentration was reduced from 467 to 152 mg/kg, or 67 percent. The analytical data indicate that the majority of biodegradation occurred during the first 5 to 10 days of treatment, and the cleanup goal for total PAHs was met for 12 of the 13 batches within approximately 19 days of treatment.

Approximately $2,900,000 were expended in this application, consisting of $2,400,000 for activities directly attributed to treatment (mobilization/setup, startup/testing/permits, and operation), and $500,000 for after-treatment activities (site restoration). The cost for activities directly attributed to treatment corresponds to $170 per ton ($230 per cubic yard) of soil and sludge treated (14,140 tons, or 10,500 cubic yards).

SITE INFORMATION

Identifying Information:

Southeastern Wood Preserving Superfund Site
Canton, Mississippi
CERCLIS # MSD0008258558
Action Memorandum Date: 9/30/90

Treatment Application:

Type of Action: Removal
Treatability Study Associated with Application? Yes
(see additional information under Background and Operation below)
EPA SITE Program Test Associated with Application? No

Period of Operation: 1991-1994

Quantity of Material Treated During Application: 14,140 tons (10,500 cubic yards) of soil and sludge

Background

Historical Activity that Contributed to Contamination at the Site: Creosote wood preserving
Corresponding SIC Code: 2491B (Wood Preserving Using Creosote)
Waste Management Practice that Contributed to Contamination: Manufacturing Process, Surface Impoundment/Lagoon

Site History:
The Southeastern Wood Preserving Superfund Site is an abandoned wood preserving facility located in Canton, Mississippi, as shown in Figure 1. The facility was used for creosote wood preserving activities between 1928 and 1979. In 1986, EPA initiated an emergency response action at the site to stabilize three unlined surface impoundments which were overflowing.

The impoundments were dewatered and bottom sediment sludge was excavated and stabilized using approximately 70 cubic yards of cement kiln dust.

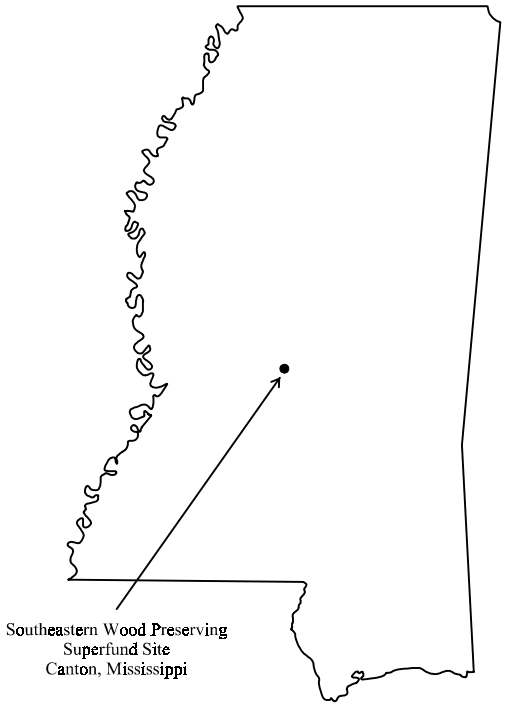

Figure 1. Site Location [1]

SITE INFORMATION (CONT.)

Background (cont.)

Excavation was based on a visual assessment of contamination. EPA sampled this material in April 1989, and found it to be contaminated with polynuclear aromatic hydrocarbons (PAHs), at levels of approximately 4,000 mg/kg, as shown in Table 1. The contaminated material from the lagoon was classified as a RCRA K001-listed hazardous waste (bottom sediment sludge from the treatment of wastewaters from wood preserving processes which used creosote). The excavated material was stockpiled on site for further treatment. [1, 2, 12]

Regulatory Context: This application was conducted as part of a removal action at the site. Cleanup goals were developed based on the results of bench-scale and field pilot studies using bioremediation and a site-specific health-based risk analysis.

Remedy Selection: Slurry-phase bioremediation was selected for this application on the basis of cost. In addition, slurry-phase bioremediation was identified as preferable to land treatment because it was believed to treat the soil in a shorter period of time and to achieve lower concentrations in the residual soil. [4, 9]

Table 1. Concentrations of PAHs in Excavated Material* [12]

Constituent	Concentration (mg/kg)
Acenaphthene	705
Acenaphthylene	78.8
Anthracene	2.44
Benzo(a)anthracene	496
Benzo(b)fluoranthene/ Benzo(k)fluoranthene	513
Benzo(ghi)perylene	9.8
Benzo(a)pyrene	224
Chrysene	305
Dibenzo(ah)anthracene	27.05
Fluoranthene	419
Fluorene	32.2
Indeno(1,2,3-cd)pyrene	64.1
Naphthalene	673
Phenanthrene	266
Pyrene	ND (0.36)
Total PAHs	3,815

ND - Not detected. Value in parentheses is the reported detection limit.
*Sample collected April 4, 1989.

SITE INFORMATION (CONT.)

Site Logistics/Contacts

Site Management: Fund-Lead

Oversight: EPA

On-Scene Coordinator:

R. Donald Rigger
USEPA Region 4
345 Courtland Street, N.E.
Atlanta, GA 30365
(404) 347-3931

Vendor:

Douglas E. Jerger/Pat Woodhull
OHM Remediation Services Corp.
16406 U.S. Route 224 East
P.O. Box 551
Findlay, OH 45840
(419) 425-6175

MATRIX DESCRIPTION

Matrix Identification

Type of Matrix Processed Through the Treatment System: soil (ex situ) and sludge (ex situ)

Contaminant Characterization

Primary Contaminant Groups: Polynuclear Aromatic Hydrocarbons (PAHs)

The excavated material at the site contained PAH concentrations of approximately 4,000 mg/kg dry weight for total PAHs and from 1,000 to 2,500 mg/kg dry weight carcinogenic PAHs. Total PAHs are defined as the sum of the 16 constituents listed below. Carcinogenic PAHs are defined as the total concentration of the seven PAHs marked with an asterisk: [3]

- Acenaphthene;
- Acenaphthylene;
- Anthracene;
- Benzo(a)anthracene*;
- Benzo(b)fluoranthene*/ Benzo(k)fluoranthene*;
- Benzo(ghi)perylene;
- Benzo(a)pyrene*;
- Chrysene*;
- Dibenzo(a,h)anthracene*;
- Fluoranthene;
- Fluorene;
- Indeno(1,2,3-cd)pyrene*;
- Naphthalene;
- Phenanthrene; and
- Pyrene.

Matrix Characteristics Affecting Treatment Cost or Performance

The major matrix characteristics affecting cost or performance for this technology and the values measured for each are shown in Table 2.

Table 2. Matrix Characteristics [2, 9, 12]

Parameter	Value	Measurement Method
Soil Classification	Information not provided	Information not provided
Clay Content and/or Particle Size Distribution*	>10 mesh (gravel) 5% <10->200 mesh (sand) 40% <200 mesh (clay) 55%	Information not provided
Bulk density (of stockpiled material)	1.83 gm/cm^3	ASTM-D1298
Ash	66.8%	ASTM-D482
Sulfur	0.08%	ASTM-D129
Free liquids	None	SW-846-9095
Total Solids	71.5%	SM-209F

*Information was not provided in the available references on whether this distribution was for soil excavated from the site and/or treated in the bioreactors.

Various types of debris were present in the contaminated soil and sludge excavated at the site. The debris included large stones, plastic sheeting, concrete, and railroad ties. [2]

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology Type: Slurry phase bioremediation

Supplemental Treatment Technology Type:
Pretreatment (Solids): screening, mixing
Post-Treatment (Solids): dewatering

Slurry Phase Bioremediation System Description and Operation

The slurry phase bioremediation system used at Southeastern Wood Preserving included a power screen, a slurry mix tank, four slurry phase bioremediation reactors (bioreactors), and a slurry dewatering unit. This system, shown in Figure 2, was used to separate out the larger particles (greater than 200 mesh, or 0.0029 inches) from the stockpiled soil and sludge, and to biologically treat the remaining soil and sludge particles (less than 200 mesh).

As shown on Figure 2, soil and sludge from the stockpile were power-screened to remove debris greater than 0.5 inches such as large stones, plastic sheeting, and railroad ties. The power-screening step removed approximately 450 cubic yards of material.

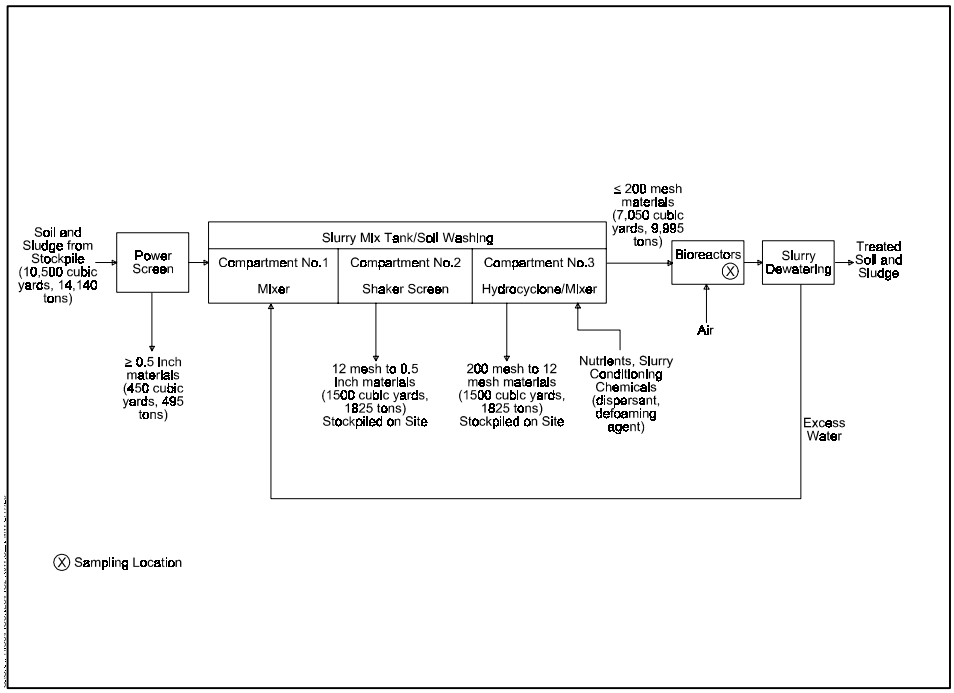

Figure 2. Slurry Phase Bioremediation System Used at Southeastern Wood Preserving [6]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Slurry Phase Bioremediation System Description and Operation (Cont.)

Soil and sludge that passed the power screening step were loaded into a slurry mix tank for soil washing. The mix tank contained three compartments:

- Compartment No. 1 - Water was added to slurry the solids.
- Compartment No. 2 - The slurry was pumped to a shaker screen to remove debris between 12 mesh (0.0661 inches) and 0.5 inches. Approximately 1,500 cubic yards of debris were removed by the shaker screen.
- Compartment No. 3 - A hydrocyclone removed approximately 1,500 cubic yards of materials (sand) and other materials between 200 mesh and 12 mesh.

In addition, nutrients and slurry conditioning chemicals (including a dispersant and defoaming agent) were added and mixed with the slurry in this compartment.

Materials removed by the shaker screen and hydrocyclone were stockpiled on site.

The slurry mixing/soil washing process was performed on a batch basis, with 20-30 minutes of processing time per batch.

Bioreactors [1, 2, 16, 26]
Four closed-top bioreactors were used in this application. Each bioreactor was 38 feet in diameter and 24 feet in height, and was equipped with diffusers and a blower for aeration and an impeller for mixing and keeping the slurry in suspension. Each bioreactor had an operating capacity of 180,000 gallons. The system was operated on a batch process, with each batch consisting of 160 to 180 cubic yards of material. Sixty-one batches were treated in this application, consisting of 17 batches in reactor 1, 23 batches in reactor 2, 14 batches in reactor 3, and 7 batches in reactor 4. During treatment, the slurry in the reactors was monitored daily for pH, temperature, dissolved oxygen, and other biological monitoring parameters, such as nutrient and biomass concentrations. Operating parameters and values for this application are shown in Table 3.

Excess water generated in the bioreactors was occasionally removed from the reactors. This excess water was first sampled, and, as appropriate, discharged to a POTW.

Operation [2, 9, 10]
Construction of the treatment facilities began in January 1991 and was completed in mid-April 1991. Demonstration testing began at that time and consisted of batch treatment of 700 cubic yards of soil. By late June 1991, the treatment vendor had demonstrated that the soil could be

TREATMENT SYSTEM DESCRIPTION (CONT.)

Slurry Phase Bioremediation System Description and Operation (Cont.)

treated in the reactors to the cleanup standards set in the contract. During the demonstration tests, the vendor also evaluated the performance of a land treatment unit (LTU) for this application. However, soil applied directly to the LTU did not meet the cleanup standards within this timeframe. In order to complete the demonstration test and receive EPA authorization to proceed with the project, the vendor decided to forego applying soil directly to the LTU and treated all soil in the reactors.

Operation of the full-scale soil treatment system began in July 1991. During full-scale operation, the vendor refined the operation by adding a slurry mix tank/soil washing (desanding) operation. The vendor found that keeping sand-sized particles in suspension in the reactors was extremely difficult, and they removed the sand prior to pumping the slurry to the reactors. The sand was analyzed separately and subject to the same clean up criteria as the fine grained particles.

Soon after full-scale operation began, the vendor began to have problems meeting the clean up standards within the anticipated 30 to 35 day reactor residence time. Specifically, problems were encountered with two compounds, pyrene and phenanthrene, which both have a K001 treatment standard of 1.5 mg/kg. The vendor identified non-homogeneity in the contaminated soil stockpile as the cause. During this early period of system operation, reactor residence time was running in the 60 to 80 day range. This problem was resolved by modifying the cleanup standards to be based on total PAH concentrations (i.e., the sum of 16 specific PAHs). This was accomplished by removing the K001 treatment standards - see additional discussion under Cleanup Goals.

Progress of the bioremediation process was measured using oxygen uptake rate (OUR). When the OUR showed a significant decline, the vendor would collect samples for chemical analysis.

The vendor noted that there was a problem with foam production during bioreactor operation. Foam would overflow the bioreactors, and the vendor had trouble containing the overflow. To correct this problem, the combination of dispersant and defoamer was revised, including addition of a lignin.

The bioreactors were located outdoors, and operated year round, but were not heated. The vendor specified that during the colder winter months, much slower degradation was observed. The bioreactor temperature ranged from 15°C to 21°C during the winter months. During the spring, summer, and fall, bioreactor temperatures ranged from 25°C to 40°C.

TREATMENT SYSTEM DESCRIPTION (CONT.)

Slurry Phase Bioremediation System Description and Operation (Cont.)

Air Dispersion Modelling [11]

To assess emissions of volatile organic compounds (VOCs) and PAHs from the bioremediation process, the treatment vendor performed air dispersion modelling. The vendor modelled off-property ground-level VOC and PAH concentrations using the EPA Industrial Source Complex (ISC) dispersion simulation model. The results of the modelling showed that proposed activities would not result in any exceedence of accepted long-term exposure screening levels for this application.

Slurry Dewatering [9]

After treatment in the bioreactors, the slurry was transferred to a slurry dewatering unit, which was a 425-foot long, 160-foot wide, and 6-foot deep high density polyethylene (HDPE)-lined cell. The water recovery system, consisting of drain tiles in coarse sand, was sloped to a sump to collect excess water. Excess water was pumped to a 350,000-gallon water management tank and was reused for slurry preparation. Soil remaining in the slurry dewatering unit was tilled to further dry the treated material.

Treated soil and sludge were placed in a lined, capped disposal cell on site. Debris and sand were also placed in the cell.

Operating Parameters Affecting Treatment Cost or Performance

The major operating parameters affecting cost or performance for this technology and the values measured for each are shown in Table 3.

Table 3. Bioreactor Operating Parameters [1, 2, 16]

Parameter	Value	Measurement Method
Air Flow Rate (SCFM)	350 ± 100	N/A
pH	7.2 ± 1.0	N/A
Residence Time (days)	8 to 29	N/A
System Throughput (yd^3 per batch)	160 to 180	N/A
No. of Batches Treated	61	N/A
Temperature (°C)	15 - 40	N/A
Biomass Concentration (cfu/ml)	10^7 - 10^8	Information not provided
Hydrocarbon Degradation	Not measured	---
Operating Volume (gallons)	180,000	N/A
Impeller Speed (RPM)	900	N/A
Solids Loading %	20	N/A
Initial Defoamer (mg/L)	200	N/A
Initial Dispersant (mg/L)	1,000	N/A
Dissolved Oxygen (mg/L)	>2.0	N/A

TREATMENT SYSTEM DESCRIPTION (CONT.)

Operating Parameters Affecting Treatment Cost or Performance (cont.)

Table 3. (Continued)

Parameter	Value	Measurement Method
NH_4-N (mg/L)	60 ± 20	Information not provided
PO_4-P (mg/L)	10	Information not provided

N/A - Measurement method not reported for this parameter because resulting value not expected to vary among measurement methods.

Timeline

A timeline for this application is shown in Table 4.

Table 4. Timeline [1, 2]

Start Date	End Date	Activity
1928	1979	Southeastern Wood Preserving operated as creosote wood treatment facility
April 1989	---	Initial samples collected from excavated materials
September 1990	---	Action memorandum signed
January 1991	April 1991	Treatment facility construction
April 1991	June 1991	Demonstration tests performed
July 1991	1994	Slurry phase bioremediation of soil and sludge performed

No additional details on the timeline for this application (e.g., for bioremediation activities) are provided in the available references.

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals/Standards

The results of laboratory and field pilot tests and a site-specific health-based risk analysis were used to develop the following cleanup goals for this application:

- 950 mg/kg dry weight soil solids total PAHs; and
- 180 mg/ky dry weight soil solids of benzo(a)pyrene (B(a)P) - equivalent carcinogenic PAHs.

Total PAHs were defined in this application as the sum of the concentrations for the 16 constituents shown in Table 7. EPA used published toxicity-equivalent factors to calculate the B(a)P-equivalent of the carcinogenic PAHs (the carcinogenic PAHs are identified in Table 7). In calculating B(a)P-equivalent concentrations, the concentration of each PAH is multiplied by a factor which is equal to its carcinogenicity relative to benzo(a)pyrene. The resulting weighted concentrations are summed to calculate the B(a)P-equivalent carcinogenic PAH value. [6, 7]

In addition, the cleanup goals allowed 15% of the treated soil to have a total PAH concentration less than 1,100 mg/kg, and 25% of the treated soil to have a B(a)P-equivalent concentration less than 230 mg/kg. [2, 6]

Additional Information on Goals

At the beginning of this application, soil was classified as RCRA hazardous waste K001. However, in February 1992, soon after full-scale operation began, an LDR treatability variance was obtained so that the soil would not need to be treated to meet the LDR treatment standards for K001. The treatability variance was obtained under 40 CFR Section 268.44, and resulted in the cleanup goals for total and carcinogenic PAHs shown above. Additional information is provided in reference 10 on the process used to obtain the variance. [10, 26]

Treatment Performance Data

Treatment performance data are available from 13 of the 61 bioreactor batches. Slurry samples were collected at the start of biotreatment and on a periodic basis during treatment. The sampling point for slurry samples is marked on Figure 2 with an “X.” No additional information on how samples were collected is provided in the available references.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Treatment Performance Data (cont.)

Table 5 presents the initial concentrations of PAHs in the slurry, and Table 6 presents the concentrations of PAHs in the slurry after treatment had occurred. [NOTE: No information is provided in the available references to explain how specific days were selected for use in calculating treatment efficiency - e.g., how Day 10 was selected for calculating treatment efficiency for bioreactor batch R1 B5; what data were used to select this day; or why treatment continued beyond this date.] Tables 5 and 6 show the concentrations of 16 individual PAH constituents measured in each of the bioreactor batches, as well as the sum of the concentrations for all 16 PAHs and for the 7 carcinogenic PAHs, and the B(a)P-equivalent for the sum of the 16 PAHs. The average concentration of each PAH is also shown on these tables. Figures 3 through 8 show the total PAH concentrations as a function of time for the first six batches shown in Tables 5 and 6, based on data in References 2 and 24.

Table 7 presents a summary of the PAH treatment performance data for the first six batches according to the number of rings in the PAH constituent (two, three, four, or five and six ring PAHs). This table shows the cleanup goals for this application, and the average results for PAHs at the start of treatment (from Table 5) and after treatment (from Table 6). The treatment efficiency included in the table was calculated based on the reduction in concentration for these average results.

No data are provided in the available references to characterize the performance of the soil washing step.

Performance Data Assessment

For the 13 batches with available data, the average total PAH concentration was reduced from 8,545 mg/kg to 634 mg/kg, which corresponds to a treatment efficiency of 93 percent. The average B(a)P-equivalent concentration was reduced from 467 mg/kg to 152 mg/kg, or 67 percent. Carcinogenic PAHs showed a similar reduction, from 1,160 mg/kg to 374 mg/kg, or 67 percent.

Table 6 shows that 12 of the 13 bioreactor batches met the cleanup goal of 950 mg/kg for total PAHs; for the 12 batches, total PAH concentrations ranged from 421 mg/kg to 898 mg/kg. For batch R1 B7, the total PAH concentration on Day 20 was 1,126 mg/kg, exceeding the maximum cleanup goal. According to the OSC, further treatment was performed on this batch, however, additional data on treatment performance for this batch are not provided in the available references. [26]

Table 5. Concentrations of PAHs in Slurry at Start of Treatment [2, 24]

Constituent	Bioreactor/Batch ID#												
	R1 B5	R1 B8	R1 B9**	R1 B10	R2 B9	R2 B10	R1 B4	R1 B6	R1 B7	R2 B5	R2 B6	R2 B7	R2 B8
	Concentration (mg/kg Dry Weight)												
Acenaphthene	642	968	692	892	1,280	981	465	574	723	508	1,440	846	949
Acenaphthylene	34	ND (163)	28	ND(59)	ND(223)	ND(51)	ND(155)	37.2	31.9	ND(50.5)	ND(373)	ND (67.1)	ND(120)
Anthracene	1,050	1,560	2,140	2,280	2,340	2,330	1,540	1,720	1,620	1,580	2,870	2,020	1,490
Benzo(a)anthracene[c]	224	287	283	237	370	277	327	279	230	245	597	241	279
Benzo(b)fluoranthene[c]/ Benzo(k)fluoranthene*[c]	367	337	278	296	345	304	233	323	344	290	710	287	349
Benzo(ghi)perylene	21	ND (163)	33	ND(59)	ND(223)	ND(51)	ND(155)	ND(32.7)	20.8	ND(50.5)	ND(373)	ND (67.1)	ND(120)
Benzo(a)pyrene[c]	92	ND (163)	105	100	ND(223)	98	ND(155)	98.2	87.4	81.5	ND(373)	94.7	ND(120)
Chrysene[c]	228	302	301	247	397	302	316	297	254	225	573	257	310
Dibenzo(ah)anthracene[c]	15	ND (163)	ND(40)	ND(59)	ND(223)	ND(51)	ND(155)	ND(32.7)	14.6	ND(50.5)	ND(373)	ND (67.1)	ND(120)
Fluoranthene	1,060	1,570	1,950	1,850	2,210	1,610	1,590	1,850	1,260	1,490	3,470	1,810	1,630
Fluorene	181	669	499	661	1,040	732	195	204	663	281	483	850	833
Indeno(1,2,3-cd)pyrene[c]	30	ND (163)	40	ND(59)	ND(223)	ND(51)	ND(155)	35.4	28.2	ND(50.5)	ND(373)	ND (67.1)	ND(120)
Naphthalene	19	ND (163)	ND(40)	ND(59)	ND(223)	ND(51)	ND(155)	ND(32.7)	24.7	ND(50.5)	ND(373)	87.3	ND(120)
Phenanthrene	220	1,250	395	2,030	1,300	988	253	279	1,360	272	639	2,710	1,680
Pyrene	878	1,080	1,220	1,010	1,610	1,090	1,130	1,270	974	950	2,430	989	1,080
Total PAHs	5,061	8,512	8,004	9,751	11,561	8,840	6,694	7,016	7,636	6,023	14,331	10,326	8,960
Total Carcinogenic PAHs	956	1,171	1,027	939	1,447	1,032	1,109	1,049	958	892	2,440	947	1,118
Benzo(a)pyrene Equivalent	245	585	295	334	818	318	570	268	245	283	1,313	349	454

[c]Carcinogenic PAHs.
*Sum of b and k isomers reported.
**The vendor specified that some concentration values were estimated for this batch. However, which values were estimated was not specified.
ND - Not detected. Value in parentheses is the reported detection limit. For calculation of averages and totals, ½ the detection limit was used for values that were not detected.

Table 6. Concentrations of PAHs in Slurry After Treatment [2, 24]

Constituent	Bioreactor/Batch ID#												
	R1 B5 Day 10	R1 B8 Day 13	R1 B9 Day 10	R1 B10 Day 10	R2 B9 Day 11	R2 B10 Day 27	R1 B4 Day 33	R1 B6 Day 11	R1 B7 Day 20	R2 B5 Day 20	R2 B6 Day 17	R2 B7 Day 13	R2 B8 Day 23
	Concentration (mg/kg Dry Weight)												
Acenaphthene	ND(7)	ND(14)	ND(16)	9	ND(7)	ND(13)	ND(11.3)	ND (6.06)	ND (34.5)	ND (10.3)	ND(27.3)	ND(12.3)	ND(22.7)
Acenaphthylene	11	13	ND(16)	19	14	23	12.1	6.63	ND (34.5)	10.5	ND(27.3)	ND(12.3)	ND(22.7)
Anthracene	104	55	102	230	135	100	115	125	229	84.1	39.6	89.3	68.2
Benzo(a)anthracene[c]	10	ND(14)	ND(16)	20	10	16	16.5	ND (6.06)	ND (34.5)	12	ND(27.3)	ND(12.3)	ND(22.7)
Benzo(b)fluoranthene[c]/ Benzo(k)fluoranthene*[c]	155	240	131	254	259	213	138	95	476	149	282	166	226
Benzo(ghi)perylene	23	26	25	ND(7)	ND(7)	29	22	13.9	ND (34.5)	18	ND(27.3)	14.8	ND(22.7)
Benzo(a)pyrene[c]	52	80	74	95	91	82	63.6	46	83.4	38.9	82.9	49.8	70.6
Chrysene[c]	24	55	30	41	33	31	57.1	31.1	69.6	18.2	61.6	33.8	57.4
Dibenzo(ah)anthracene[c]	10	ND(14)	ND(16)	ND(7)	ND(7)	20	ND(11.3)	ND (6.06)	ND (34.5)	ND (10.3)	ND(27.3)	ND(12.3)	ND(22.7)
Fluoranthene	25	32	26	31	37	43	41.3	21	40.2	37	26	21.4	24.9
Fluorene	14	ND(14)	ND(16)	25	16	15	ND(11.3)	16.2	ND (34.5)	ND (10.3)	ND(27.3)	ND(12.3)	ND(22.7)
Indeno(1,2,3-cd)pyrene[c]	28	33	31	31	24	40	28.3	17.9	ND (34.5)	23.6	33.1	19	30.7
Naphthalene	ND(7)	ND(14)	ND(16)	9	ND(7)	ND(13)	ND(11.3)	ND (6.06)	ND (34.5)	ND (10.3)	ND(27.3)	ND(12.3)	ND(22.7)
Phenanthrene	27	14	23	79	30	31	22.3	24.6	53.9	19.9	11.3	20.7	15.9
Pyrene	25	18	30	48	46	33	40.4	11.7	36.2	29	14.7	28	17
Total PAHs	515	601	520	898	709	689	579	421	1,126	461	646	480	591
Total Carcinogenic PAHs	279	422	282	445	421	402	309	196	681	247	487	281	407
Benzo(a)pyrene Equivalent	123	144	133	146	140	211	112	74	224	84	185	249	156

[c]Carcinogenic PAHs.
*Sum of b and k isomers reported.
ND - Not detected. Value in parentheses is the reported detection limit. For calculation of averages and totals, ½ the detection limit was used for values that were not detected.

Table 7. Summary of PAH Treatment Performance Data [2]

Constituent	Cleanup Goal (mg/kg)	Average Concentration at Outset of Treatment*** (mg/kg)	Average Concentration After Treatment*** (mg/kg)	Treatment Efficiency (%)
Two Ring PAHs				
Naphthalene	N/A	48	6	88
Three Ring PAHs				
Acenaphthene	N/A	909	6	99
Acenaphthylene	N/A	52	15	71
Anthracene	N/A	1,950	121	94
Fluorene	N/A	630	14	98
Phenanthrene	N/A	1,031	34	97
Four Ring PAHs				
Benzo(a)anthracene*	N/A	280	12	96
Chrysene*	N/A	296	36	88
Fluoranthene	N/A	1,708	32	98
Pyrene	N/A	1,148	33	97
Five and Six Ring PAHs				
Benzo(b)fluoranthene*	N/A	321	209	35
Benzo(k)fluoranthene*	N/A	**	**	**
Benzo(ghi)perylene	N/A	50	18	64
Benzo(a)pyrene*	N/A	98	79	19
Dibenzo(ah)anthracene*	N/A	47	9	81
Indeno(1,2,3-cd)pyrene*	N/A	53	31	42
Total PAHs	950	8,621	655	92
Carcinogenic PAHs	N/A	1,095	376	66
Benzo(a)pyrene Equivalent	180	433	150	65

*Carcinogenic PAHs.
**Combined with benzo(b)fluoranthene.
***Concentration values are averages from first six batches shown on Tables 5 and 6, and are reported as mg/kg dry weight.
N/A - Not applicable. No cleanup goal established for this constituent/group of constituents.

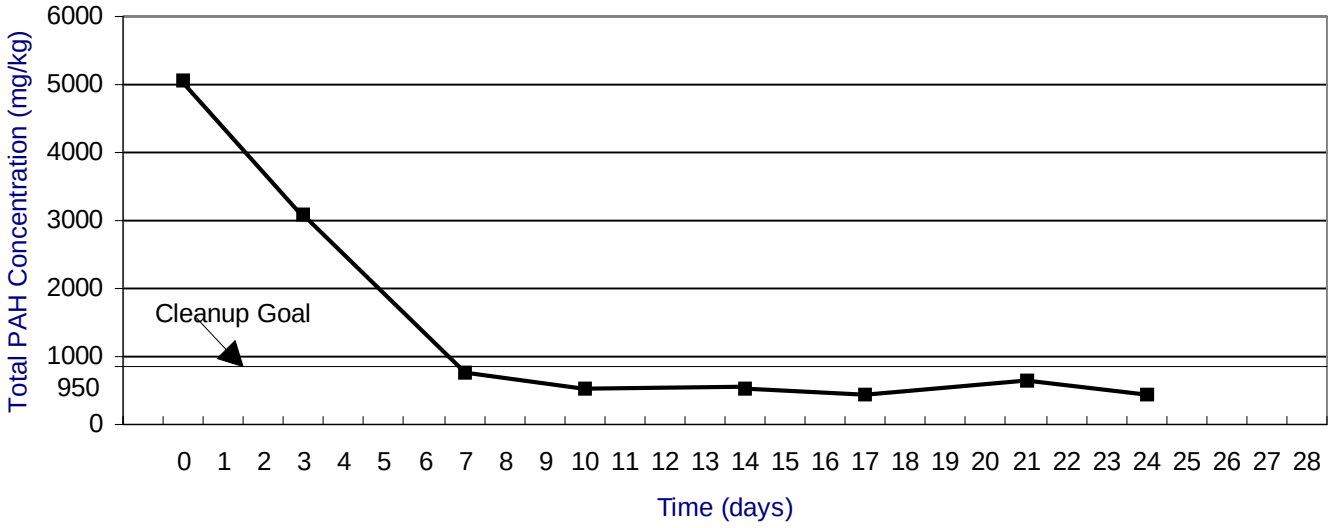

Figure 3. Total PAH Concentration vs. Time
Bioreactor/Batch R1 B5 [2]

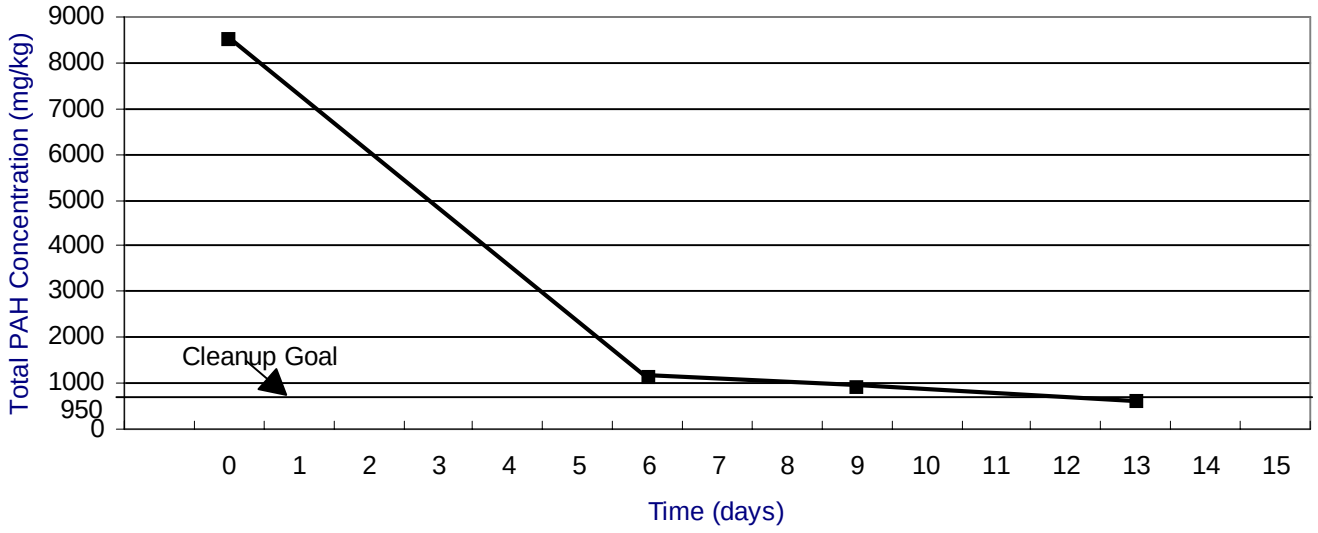

Figure 4. PAH Concentration vs. Time
Bioreactor/Batch R1 B8 [2]

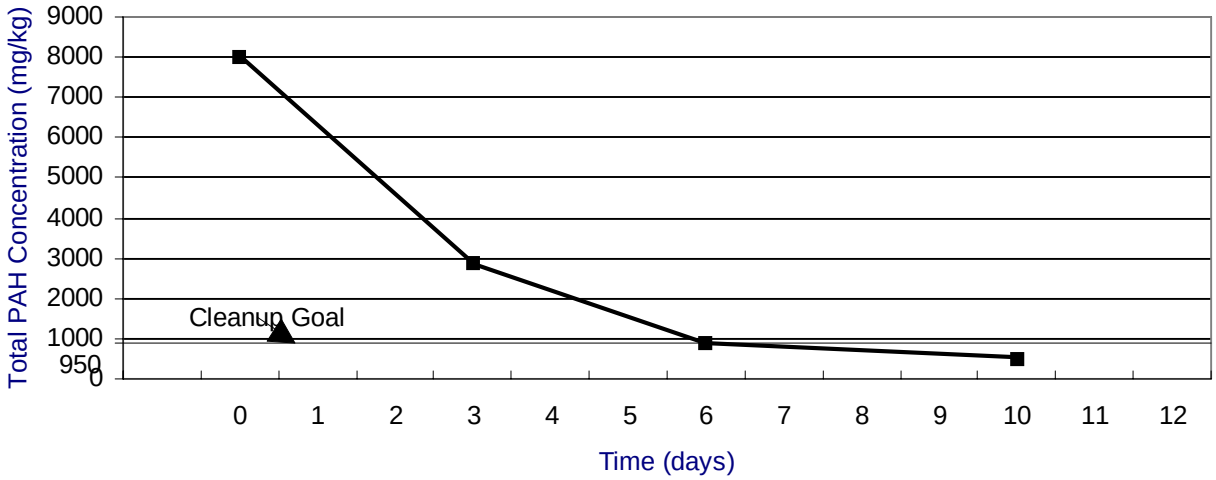

Figure 5. PAH Concentration vs. Time
Bioreactor/Batch R1 B9 [2]

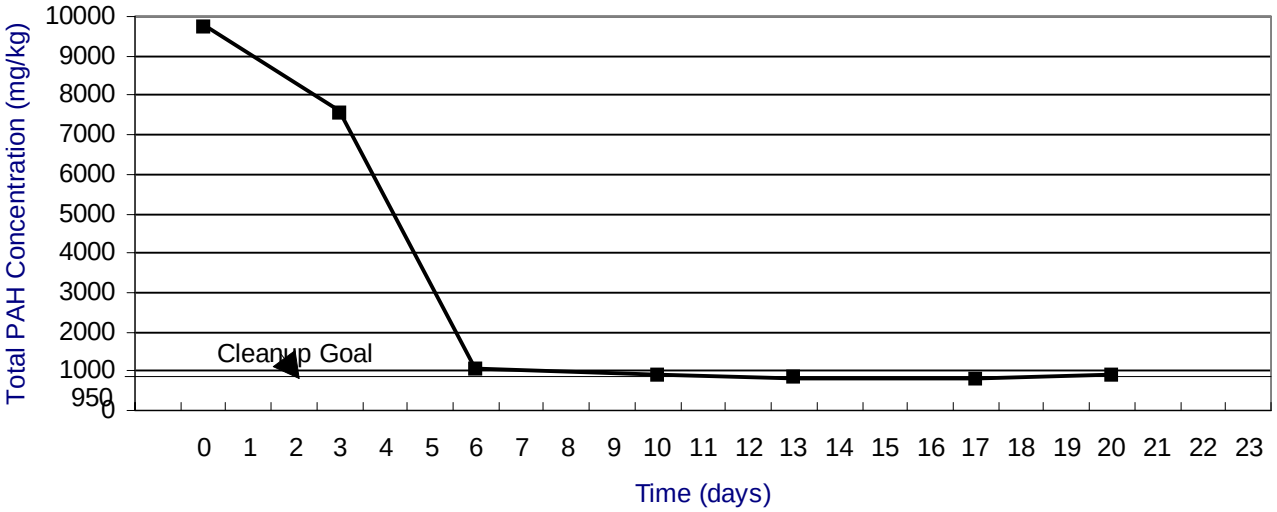

Figure 6. PAH Concentration vs. Time
Bioreactor/Batch R1 B10 [2]

[redacted]

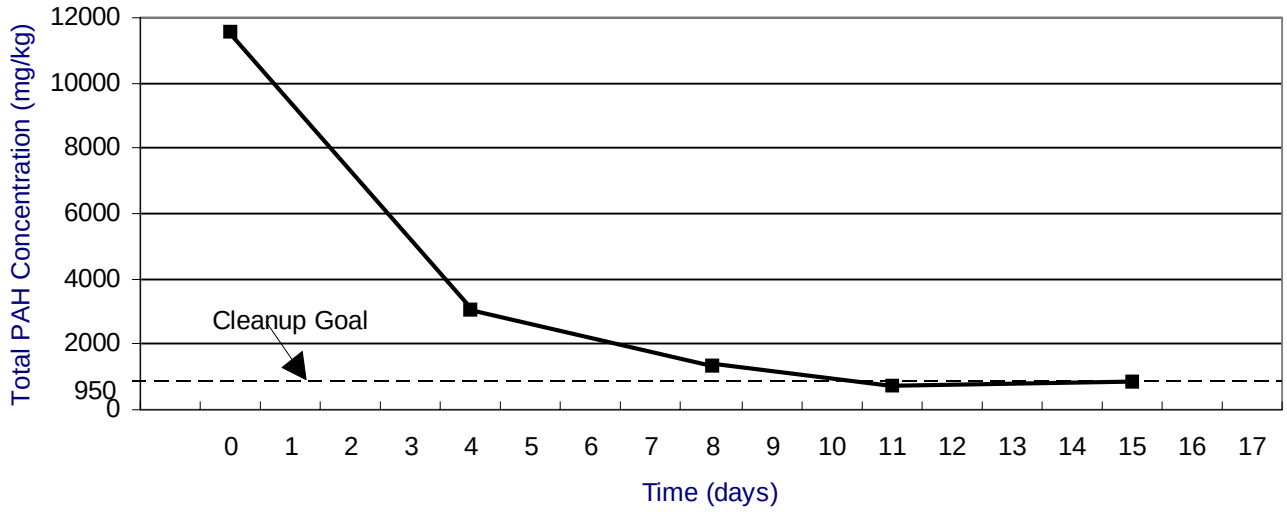

Figure 7. PAH Concentrations vs. Time
Bioreactor/Batch R2 B9 [2]

[redacted]

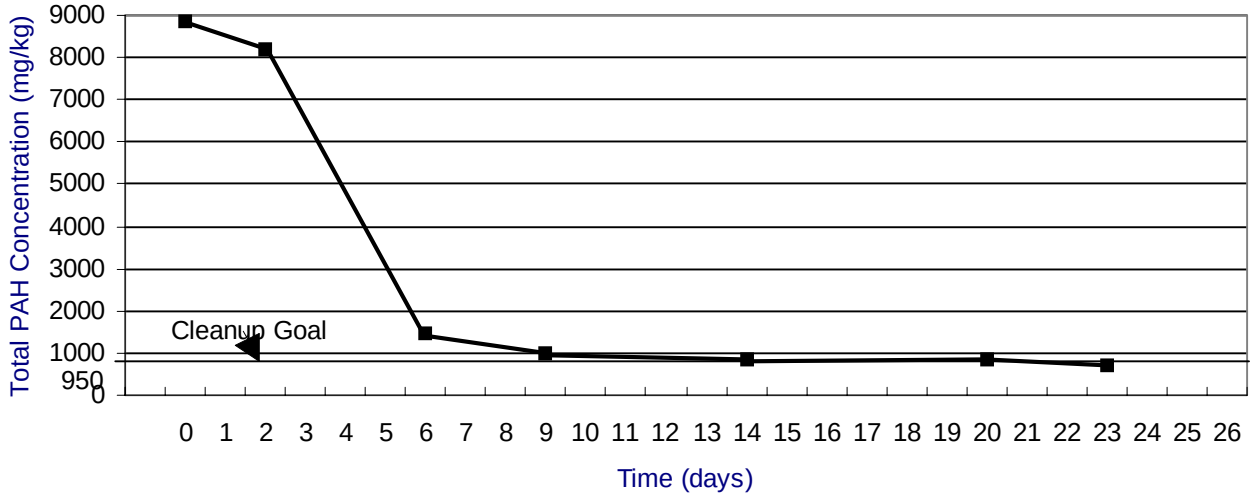

Figure 8. PAH Concentrations vs. Time
Bioreactor/Batch R2 B10 [2]

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Assessment (cont.)

Nine of the 13 batches met the cleanup goal of 180 mg/kg for B(a)P-equivalent; the batches that met the cleanup goal ranged from 24 to 156 mg/kg. According to the OSC, further treatment was also performed on the four batches that did not appear to meet the cleanup goal for B(a)P (R2 B20 at 211 mg/kg; R1 B7 at 224 mg/kg; R2 B6 at 185 mg/kg; and R2 B7 at 249 mg/kg). However, additional data on treatment performance for these batches are not provided in the available references. [26]

As shown in Figures 3 through 8, the majority of the biodegradation occurred during the first 5 to 10 days of treatment, and the cleanup goal for total PAHs was met for 12 of the 13 batches within approximately 19 days of treatment.

The data in Table 7 show that the number of ring structures in the PAH constituent (two, three, four, or five and six rings) affected the treatment efficiency. The concentrations of constituents with two to four rings were reduced 71% to 99%, while five and six ring constituents were reduced 19% to 81%. These results are consistent with reports in the technical literature that show that higher molecular weight PAHs (e.g., five and six ring structures) are more difficult to biodegrade than two to four ring structures. [8]

Performance Data Completeness

Analytical data for 16 PAHs are available for 13 of the 61 batches processed through the treatment system during the course of remediation. Data are available for specific days during each batch treatment, as well as for the range of operating conditions over the course of the treatment application.

Performance Data Quality

Limited information is contained in the available references on performance data quality. A quality assurance program plan (QAPP) for this application was developed by a commercial analytical laboratory (Analytical Services Corp.). The QAPP addressed project organization and responsibilities, QA objectives, sampling procedures, sample custody, analytical procedures, and other items.

PAH slurry samples were centrifuged and extracted following SW846 Method 3540. PAH concentrations were quantified using gas chromatography with a mass spectrometer detector following SW846 Method 8270. As shown in Appendix A, detection limits for individual PAHs ranged from 5 mg/kg to 223 mg/kg for the first six batches shown in Table 5 for this application.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Quality (cont.)

The vendor noted two problems related to performance data quality for this application. Problems were noted concerning implementation of the sampling plan, and for sample extraction and quantification. These problems were resolved by developing an approved sampling plan, and by performing audits on the extraction and analytical methodology.

According to the OSC, the vendor evaluated two potential methods for PAH sample extraction (soxhlet and sonic extraction) and found “significant differences” in analytical results based on method used. Based on these results, the analytical method was standardized and written into the contract. [26]

TREATMENT SYSTEM COST

Procurement Process

The contract for remediation services at Southeastern Wood was competitively procured by EPA. For this procurement, EPA's Contracting Officer (CO) obtained a deviation from the EPA Acquisition Regulations which allowed a negotiated procurement without submission of technical proposals. Performance specifications were used instead of specifying a technology. Twelve bidders submitted proposals for different technologies and price was the determining factor for award. The contract was awarded to OHM Remediation Services Corporation. EPA required the vendor to perform a technology demonstration at the site to ensure that the technology would be feasible. The contract with OHM was a firm fixed price (lump sum) service contract. Additional information on the procurement process for this application is provided in Reference 4. [4]

Treatment System Cost [1, 2, 12]

Tables 8 and 9 present the costs for the slurry phase bioremediation treatment application at Southeastern Wood. In order to standardize reporting of costs across projects, costs are shown in Tables 8 and 9 according to the format for an interagency Work Breakdown Structure (WBS). The WBS specifies 9 before-treatment cost elements, 5 after-treatment cost elements, and 12 cost elements that provide a detailed breakdown of costs directly associated with treatment. Tables 8 and 9 present the cost elements exactly as they appear in the WBS, along with the specific activities as provided by the treatment vendor.

As shown in Table 8, the vendor provided actual cost data that shows a total of $2,400,000 for activities directly associated with treatment of 14,140 tons (10,500 cubic yards) of soil and sludge (i.e., excluding after-treatment cost elements). This total consists of costs for mobilization/setup, startup/testing/permits, and operation. Included in this total are costs for treatment of 61 batches at $18,700 per batch. The total costs for activities directly attributed to treatment corresponds to $170 per ton ($230 per cubic yard) of soil and sludge treated. In addition, the vendor provided cost data that show a total of $500,000 for after-treatment activities (site preparation and closure). The vendor provided no information on before-treatment activities, such as for monitoring, sampling, testing, and analysis in this application. [3, 19]

Table 10 shows actual costs provided by the vendor for slurry preparation, slurry phase biological treatment, and dewatering on a per ton of material basis. This table shows that the relatively largest costs associated with this system are for the slurry preparation process. [1]

TREATMENT SYSTEM COST (CONT.)

Treatment System Cost (Cont.)

Table 8. Treatment Activity Cost Elements According to the WBS* [3]

Cost Elements (Directly Associated With Treatment)	Cost ($)	Actual or Estimated (A) or (E)
Mobilization/Set Up (Design Engineering)	100,000	A
Startup/Testing/Permits (Treatability and Pilot-Scale Testing)	200,000	A
Operation (short-term - up to 3 years) (soil screening and slurry preparation, slurry treatment, slurry dewatering, and project administration and support)	2,100,000	A
TOTAL TREATMENT ACTIVITY COST	2,400,000	A

Table 9. After-Treatment Cost Elements According to the WBS* [3]

Cost Elements	Cost ($)	Actual or Estimated (A) or (E)
Site Restoration (site preparation and closure)	500,000	A
TOTAL AFTER-TREATMENT COST	500,000	A

Table 10. Unit Costs for Treatment of Soil and Sludge at Southeastern Wood Preserving Superfund Site [1]

Process	Cost per Dry Ton of Material Treated ($)	Actual or Estimated (A) or (E)
Slurry Preparation	50 - 60	A
Slurry Phase Biological Treatment	40 - 55	A
Dewatering Process	20 - 30	A
Total for Slurry Phase Biological Treatment System	110 - 145	A

*Cost figures rounded up to the nearest $100,000.

TREATMENT SYSTEM COST (CONT.)

Cost Data Quality

The cost data presented above are actual costs for this application as reported by the treatment vendor, and are believed to accurately represent the costs associated with this application.

Vendor Input

The vendor specified three variables that have a significant impact on the cost of remediation using this technology: the slurry phase reactor solids concentration, residence time in the reactors, and the percentage of material removed in the slurry preparation/soil washing process. According to the vendor, increasing the solids concentration in the reactors increases the amount of soil treated per batch. This results in a decrease both in the total number of batches treated and the cost per ton of treatment. In addition, longer batch residence times reduce the system throughput and, therefore, increase the cost of treatment. The higher the percentage of material that is removed by the slurry preparation/soil washing process, the lower the cost for the bioreactors, since less material will remain to be biologically treated. [3]

OBSERVATIONS AND LESSONS LEARNED

Cost Observations and Lessons Learned

- The total project cost for slurry phase bioremediation at Southeastern Wood, including treatment, design engineering, treatability and pilot-scale testing, site closure, and project administration was $2,900,000. Of the total, $2,400,000 were for costs directly attributed to treatment, and $500,000 were for after-treatment activities.

- The $2,400,000 for costs directly attributed to treatment corresponds to $170 per ton ($230 per cubic yard) of soil and sludge treated.

- According to the OSC, this treatment process, which combined soil washing with biotreatment, would be more cost-effective at a site with 50 to 60% sand than at Southeastern Wood, which had only 10-15% sand. At a site with 50% sand, the waste volume would be cut in half, reducing the amount which had to be biotreated.

- According to the OSC, the treatment vendor invested significant amounts of time and resources for research and development on this application, including extensive treatability testing.

Performance Observations and Lessons Learned

- Cleanup goals for total PAHs and B(a)P-equivalent PAHs were met in this treatment application. The cleanup goal for total PAHs was specified as 950 mg/kg and for B(a)P-equivalent PAHs as 180 mg/kg, with allowances for a portion of the treated soil to be at levels slightly greater than these values.

- For the 13 bioreactor batches with available data, the average total PAH concentration was reduced from 8,545 mg/kg to 634 mg/kg, which corresponds to a treatment efficiency of 93 percent. The average B(a)P-equivalent concentration was reduced from 467 mg/kg to 152 mg/kg, or 67 percent. Carcinogenic PAHs showed a similar reduction from 1,160 mg/kg to 374 mg/kg or 67 percent.

- Biodegradation primarily occurred during the first 5 to 10 days of treatment, and the cleanup goal for total PAHs in 12 of 13 batches was met within approximately 19 days of treatment.

OBSERVATIONS AND LESSONS LEARNED (CONT.)

Performance Observations and Lessons Learned (cont.)

- The number of ring structures in the PAH constituent were found to affect treatment efficiency. Concentrations of constituents with two to four rings were reduced 71% to 99%, while five and six ring constituents were reduced 19% to 81%. These results are consistent with reports in the technical literature that show that higher molecular weight PAHs (e.g., five and six ring structures) are more difficult to biodegrade than two to four ring structures.

- Temperature was identified by the vendor as a factor which affected degradation rates. Degradation was slower during the winter months than during the spring, summer, and fall.

Other Observations and Lessons Learned

- According to the OSC, the design of the treatment system was modified significantly from the original plans, including addition of a desanding process. At the beginning of full-scale operation, the vendor found that keeping sand-sized particles in suspension in the reactors was extremely difficult, and therefore they removed the sand prior to pumping the slurry to the reactors.

- According to the vendor, there were several problems with the operation of this technology. These included foam production in the bioreactors during this application. Foam would overflow the bioreactors, and the vendor had trouble containing the overflow. The problem was resolved by revising the combination of dispersant and defoamers used in the slurry preparation, including adding a lignin. In addition, the vendor had problems with treating the soil to meet the K001 treatment standard of 1.5 mg/kg for pyrene and phenanthrene. This problem was resolved by modifying the cleanup standards to be based on total PAH concentrations (i.e., the sum of 16 specific PAHs) instead of individual constituent standards.

- According to the vendor, there were variations caused by sampling and analytical methods in this application. According to the OSC, the vendor evaluated two potential methods for PAH sample extraction (soxhlet and sonic extraction) and found “significant differences” in analytical results based on method used. Based on these results, the analytical method was standardized and written into the contract.

- To assess emissions of VOCs and PAHs from the bioremediation process, the treatment vendor performed air dispersion modelling. The vendor modelled off-property ground-level VOC and PAH concentrations using the EPA Industrial Source Complex (ISC) dispersion simulation model. The results of the modelling showed that proposed

OBSERVATIONS AND LESSONS LEARNED (CONT.)

Other Observations and Lessons Learned (cont.)

activities would not result in any exceedence of accepted long-term exposure screening levels for this application.

- According to the OSC, soil in the slurry dewatering unit was very soft and could not have supported equipment to till the soil. Therefore, while post slurry-treatment using land treatment was considered, it was determined that this would not be feasible without amending the soil to increase its bearing capacity. Therefore, land treatment was not performed.

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16. Summary of Bioremediation Batches Invoiced to Date, U.S. EPA Contract No. 68-SO-4001, Southeastern Wood Preserving Site, Canton, Mississippi, OHM Project No. 9782; Compilation Date: June 16, 1994.

17. Correspondence from Sharyn A. Erickson, Contracting Officer, USEPA, Region IV, to Michael A. Szomjassy, V.P., S.E., Region, OHM Remediation Services Corp., regarding EPA Contract 68-SO-4001, for Southeastern Wood Preserving. April 14, 1993.

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Analysis Preparation

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