Portland Cement Association

Solidification/Stabilization for Remediation of Wood Preserving Sites: Treatment for Dioxins, PCP, Creosote, and Metals

by Edward R. Bates, Endalkachew Sahle-Demessie,
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RP371

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PCA RP371

Solidification/Stabilization for Remediation of Wood Preserving Sites: Treatment for Dioxins, PCP, Creosote, and Metals

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ABSTRACT

This article discusses the use of solidification/stabilization (S/S) to treat soils contaminated with organic and inorganic chemicals at wood preserving sites. Solidification is defined for this article as making a material into a free standing solid. Stabilization is defined as making the contaminants of concern non-mobile as determined from a leaching test. S/S then combines both properties. For more information on S/S in general the reader should refer to other publications including *Chemical Fixation and Solidification of Hazardous Wastes* by J.R. Conner (1990), *Engineering Bulletin Solidification/Stabilization of Organics and Inorganics* by the United States Environmental Protection Agency (EPA) (1993), *Solidification and Stabilization Technology* by C.C. Wiles published in H.M. Freeman Standard Handbook of Hazardous Waste Treatment and Disposal (1989) as this article addresses only wood preserving sites and assumes basic knowledge of S/S processes. For a more general discussion of wood preserving sites and some other remedial options, the reader may wish to refer to a previous EPA publication titled *Contaminants and Remedial Options at Wood Preserving Sites* (1992).

This article includes data from the successful remediation of a site with mixed organic/inorganic contaminants, remediation of a site with organic contaminants, and detailed treatability study results from four sites for which successful formulations were developed. Included are pre- and post-treatment soil characterization data, site names, vendor names (in some cases), treatment formulas used (generic and proprietary), costs, recommendations and citations to more detailed references. The data presented indicate that dioxins, pentachlorophenol, creosote polycyclic aromatic hydrocarbons (PAHs) and metals can be treated at moderate cost by the use of S/S technology.

INTRODUCTION

Solidification/stabilization (S/S) immobilizes contaminants rather than removing the contaminants. Solidification is defined for this article as making a material into a free standing solid. Stabilization is defined as making the contaminants of concern non-mobile as determined from a leaching test. S/S then combines both properties. The remediations and treatability studies described in this article all used portland cement as part of the reagent mix producing a solid monolithic, treated product. For a general description of S/S processes and applications, the reader may wish to refer to other publications (Connor, 1990, EPA 1993a; Wiles, 1989).

Edward R. Bates has worked at the U. S. Environmental Protection Agency (EPA), National Risk Management Research Laboratory (NRMC) in Cincinnati, Ohio, as a physical scientist since 1977. Since 1989 his principal duties have been to provide expert technical assistance on all aspects of Superfund site remediation, including characterization, remedy selection, remedy design, and field implementation. Endalkachew Sahle-Demessie is a research engineer at the NRMC. He has been working on the application of emerging treatment technologies for remediating contaminated soils. Douglas W. Grosse has worked as an environmental engineer at NRMC, for the past 21 years. Currently, he is working in Technology Transfer by serving as a specialist in site remediation and industrial wastewater treatment.

Citation of product, company, or trade names do not constitute endorsement by the U.S. Environmental Protection Agency and are provided only for the purpose of better describing information in this article. Opinions expressed are those of the authors and should not be construed as representing positions or policy of the U.S. Environmental Agency.

Exhibit 1. Remediation of the SPT Site[a]

Parameter	Measurement Method[b]	Untreated mg/Kg (mg/L)	Action Level[c] mg/Kg (mg/L)	Treatment Criteria[d] mg/Kg (mg/L)	Actual Performance mg/Kg (mg/L)		
					Samples[e]	Mean	High
As /Total	7060	1500	25	–	–	–	–
As TCLP	1311 & 6010	10	5.0	5.0	543	<0.1	0.2
PCP Total	8040	3000	17	–	-	-	-
PCP TCLP	1311	3.1	0.300	0.300	543	<0.1	0.21
PCP SPLP	1312	39	–	–	–	<0.1	-
Cr Total	6010	2000	3910	–	–	–	-
Cr(Total) via TCLP	1311 & 6010	1.0	0.5	0.5	543	<0.1	0.3
Cr Hexavalent via TCLP	1311 & 7197	<0.1	0.5	0.5	543	<0.1	0.1
Cu Total	6010	1500	31800	–	–	–	-
Cu via TCLP	1311 & 6010	5.0	10.0	10.0	543	<0.1	1.1
Permeability	ASTM D5084	–	–	<1X10^{-7} cm/sec	>300	All Passed	
Unconfined Compressive Strength	ASTM D2166	–	–	>15 psi at 5 days 100 psi at 28 days	>300	All Passed	

a) Bates and Lau, 1995
b) All methods per EPA 1995 (SW846) except ASTM.
c) Action level is the contaminant level in untreated soil, at or above which, treatment (action) is judged to be necessary.
d) Treatment criteria is the targeted value to be achieved by treatment.
e) Total number of samples collected and analyzed.

REMEDIATION OF THE SELMA PRESSURE TREATING SITE

In 1990 the United States Environmental Protection Agency (EPA)conducted a successful Superfund Innovative Technology Evaluation (SITE) Demonstration of an innovative S/S technology at the Selma Pressure Treating (SPT) site in Selma, California (national priority listed Superfund site). The technology developed by Silicate Technology Corporation of Scottsdale, Arizona (now known as STC, Inc.) stabilized soil contaminated with pentachlorophenol (PCP) and chromated copper arsenate (CCA)(Bates, et al, 1991; U.S. EPA, 1992b).

Following this successful field test the remediation of the SPT site was bid and awarded. In 1993-1994 the site was remediated by Chem Waste Management using the STC technology. PCP and CCA were the target contaminants. A previously published article provides more details on the design, construction, and cost of this innovative remediation (Bates and Lau, 1995). **Exhibit 1** summarizes the soil characteristics before and after remediation. Dioxins/furans were not designated target contaminants during this remediation. However, several months following the remediation, EPA did arrange to have archived samples from the remediation analyzed for total and leachable

Exhibit 2. Dioxin and PCP Analyses on Archived Samples from Remediation of the SPT Site (Area C)[a]

Parameter	Measurement Method[b]	Mean[c] Untreated	Mean[c] Treated
Dioxin/Furan (TCDD-TEQ)			
Total	8280	12 µg/Kg (ppb)	–
TCLP	1311, 8290	28 pg/L (ppq)	<0.025 pg/L (ppq)
SPLP	1312, 8290	144 pg/L (ppq)	<0.01 pg/L (ppq)
PCP			
Total	8270	1100 mg/Kg (ppm)	–
TCLP	1311, 8270	3.1 mg/L (ppm)	<0.1 mg/L (ppm)
SPLP	1312, 8270	38.5 mg/L (ppm)	<0.1 mg/L (ppm)

a) EPA, 1996a
b) All methods per EPA 1995 (SW846)
c) Average of all samples analyzed.

Exhibit 3. Stabilization Formulas for Treatability Tests[a]

	Site Name					
	ACW[f]		TWT[g]		MCB[h]	RAB[h]
Formula Cost[b]$	39	62	66	54	50	50
Vendor Name[c]	STC	STC	OHM	OHM	STC	STC
Reagent Additions (wt/wt of untreated soil)						
Untreated Soil	1.0	1.0	1.0	1.0	1.0	1.0
Type 1 Portland Cement[a]	0.2	–	0.1	0.2	0.08	0.08
Class F Fly Ash[a]	0.1	–	0.1	0.1	–	–
Activated Carbon[a]	0.02	–	0.02	0.05	–	–
OHM AR-8[ad]	–	–	0.02	–	–	–
STC P-1[ae]	–	0.2	–	–	–	–
STC P-4[ae]	–	0.06	–	–	0.12	0.12
Water Added[a]	–	–	0.15	0.2	–	–
Dilution Factor[i] (Water Excluded)	1.32	1.26	1.24	1.35	1.2	1.2

a) Weight ratio of reagent to untreated soil
b) Cost of Formula to Treat one Ton of Raw Soil
c) OHM = OH Materials, Findley, Ohio
STC = STC, Inc., Scottsdale, Arizona
d) Proprietary OHM Reagent
e) Proprietary STC Reagent
f) EPA, 1997 b., Tier 1
g) EPA, 1997 a., Tier 2
h) EPA, 1998, Vendor C, Round 2
i) Weight of untreated soil plus reagents divided by the weight of untreated soil

dioxins/furans. These results are presented in **Exhibit 2** with PCP concentration measurements made at that time. The data in Exhibits 1 and 2 document substantial reductions in the mobility of both the inorganic and organic contaminants of concern including dioxin. Referring to Exhibit 2 and the synthetic precipitation leach procedure (SPLP) (designated SW846, MTD 1312) the data show more than a 99 percent reduction in the mobility of both PCP and dioxin.

TREATABILITY STUDIES

Following successful remediation of the SPT site, the EPA National Risk Management Research Laboratory (NRMRL) became involved in assessing the applicability of a number of technologies for possible application to the remediation of wood preserving sites. Consequently, a number of treatability studies were conducted including S/S tests using formulations on soils from several Superfund sites including: McCormick and Baxter (MCB), Stockton, California; American Creosote Works (ACW), Jackson, Tennessee; Texarkana Wood Treating (TWT), Texarkana, Texas; and RAB Valley Wood Preserving Site (RAB) near Panama, Oklahoma.

The primary objective for all the S/S studies was to develop formulations that could treat all contaminants of concern, which included dioxins, PCP, and creosote PAHs to meet all treatability criteria. For the ACW site a subsequent remedial design treatability study also focused on minimizing the formula cost while still meeting the treatment criteria. For most tests the treatment criteria (targets) were established in advance and are shown in Exhibits 4 through 8, which also depict the treatment results for each site. The reader should be aware that two to three rounds of treatability tests were conducted for each site in order to develop cost effective formulations that could meet all the chemical and physical treatment criteria. Although toxicity characteristic leaching procedure tests (TCLP) (designated SW846, MTD 1311) were run on successful formulations, the primary test used to assess environmental mobility was the SPLP test as this leaching test more closely represented potential leaching in the proposed on-site placement for treated material. The SPLP method more closely approximates leaching conditions in the field resulting from precipitation because the SPLP leaching fluid consists of a mixture of inorganic acids in water and was formulated to simulate acid precipitation.

Formulations Used - **Exhibit 3** describes the formulations developed and used in these studies that met all treatment criteria. Two to three rounds (or tiers) of treatability tests using generally three to six formulations per round were conducted for each site-specific treatability test. Exhibit 3 presents only the formulations that were able to meet treatability study objectives. However, much can also be learned from formulations that failed. The reader may wish to reference the cited documents for more information on performance of all formulations tested. Generally, the performance criteria most difficult to meet were low leachability of PCP and low permeability properties (1x10^{-6}cm/sec).

Exhibit 4. Stabilization of Pentachlorophenol in Treatability Tests

Reagent	Site Name					
	ACW[a]		TWT[b]		MCB[c]	RAB[c]
Formula Cost $/Ton Raw Soil	39	62	66	54	50	50
Untreated						
Total mg/kg	200	200	270	270	347	1210
TCLP µg/L (pH)	—	—	690 (5.0)	690 (5.0)	360 (5.0)	2400 (5.2)
SPLP µg/L (pH)	8200(7.0)	8200 (7.0)	7200 (7.2)	7200(7.2)	13000(6.8)	3900 (7.0)
Treated						
TCLP µg/L (pH)	–	–	5.1 (6.4)	77 (8.1)	<1.0 (5.9)	21 (6.6)
SPLP µg/L (pH)	120(11.8)	12 (11.8)	67 (12.2)	150(12.5)	<1.0(11.2)	24 (11.2)
Target SPLP µg/L	200	200	200	200	–	–
% Reduction–TCLP[d]	–	–	99	85	>99	99
% Reduction–SPLP[d]	98	>99	99	97	>99	>99

a) EPA, 1997 a., Tier 1
b) EPA, 1997 b., Tier 2
c) EPA, 1998, Vendor C, Round 2
d) Percent Reduction values have been adjusted to eliminate the effect of dilution by reagents added (see dilution factor Exhibit 3)

Exhibit 3 shows six successful formulations: two for the ACW site, one proprietary to STC and one generic; two for the TWT site, one proprietary to OHM and one generic; and one proprietary to STC for both the McCormick Baxter and RAB Valley sites. The cost of the S/S formula to treat one ton of raw soil ranged from $39 to $66, with an average cost of approximately $53. These are the costs for the chemical reagent in the formulations only. Transportation and all other site-specific costs such as excavation, mixing, replacement on-site (or disposal off-site), performance verification testing, installation of final cover, design and oversight costs, and any other site-specific remediation costs were not factored into these costs. These other costs are very site and design specific and are heavily influenced by the volume of soil to be treated and the specific treatment criteria. In the authors' experience the total of all these site specific costs may range from $30 to more than $100 per ton of raw soil (excluding the cost of the treatment formula).

Exhibit 3 includes four proprietary formulations by STC and OHM, but also includes two generic formulations containing no proprietary materials. Proprietary formulation names are included only for the purpose of describing the work performed. Exhibit 3 also includes the dilution factor due to reagent addition, which ranged from 1.2 to 1.35. These dilution factors were used in determining the percent reduction of contaminants in the leaching tests. The actual measured concentration of a contaminant in a leachate was multiplied by the dilution factor of the reagents added, to produce an adjusted (not shown in Exhibits) after treatment contaminant concentration. This adjusted contaminant concentration was then compared to the contaminant concentration in leachate from the untreated soil to produce a percent reduction so that no credit was given for the effects of dilution by the treatment formula.

Stabilization of PCP - Of all the target contaminants treated, PCP was the most difficult to stabilize and meet treatment criteria. **Exhibit 4** provides the results from four treatability tests in which PCP was successfully stabilized. However, the reader should be aware that there were also many formulations tested that failed to adequately stabilize PCP. For example, the entire first round of formulas tested for the Texarkana Wood Treating site failed to meet the PCP criterion of 200 µg/L or less in SPLP extracts. This was in spite of the fact that formulations that had been successful on American Creosote Works soils were included in the first round of the TWT test. This illustrates the important point that each site is unique and it is essential to conduct treatability tests for each specific site. Formulations that were demonstrated to work well on other sites may not work well on a new site.

Exhibit 4 contains leachate data for both TCLP and SPLP test methods. (Reference U.S. EPA 1995a for Leaching Method Descriptions). The final leachate pH is provided in addition to the PCP concentration. Data in Exhibit 4 clearly illustrate that leachate results for the two leaching methods can differ dramatically. In the authors' experience, the SPLP method usually extracts far more PCP than the TCLP method. This holds true for both the untreated and the treated soil. The difference often approaches or exceeds one order of magnitude (X10). Further, it can be argued that the SPLP method more closely approximates leaching conditions in the field resulting from precipitation because the SPLP leaching fluid consists of a mixture of inorganic acids in water and was formulated to simulate acid precipitation. Thus, the selection of the leaching method may have a substantial impact on assessing the risk to surface or groundwater posed by leaching of either untreated or treated material. However, it should be noted that not all PCP in soil appears to be equal when it comes to leaching. Examination of untreated soil leachates reveals that sometimes lower total concentrations of PCP in soil yield higher concentrations in the leachate. It can be speculated that this may be due in part to the fact that PCP is a weak acid with solubility dependent partly on the degree of protonation and that solubility may be equilibrium controlled. Thus, other chemicals in the soil, such as humic acids may affect

Exhibit 5. Stabilization of Dioxins[a] in Treatability Tests

Reagent	Site Name					
	ACW[b]		TWT[c]		MCB[d]	RAB[d]
Formula Cost $/Ton Raw Soil	39	62	66	54	50	50
Untreated						
Total μg/kg	50	50	8.75	8.75	14	10
TCLP pg/L (pH)	9.8 (5.0)	9.8 (5.0)	<14 (5.0)	<14 (5.0)	110 (5.0)	23 (5.2)
SPLP pg/L (pH)	320 (7.0)	320 (7.0)	6200 (7.2)	6200(7.2)	9800(6.8)	460 (7.0)
Treated						
TCLP pg/L (ppq) (pH)	–	–	<17 (6.4)	<17 (8.1)	26 (5.9)	530 (6.6)
SPLP pg/L (ppq) (pH)	12 (11.8)	14 (11.8)	29 (12.2)	12 (12.5)	11 (11.2)	17 (11.2)
Target SPLP pg/L (ppq)	30	30	30	30	–	–
% Reduction–TCLP[e]	–	–	NC	NC	72	Increase
% Reduction–SPLP[e]	95	95	>99	>99	>99	96

a) All concentrations expressed as equivalents of 2,3,7,8-TCDD (EPA 1989)
b) EPA, 1997 a., Tier 1
c) EPA, 1997 b., Tier 2
d) EPA, 1998, Vendor C, Round 2
e) Percent Reduction values have been adjusted to eliminate the effect of dilution by reagents added (see dilution factor Exhibit 3)
NC = Not Calculated

the solubility of the PCP. It also may be that the PCP is more tightly adsorbed to organic constituents in some soils and thus not easily extracted by the leaching fluid.

Overall Exhibit 4 indicates that PCP in soil was successfully treated by S/S, by at least one formulation, to below target level at four sites. Percent reductions generally ranged from 97 to over 99 (85% in one case), after adjusting to eliminate any effect of dilution by the treatment reagents. Note that in exhibits 4,5, and 6 the pH of the final leaching solution is reported, as the alkaline nature of the treatment reagents causes the leaching solutions to be alkaline, which impacts the solubility of the contaminants.

Stabilization of Dioxins - The results from tests to stabilize dioxins in soils from the four wood preserving sites are presented in **Exhibit 5**. Data for both TCLP and SPLP are provided along with the pH of the final leachate solutions. The total values of dioxins in soils from the four sites ranged significantly. The dioxins were a contaminant in the PCP wood preserving solutions. In the authors' experience, the range of 9 to 50 μg/L 2,3,7,8 tetrachlorodibenzo-p-dioxin (TCDD) toxicity equivalents (TCDD-TEQ) represents most wood preserving sites where PCP was used. An explanation for calculating dioxin TEQ values is presented in a previous EPA publication (U.S. EPA 1989).

Similar to PCP, the dioxins in the untreated soil appear to be much more soluble in the SPLP leachate than in the TCLP leachate. However for dioxins, the factor often approaches or exceeds two orders of magnitude (X100)(TWT, MCB, RAB) for the untreated soil. In the treated soil the differences are neither clear nor consistent. For example, the data for the MCB and RAB sites show higher dioxin concentrations in the TCLP extract while the TWT formulations show slightly higher dioxin concentrations in the SPLP extract for one formulation and are unclear regarding the second formulation.

Overall, the data in Exhibit 5 indicate successful stabilization of dioxins as measured by SPLP extracts with reductions ranging from 95 to over 99 percent, after adjusting for dilution by reagents. Target concentration levels were met for dioxins in SPLP leaches for all sites by use of at least one of the formulations. The data for TCLP extracts are more limited and no general pattern is obvious. For the TWT formulas, dioxins in the TCLP extracts were below detection limits both before and after treatment; MCB shows a 72% decrease following treatment; and RAB shows a substantial increase following treatment. It is interesting to note that the same treatment formula was used for the MCB and RAB soils. This again demonstrates the need for site-specific treatability tests, since site-specific soil characteristics can produce substantially different impacts on performance of a treatment formulation, and the impact of specific soil characteristics on treatment performance can not be predicted.

Stabilization of PAHs - A summary of PAH data from the treatability tests is provided in **Exhibit 6**. Data are provided as a benzo(a)pyrene potency estimate [B(a)P potency estimate] and on the sum of all detected PAHs. An explanation on calculation of the benzo(a)pyrene potency estimates is provided in a previous EPA publication (EPA 1993b). The references cited in Exhibit 6 provide extensive data showing performance on each individual detected PAH.

B(a)P potency estimates are often used to obtain an overall assessment of the risk from PAH compounds. The principal observation on B(a)P potency estimates in Exhibit 6 is that these compounds were only very slightly leachable before treatment and are even less leachable after treatment, due to their low water solubility. Often the concentrations were below detection limits. There appears to be a slight, but consistent, tendency for the SPLP extrac-

Exhibit 6. Stabilization of PAHs[a] in Treatability Tests

Treatment Characteristic	Site Name					
	ACW[b]		TWT[c]		MCB[d]	RAB[d]
Formula Cost $/Ton Raw Soil	39	62	66	54	50	50
Untreated						
Total mg/kg	29	29	36	36	55	75
TCLP µg/L (pH)	2.8 (5.0)	<2.8 (5.0)	<0.9(5.0)	<0.9(5.0)	<2.8(5.0)	<2.8 (5.2)
SPLP µg/L (pH)	2.8 (5.0)	2.8 (7.0)	11 (7.2)	11 (7.2)	14 (6.8)	<14 (7.0)
Treated						
TCLP µg/L (pH)	–	–	<3.6 (6.4)	3.6 (8.1)	<2.8(5.9)	<2.8 (6.6)
SPLP µg/L (pH)	<2.8(11.8)	<2.8(11.8)	<1.0(12.2)	<0.8(12.5)	<2.8(11.2)	<5.5(11.2)
Target SPLP µg/L	10	10	10	10	–	–
%Reduction–TCLP[e]	–	–	NC	Increase	NC	NC
%Reduction–SPLP[e]	NC	NC	89	>90	>76	NC
Total All Detected PAHs						
Untreated TCLP µg/L	850	850	2100	2100	110	920
Treated TCLP µg/L	–	–	70	60	<1.0	66
Untreated SPLP µg/L	510	510	1400	1400	190	690
Treated SPLP µg/L	1.2	<1.0	105	168	1.3	54
%Reduction–TCLP[e]	–	–	96	96	99	91
%Reduction–SPLP[e]	>99	>99	91	84	99	91

a) All concentrations expressed as Benzo(a)Pyrene potency estimate(EPA 1993b), except as noted
b) EPA, 1997 a., Tier 1
c) EPA, 1997 b., Tier 2
d) EPA, 1998, Vendor C, Round 2
e) Percent reduction values have been adjusted to eliminate the effect of dilution by reagents added (see dilution factor Exhibit 3)
NC = Not calculated

tion procedure to produce higher concentrations from the untreated soil than was the case for the TCLP extraction procedure. In all cases the SPLP extract after treatment met the treatability criteria of having less than a 10 µg/L B(a)P potency estimate.

Since B(a)P potency estimates were at such low levels, the total (sum) of all detected PAHs are also included in Exhibit 6. Generally, the TCLP test procedure produced slightly higher concentrations of total detected PAHs than the SPLP for untreated soils (five of six cases) while SPLP produced slightly higher concentrations in treated samples (three of four cases). However, the principal message from looking at total detectable PAHs is that S/S treatment successfully reduced the total detected PAHs by over 90% in leachates, in all except one case which was 84%. However, SPLP leachates met target levels for all three sites for which target levels had been established.

Stabilization of Metals - Stabilization of metals was not a primary goal of the treatability tests discussed in this article. However, the results for metal treatment are presented in **Exhibit 7** because leachable metal data were collected for three of the sites. However, the reader is cautioned not to draw too many conclusions from this data as the concentrations are quite low, both before and after treatment, and no emphasis was placed on developing formulations for metal stabilization in these particular tests. The data in Exhibit 1, which was a full scale remediation that targeted metals, is considered much more indicative of the success of S/S to treat metals at wood preserving sites than the data presented in Exhibit 7.

Physical Properties of Treated Soils - **Exhibit 8** summarizes the principle physical properties achieved in the treatability tests. The treatability criteria of over 100 psi unconfined compressive strength and a permeability of less than 1x10^{-6} cm/sec were achieved by all formulations listed. The reader is cautioned, however, on two points. First, these criteria were set for the treatability tests and do not necessarily reflect the final goals for site remediation. Second, not all of the formulations tested were able to meet these criteria. Many failed to meet one, or both; however, the data do indicate that it was possible to develop formulations for each of these four sites that could meet these treatment criteria.

CASE STUDY - REMEDIATION OF THE AMERICAN CREOSOTE WORKS SITE

The ACW site encompasses 60 acres of marshy flood plain along the forked Deer River just southwest of Jackson, Tennessee. The facility treated wood from the 1930's to 1981 using both creosote and PCP. Surface soils in an approximate eight acre main process and drip tracks area,

Exhibit 7. Stabilization of Metals[a] μg/L in Treatability Tests

Treatment Characteristic	Site Name						
	ACW[d]			MCB[e]		RAB[e]	
Formula Cost $/Ton Raw Soil	Untreated	39	62	Untreated	50	Untreated	50
TCLP[b]							
(pH)	–	–	–	5.0	5.9	5.2	6.6
Arsenic	–	–	–	191	64	<20	<20
Chromium	–	–	–	<20	<20	<20	<20
Copper	–	–	–	610	62	26	<20
Lead	–	–	–	<10	29	198	31
Zinc	–	–	–	1190	441	3690	9
SPLP[c]							
(pH)	7.0	11.8	11.8	6.8	11.2	7.0	11.2
Arsenic	<20	<20	<20	189	<20	<20	<20
Chromium	<20	60	70	27	26	<20	<20
Copper	22	<20	<20	211	27	<20	<20
Lead	24	<10	14	37	<10	15	<10
Zinc	418	<50	<50	579	<50	666	<50

a) Metals were not a target for treatment in these studies, thus results should not be interpreted as the best achievable
b) EPA SW 846 Method 1311
c) EPA SW 846 Method 1312
d) EPA 1997 a., Tier 1
e) EPA 1998, Vendor C, Round 2

Exhibit 8. Physical Properties of Treated Soils[a] in Treatability Tests

Property	Site Name					
	ACW[c]		TWT[d]		MCB[e]	RAB[e]
Formula Cost $/Ton Raw Soil	39	62	66	54	50	50
Unconfirmed Compressive Strength (psi)	1435	1240	340	620	170	100
Goal (psi)	>100	>100	>100	>100	–	–
Permeability (cm/sec)	$1.1x10^{-6}$	$4.1x10^{-7}$	$1.4x10^{-7}$	$5.6x10^{-7}$	$2.2x10^{-7}$	$3.1x10^{-7}$
Goal (cm/sec)	$<1x10^{-6}$	$<1x10^{-6}$	$<1x10^{-6}$	$<1x10^{-6}$	–	—
Dilution Factor[b]	1.32	1.26	1.24	1.35	1.2	1.2

a) All values after 28 day cure
b) Weight of Reagent plus soil divided by weight of untreated soil. Water added not included
c) EPA, 1997 a., Tier 1
d) EPA, 1997 b., Tier 2
e) EPA, 1998, Vendor C, Round 2

consisting primarily of sands and silts, were contaminated by creosote, PCP, and dioxins. The main process area is underlain by a confining clay layer at a depth of approximately two to five feet limiting the depth to which soils were contaminated.

In 1996 the EPA completed a focused risk assessment for the ACW site. Based on a future industrial use scenario and a defined risk of $1X10^{-4}$, soil action levels were defined for contaminants of concern as shown in **Exhibit 9**. Later that same year the EPA, with concurrence from the State of Tennessee, signed a Record of Decision which called for remediation by excavation, ex-situ treatment by S/S, and replacement of treated soil under a cap. Following comple-

Exhibit 9. Soil Action Level Goals[a] as Determined for the American Creosote Site, Jackson, Tennessee[b]

Contaminant	Soil Action Level[c](mg/kg)
Arsenic	225
Benzo(a)pyrene	41.5
Dibenzo(a,h,)anthracene	55.0
Pentachlorophenol	3,000
Dioxins TCDD-TEQ	0.00225

a) Level of contaminant in soils at, or above which, remedial action is required.
b) Source EPA 1996b
c) Based on lifetime cancer risk future adult worker, $1X10^{-4}$ risk.

Exhibit 10. Solidification/Stabilization Specifications for Remediation of the American Creosote Site, Jackson, Tennessee

	Average All Treated	Maximum Any Batch[b]	Method
Leaching Properties[a]			
Arsenic	<50 µg/L	<75 µg/L	SW846 7061
PAHs (B(a)P Potency Estimate	<10 µg/L	<15 µg/L	SW846 8270
Dibenzo(a,h) Anthracene	<4.4 µg/L	< 6.6 µg/L	SW846 8270
PCP	<200 µg/L	<300 µg/L	SW846 8270
Dioxins TCDD-TEQ	<30 pg/L	< 45 pg/L	SW846 8290
Physical Properties			
Permeability	<1x10^{-6} cm/sec	<1x10^{-5} cm/sec	ASTM D5084
UCS	>100 psi	>80 psi	ASTM D1633
Volume Increase	<35 percent		

a) Synthetic precipitation leach procedure, EPA SW846, Method 1312
b) Batch size 500 cubic yards

Exhibit 11. Major Bid Cost Components of the Remedial Action at the American Creosote Site, Jackson, Tennessee

Item	Cost Per Unit	Total 1,000$
Mobilization and Documents	–	142
Demolition/Debris	–	34
NAPL Recovery	System	124
Cutoff Wall	$9 Lin. Ft.[b]	20
Drainage Trenches	$14.90 cy	75
Excavate, Treat and Replace Soil	$44.25 cy[c]	1996
Water Treatment	$ 0.68 gal[d]	20
Creosote Disposal	$ 3.05 gal[d]	47
CAP (GCL[a] plus 2 ft. soil)	$ 50,460 Acre	363
Site Restoration and Demobilization	–	55
Other	–	10
Total		2,886

a) Geosynthetic Clay Liner Linear Foot
b) Linear Foot
c) Cubic Yard
d) Gallon U.S.

tion of the remedial design treatability study in 1997, the USEPA, in cooperation with the State of Tennessee, developed a performance based remedial action design and bid package in 1998 for the main processing area. In 1999 the State of Tennessee bid the project and awarded the contract to the IT Group (as IT/OHM Corporation) and the remediation project commenced in the spring of 1999. As of the end of December 1999, excavation, treatment, and onsite disposal of treated soils was complete and construction of the cap over the treated material was well advanced. Vendor records show that 46,700 cubic yards (80,700 tons) of contaminated soil were excavated, treated, and replaced into the excavation area. The S/S treatment specifications are shown in **Exhibit 10**, while the major remediation cost elements are shown in **Exhibit 11**. Note that the bid cost to excavate, treat, and replace soils was $44.25 per cubic yard (measured as untreated soil in place before treatment) and the total bid costs for all activities averaged over the estimated 45,000 cubic yards came to just over $64 per cubic yard. The treatment formulation developed by IT/OHM Corporation and used for this successful treatment of dioxins, PCP and creosote was 1.3% powdered carbon, 5% portland cement, and 4.5% fly ash, all determined as weight percents of the untreated soil. This project demonstrated that a highly contaminated wood preserving site containing dioxins, PCP, and creosote, can be remediated at moderate cost by using S/S technology.

CONCLUSION

During two full scale remediations and various treatability tests on several wood preserving sites, it has been documented that S/S formulations can be developed that meet all physical properties and chemical stabilization (immobilization) goals. The cost for the chemical formulations in the treatability tests ranged from $39 to $66 (chemicals only). Complete costs for remediation are highly dependent on site-specific factors, but could be expected to range from $40 to $100 per ton ($60-$120 per cubic yard) of untreated soil.

TCLP and SPLP leaching tests often produce dramatic differences in concentrations of contaminants in leachates for both untreated and treated soil samples. For both PCP and dioxins, the SPLP leach procedure produced dramatically higher concentrations in leachates than did the TCLP leach procedure, thus careful consideration should be given to selection of the leaching procedure to be used in evaluating leaching properties of either treated or untreated soils. In the authors' opinion, the SPLP appeared to be a better test method to measure the effectiveness of the S/S treatment technology. The concentrations of contaminants of concern in SPLP leachates for S/S treated soils were generally 95 to 99% less than in SPLP leachates from untreated soils.

Following development of successful formulations during treatability tests for the ACW site in Jackson, Tennessee, this site remediation was bid by the State of Tennessee. In 1999 a contract was awarded for remediation of this site including S/S of an estimated 45,000 cubic yards of highly contaminated soil. The bid price for excavation, S/S treatment, and replacement (including reagent costs and performance sampling) was $44.25 per cubic yard while total project bid costs including the draining, collection, treatment, and disposal of a water and creosote NAPL and placement of a cap came to slightly over $64 per cubic yard if divided by the 45,000 cubic yards of contaminated soil. By the end of December 1999, excavation, treatment, and on site disposal of treated soils was complete with vendor records showing 46,700 cubic yards (80,700 tons) of contaminated soil successfully treated.

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