COST AND PERFORMANCE REPORT

Vitrification at the New Bedford Harbor Superfund Site
New Bedford, Massachusetts

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U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Solid Waste and Emergency Response
Technology Innovation Office

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Summary Information [1,2,4,5,7]

The New Bedford Harbor Superfund Site (NBH) is located along the northwestern shore of Buzzards Bay in New Bedford Massachusetts, approximately 55 miles south of Boston. From the 1940s to 1978, two manufacturing facilities located along the New Bedford Harbor, the Aerovox facility and the Cornell-Dubilier electronics facility, discharged polychlorinated biphenyl (PCB)-contaminated wastewater from industrial operations onto the shoreline and into the harbor. During investigations of the site performed by EPA in the late 1970s, widespread PCB contamination was found in sediments and marine life throughout the 18,000 acres of estuary, harbor, and bay areas. In September 1979, the Massachusetts Department of Public Health (MDPH) closed major fishing areas within the harbor. In August 1982, EPA began a remedial investigation (RI) of the site. Sediments were found to be contaminated with PCBs, polycyclic aromatic hydrocarbons (PAHs), and heavy metals including lead, cadmium, copper, and chromium. The site was listed on the National Priorities List in September 1983.

Figure 1 shows a general layout of the NBH area. The NBH site has been divided into three operable units (OU) - Upper and Lower Harbors (OU1), 5-acre Hot Spot Area (OU2), and the Outer Harbor (OU3). EPA has performed RIs at OU1 and OU2; an RI has not yet been performed at OU3. PCB concentrations in OU1 were found to range from below detection levels to 4,000 mg/kg, while concentrations in the OU2 Hot Spot Area ranged from 4,000 mg/kg to more than 200,000 mg/kg. This report addresses the cleanup of OU2.

The Record of Decision (ROD) for OU2 was signed in April 1990 and specified source control measures that included dredging of PCB contaminated sediments from the Hot Spot area followed by incineration. The ROD specified that dredging would occur at depths of up to four feet to remove sediments with PCB concentrations of 4,000 mg/kg or higher. Dredging of the Hot Spot area was completed in the fall of 1995, with the dredged sediment temporarily stored in a Confined Disposal Facility (CDF) located along the New Bedford shoreline at the end of Sawyer Street. The CDF is a three cell, double-lined (high density polyethylene) holding pond that was planned to be used for staging sediments prior to incineration. However, due to local and congressional opposition to incineration, EPA postponed the incineration component of the Hot Spot remedy to explore alternative treatment technologies. In 1995, EPA issued an Explanation of Significant Difference to address interim storage of the Hot Spot sediments at the CDF. The CDF is covered with a 10-millimeter permalon cover.

EPA evaluated four technologies as possible alternatives to incineration of the Hot Spot sediments - solvent extraction/dechlorination, vitrification, thermal desorption/gas phase chemical reduction, and solidification/stabilization. Pilot-scale testing was performed for the first three technologies and bench-scale testing was performed for solidification/stabilization. Testing was conducted at the 8-acre NBH Sawyer Street location which includes the CDF, a test pad, a water treatment building, and a laboratory (see Figure 2). This report addresses the results of the pilot-scale study of the vitrification technology. Reports about the other technologies tested are available at www.frtr.gov/cost.

According to the EPA RPM, none of the four technologies tested have been implemented for OU2 because of lack of community support for the use of on-site technologies to remediate the Hot Spot sediments. As a result, the ROD for OU2 was amended in April 1999 to specify dewatering of the sediments on-site and transporting them off-site, without further treatment, to a Toxic Substances Control Act (TSCA) permitted landfill.

Figure 1 - Site Layout [1]

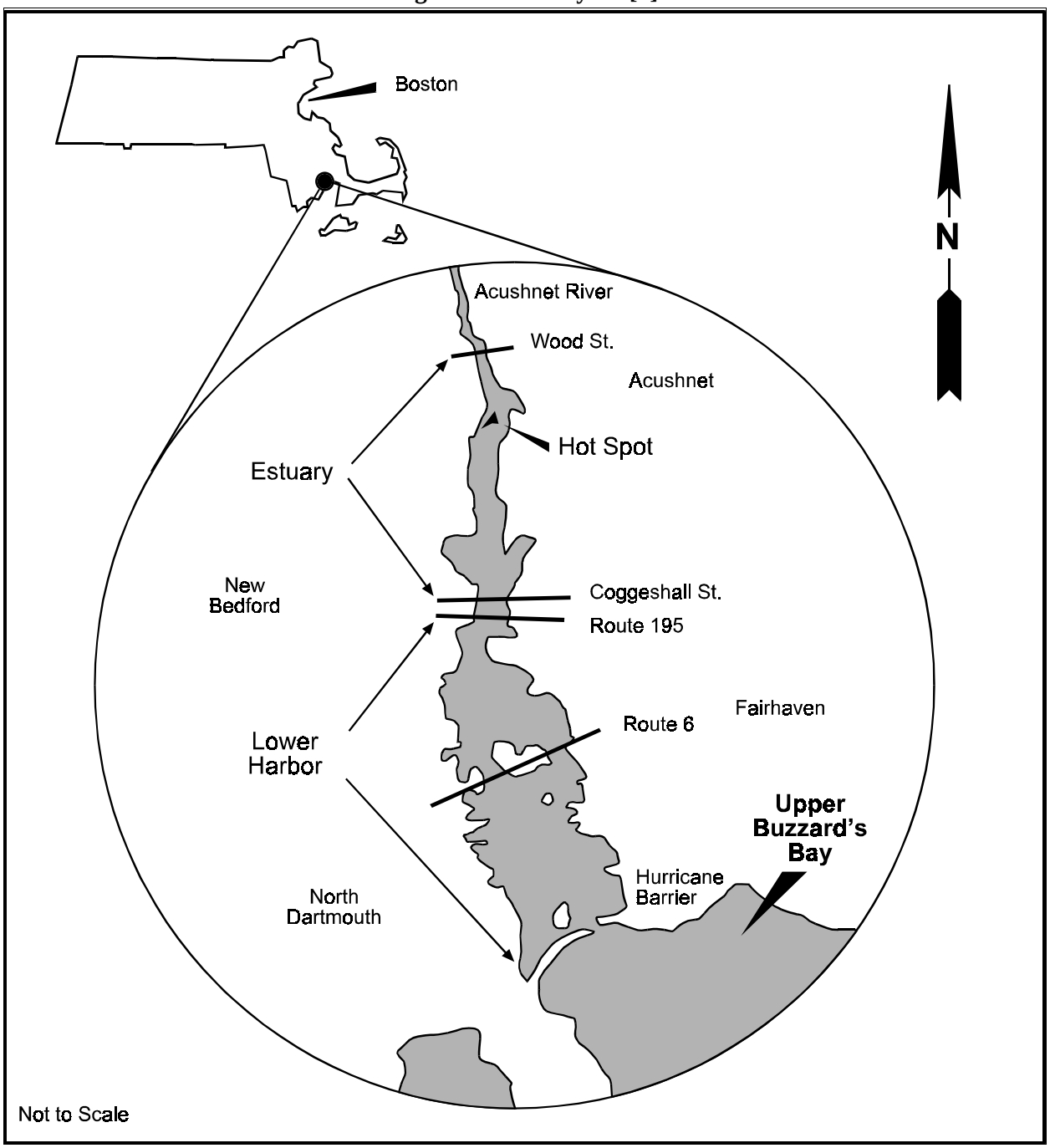
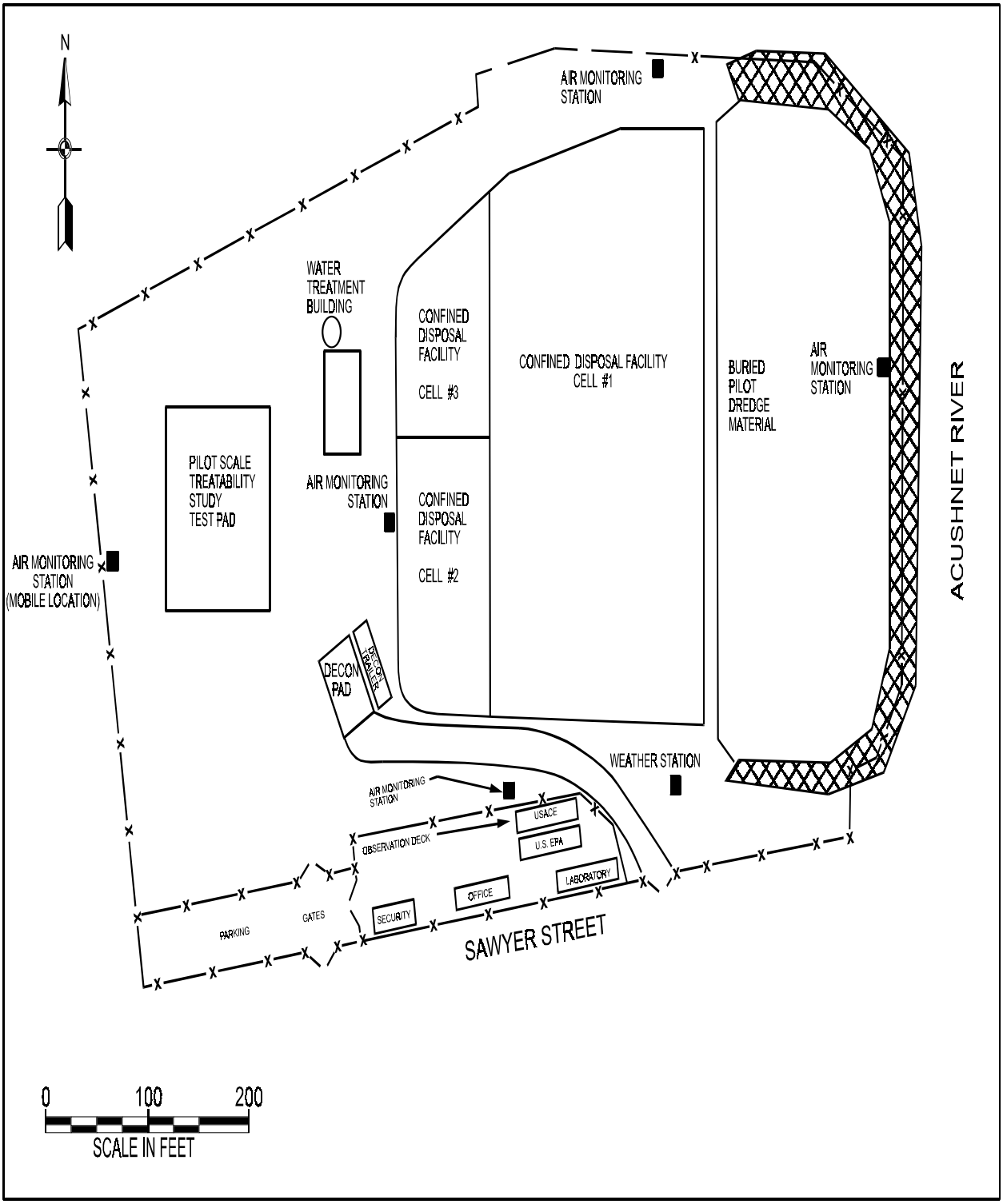


Figure 2. Layout of Confined Disposal Facility and Test Area [1]



Factors That Affected Cost or Performance of Treatment [1,3]

The sediment used in the pilot-scale demonstration was from the Hot Spot area of New Bedford Harbor, which had been dredged in 1995. PCB concentrations in the sediments in the Hot Spot area ranged from 4,000 to more than 200,000 mg/kg.

Matrix Characteristics [1,3]

Listed below are the key matrix characteristics for this technology and the values measured for each based on sediment samples collected in June 1995 from the CDF and from pilot study feed sediments.

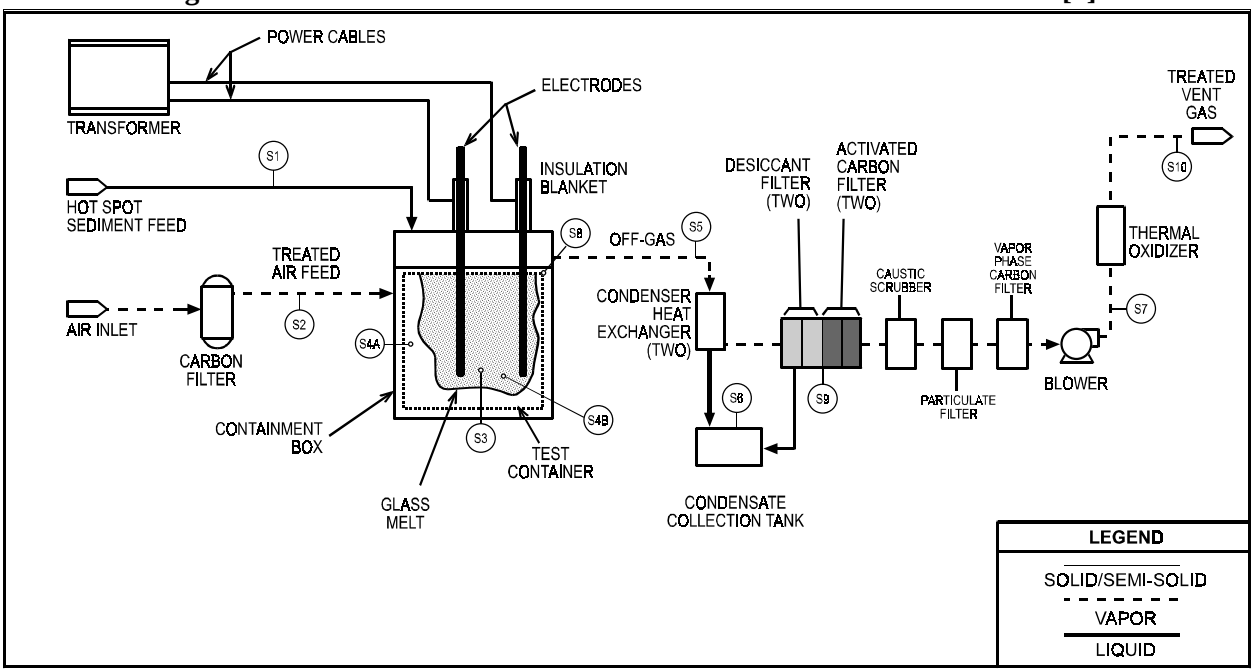
Parameter	Value
Soil Classification	Fine sandy silt with some clay-sized particles present
Clay Content and/or Particle Size	50 - 70% of sediment passing a number 200 sieve; sediment contains some small shell fragments (pass through a 1-inch screen)
pH	Not provided
Moisture Content	50% by weight
Total organic carbon	7% (average)
Density	1.2 tons/cubic yard (wet weight)
Oil and Grease	CDF representative sample: 22,000 - 34,000 mg/kg Pilot study feed: 11,700 - 36,900 mg/kg

Treatment Technology Description [1,6]

Geosafe Corporation (Geosafe) conducted a pilot-scale study of vitrification for treating the Hot Spot sediments, using a treatment system with a capacity of 2,000 pounds of sediment per batch. As shown in Figure 3, the system included a power supply, a test container, a containment box, an off-gas treatment and water collection system, and a data monitoring and storage system. The power system used a 30 kW Scott-Tee transformer to convert three phase primary input power into a balanced two phase secondary output. Power connections for the test were supplied by the local utility.

The pilot study involved testing two batches of Hot Spot sediment. Two test containers were used, one for each batch. The test containers were cylindrical carbon steel, 60 inches high and 50 inches in diameter. Before sediment was placed in the container, 14 type K thermocouples were placed vertically in the center of the container, arrayed in 3-inch increments from the top of the container to a depth of 42 inches, and were used to monitor the depth of the melt. In addition, an array of 7 type K thermocouples were placed laterally in the container 20 inches below the top vertical thermocouple to monitor the width of the melt. The lateral thermocouple array extended horizontally from the electrode plane out 21 inches towards the edge of the test container in 3-inch increments. Type C thermocouples, equipped with alumina sheaths to prolong service life, were placed in each container and used to monitor the melt temperature. The sediment was staged by pouring wet sediment into each test container. Each test container was placed inside a containment box, which was constructed of carbon steel and fitted with

Figure 3 - Geosafe Pilot-Scale Vitrification Process with Enhancements [1]



ports for off-gas removal, electrode feeding, and instrumentation. The system was equipped with moveable electrodes, placed inside each container.

The off-gas system used for the pilot study was designed to facilitate the acquisition of off-gas samples and was not intended to be used to evaluate performance of a full-scale system. For the first test of the study, the off-gas system included two parallel, single pass shell and tube heat exchangers to cool the off-gas, a filter system containing a desiccant to remove moisture, a blower, and activated carbon to remove particulates and organic vapors. For the second test, an enhanced off-gas treatment system was used.

The enhancements included the addition of a scrubber equipped with caustic to control the pH of the scrubber solution, a larger blower, a particulate roughing filter, a two-stage venturi vapor phase carbon filter, and a thermal oxidizer. The enhancements were added based on field observations and preliminary air sampling performed during the first test to reduce the possibility of contaminant release during testing.

Operation [1,6]

Two pilot tests of the vitrification process (Batch No. 1 and Batch No. 2) were performed in July and August 1996. The operating parameters for each test are summarized in Table 1. The configuration and operation of each test is described below.

Table 1 - Operating Parameters for Vitrification Pilot Tests [1]

Batch No.	Dates of Test*	Average Power Input	Duration Power Applied	Target Depth of Melt	Average Melt Rate	Total Energy Consumed
1	7/20-21/96	24 kW	34 hours	31.5 in.	0.93 in/hr	785 kWhr
2	8/26-27/96	24 kW	22 hours	33 in.	0.9 in/hr	522 kWhr

* Off-gas treatment system revised 7/22-8/25/96, as described under Batch No. 2 operation.

Batch No. 1 Configuration and Operation:

For the first batch, the surface of the sediment in the test container was at the same level as the uppermost thermocouple. A plastic sheet barrier was placed on top of the sediment, followed by a layer of clean soil (1-inch, mounded to 4-inches in the vicinity of the electrodes) to allow initiation of melting in a dry layer of soil, as it was not practical to start the melt in the wet sediment. As described by Geosafe, the plastic allowed a quantity of dry soil to be "floated" on top of the wet sediment with the melt being started in the dry soil (were the dry soil to be placed directly on the sediment, it would have immediately absorbed the water from the sediment). The test container was placed in the containment box and the two electrodes were inserted to a depth of 3 inches. To provide a conductive pathway, a starter path (a mixture of graphite flake and glass), was placed 1-inch thick in a pattern (an X within a square) between the electrodes. The area was then covered with a 2-inch thick layer of Kaowool insulation blanket to promote subsidence of the molten zone and improve process efficiency. The target depth for the melt was 31.5 inches.

Power to the electrodes was initiated at 0955 hours on July 20, 1996 and power input was normal and stable up to the target operating level of 25 kW, achieved within about 3 hours. The total test duration with power applied was 34 hours. The vitrification process occurred at the target depth of 31.5 inches, based on a reading of greater than 1,000°C centerline temperature measured just below this depth. A molten surface was formed once the starter path was consumed and the surface of the melt bubbled vigorously during the melt. A relatively linear melt rate was observed after startup, with the rate slowing as the size of the melt increased. The average melt rate was 0.93 inches/hour, which was slower than expected as a result of the high concentration of water in the sediment.

A total of 785 kWhr of energy was consumed during this batch melt and approximately 700 pounds of melt were produced. The average power during the melt operation was 24 kW. According to Geosafe, the power density (power divided by surface area of the vitrification zone) and melt resistence observed during Batch No. 1 was consistent with that observed during other full-scale operations.

Periodic off-gas sampling was initiated four hours after the test was started and continued for four hours after the test was completed. During operation, elevated concentrations of particulates and organics were released in the off-gas. These problems were attributed to the high moisture content and the fine-grained nature of the sediment. Additional information on the cause of these problems is discussed under the Performance Information section of this report.

Batch No. 2 Configuration and Operation:

In an attempt to alleviate the problem with particulate and organic emissions experienced with Batch No. 1, several modification were made to the configuration for Batch No. 2. The off-gas system was enhanced, as discussed above under Technology Description, adding scrubbers and a thermal oxidizer. In addition, the depth of clean soil cover was increased to 10 inches and an extra Kaowool blanket was added to attempt to reduce the amount of particulate generated during the process. The Batch No. 2 container sat undisturbed for 5 weeks between filling and the start of the test. Approximately 70 gallons of standing water were decanted from the test container to reduce the amount of steam generated during the test, thereby helping to reduce the amount of particulate generated. The target depth for the melt was 33 inches.

The test was initiated on August 26, 1996, but had to be terminated on August 27, 1996 as a result of high particulate and organic vapor readings. The total test duration was 22 hours, with a melt depth of 20 inches. A total of 522 kWhr was consumed during Batch No. 2, with the power level decreased in the latter stages of the melt in an attempt to reduce emissions. According to Geosafe, the power density and melt resistence for Batch No. 2 were typical of full-scale vitrification.

During Batch No. 2, a molten surface formed once the starter path was consumed. However, the surface of the melt did not bubble as vigorously as Batch No. 1. The observed melt rate was linear after startup, with an average melt rate of 0.9 inches/hour. According to Geosafe, the melt rate was slower than expected as a result of the high concentration of water in the sediment.

Performance Information [1,6]

The objectives of the pilot study included evaluating the effectiveness of vitrification in treating PCBs and heavy metals in the Hot Spot sediments, identifying potential environmental or engineering constraints related to the use of the technology to remediate sediments, and evaluating scale-up to full-scale operation. The target treatment goal for PCBs was 50 mg/kg, based on the Toxic Substances Control Act (TSCA) disposal requirements for PCB-contaminated dredged spoil. The target treatment goal for metals were the Resource Conservation and Recovery Act (RCRA) Toxicity Characteristic Leaching Procedure (TCLP) criteria. In addition, Federal and State air regulations require air monitoring for on-site technologies that have the potential to generate polychlorinated dibenzo-p-dioxins (PCDD) and dibenzofurans (PCDF), reported as total PCDD/PDCF and as toxicity equivalent quotient (TEQ), calculated based on EPA toxicity equivalent factors.

The vitrified material was allowed to cool for three days prior to removal from the test container. The vitrified block was steam cleaned, then broken into pieces with a sledge hammer. Because pieces that were in contact with the outside boundary (fusion zone) of the vitrified mass were potentially in contact with unvitrified (untreated) material, these pieces were not sampled. The results for each test are described below.

Batch No. 1 Results:

During Batch No. 1, significant operational difficulties were encountered as a result of the high moisture content and fine-grained nature of the sediment. According to Geosafe:

- The high moisture content of the sediment resulted in significant steam generation during processing causing airborne dispersal of sediment within the test container. The airborne

sediment had increased in temperature but had not melted. The release of hot, untreated sediment in the test container in the form of particulates resulted in elevated levels of organics such as PCBs and dioxins and furans in the off-gas.

- The fine-grained nature of the sediment and its lack of cohesiveness in a dry state made it readily mobile. As the melt progressed outward, the water in the sediment boiled and evaporated, creating turbulance that resulted in a large amount of particulates becoming airborne above the sediment.

Because of the problems encountered during Batch No. 1, Geosafe considered this batch to be an optimization test and Batch No. 2 to be the verification test. Therefore, data from the Batch No. 1 test was not included in the analysis of the performance of the vitrification process on the Hot Spot sediments.

Batch No. 2 Results:

Table 2 is a summary of concentrations of contaminants in the feed sediment (S1) and in the vitrified product (S3). Total PCB concentrations were reduced from an average of 2,085 mg/kg in the Hot Spot feed sediment to non-detect levels. TCLP concentrations of metals in the feed sediment were below regulatory levels and remained below the target levels in the vitrified product. Concentrations of arsenic, cadmium, chromium, and lead were reduced in the vitrified product while concentrations of barium and selenium increased.

Table 2 - Summary of Contaminant Concentrations in Feed Sediment and Vitrified Product for Batch No. 2 [1]

Parameter	Target Level*	Average Concentration	
		Feed Sediment (S1)	Vitrified Product (S3)
PCBs (total)	50 mg/kg	2,085 mg/kg	ND
TCLP Metals			
Arsenic	5,000 ug/L	17 ug/L	5.37 ug/L
Barium	100,000 ug/L	264 ug/L	329 ug/L
Cadmium	1,000 ug/L	43.6 ug/L	ND
Chromium	5,000 ug/L	71.7 ug/L	14.3 ug/L
Lead	5,000 ug/L	694 ug/L	14.4 ug/L
Mercury	200 ug/L	Not detected	0.24 ug/L
Selenium	1,000 ug/L	4.1 ug/L	8.9 ug/L
Silver	5,000 ug/L	ND	ND

* Target levels for metals are the TCLP regulatory limits.
ND - Not detected

In addition, samples of sediment were collected from the areas that were adjacent to and below the vitrified block. After the soil cover was removed from the test container, a stainless steel tube was used to collect samples from areas that had reached 100°C adjacent to and beneath the block (3.5 inches from the block, based on thermocouple readings) and 300-400°C (1.5 inches from the block, based on thermocouple readings). The results, which are the averages measured for Batches Nos. 1 and 2, are presented in Table 3.

Table 3 - Results for Sediment Collected Adjacent to and Beneath the Melt [1]

Parameter (mg/kg) (Total)	Feed Sediment	Sediment Adjacent to and Beneath the Melt		
		Adjacent (1.5 inches)	Adjacent (3.5 inches)	Beneath (3.5 inches)
Sediment Temperature	Not measured	300 - 400 °C	100 °C	100 °C
PCBs	2,085	64	750	410
Mercury	1	0.08	0.05	0.28
Lead	418	396	809	864
Cadmium	7	6.9	14	7.8
Arsenic	5	5	6.5	4.9

The concentrations of PCBs in the zones adjacent to and beneath the melt were reduced, with concentrations in the 1.5 - inch zone reduced by more than 90%. These results suggest that PCBs are removed during the heating process, and were consistent with other vitrification tests performed by Geosafe. The metals data indicate little change except for an increase in lead concentrations at 3.5 inches indicating that the lead may have been desorbed and recondensed in this zone.

The destruction removal efficiency (DRE) was calculated for the vitrification process for total PCBs. As shown in Table 4, the DRE was calculated as the mass of contaminant removed from the sediment (W_{in}) minus the mass of contaminant detected in the outlet from the thermal oxidizer unit (W_{out}), divided by W_{in} times 100. The DRE for total PCBs was 99.9905%.

In addition, data were collected from the vitrification offgas (S5). According to Geosafe, these data indicate that approximately 25 to 50% of the mass of PCBs from the sediment were desorbed into the vent gas, suggesting that vitrification did not destroy the organic contaminants, but rather released them into the vent gas. The off-gas data also indicate that the process produced dioxin and furan as organic by-products, with the mass of these contaminants increasing by as much as ten fold in the vitrification off-gas.

Table 4 - DRE for the Vitrification Process and Data on Mass of PCBs [1]

Parameter	Mass Removed from Sediment (W_{in})	Mass Detected at the Thermal Oxidizer Outlet (W_{out}) (S10)	DRE (%) $\frac{W_{in}-W_{out}}{W_{in}} \times 100$	Mass Detected in Vitrification Off-gas (S5)
PCB -Total (mg)	654,995	61.9	99.9905	376,704

Performance Data Quality [1]

Samples were analyzed using EPA methods or analytical methods similar to those used by an EPA Contract Laboratory Program (CLP) laboratory. In general, the data were used in the evaluation process as the data were found to be consistent and comparable to historical data and analyses typically performed under the EPA CLP program. PCDD and PCDF were analyzed for total isomers and 2,3,7,8-substituted congeners. TEQs were calculated for each 2,3,7,8-substituted congeners based on EPA toxicity equivalent quotient. EPA Method 1311 was used to analyze TCLP metals.

A comprehensive quality control (QC) program was used during the testing, including field and laboratory duplicates, performance evaluation samples, and data validation. The results of the QC program indicated that, overall, analytical results were comparable and accurate for the purpose of assessing process performance as part of an engineering evaluation. While some QC results exceeded established criteria, resulting in some data being considered as “estimated”, the data do not pose a significant concern for the purposes of the engineering evaluation.

Cost Information [1,6]

The pilot-scale testing of vitrification for the Hot Spot sediments from the New Bedford Harbor Superfund Site were conducted by EPA under an Alternative Remedial Contracting Strategy (ARCS) contract. Foster Wheeler served as the prime contractor, providing overall management and technical oversight of the testing and preparing the evaluation report (Reference 1) and projected cost estimates for full-scale projects, with input from the vendors.

As shown in Table 5, the projected cost for full-scale vitrification of Hot Spot sediments, developed by Foster Wheeler using input from Geosafe, is $20,687,000 or $1,149 per ton based on 18,000 tons of sediment. The projected costs assume treatment only based on the treatment of 18,000 tons of Hot Spot sediment. Foster Wheeler made several modifications to the estimated Geosafe costs. The modification included: (1) increasing Geosafe’s estimated costs for electrical power, which Foster Wheeler determined was low by a factor of two; (2) adding a comprehensive design scale test program; (3) adding a thermal sprayer and enhanced off-gas treatment system.

Table 5 - Project Full-Scale Costs for Vitrification of Hot Spot Sediments [1]

Item	Cost (1997$)
Capital costs	
Mobilization	300,000
Demobilization	250,000
Design scale testing	1,616,000
Dewatering of sediment	6,324,000
Melt processing	8,196,000
Off-gas treatment for melt operations	4,001,000
Total cost	**$20,687,000**
Cost per ton of wet sediment (18,000 tons)	$1,149/ton

The estimated cost for design scale testing includes a month long test for both thermal dewatering and vitrification operations. For the tests, a minimum of four separate melts would be conducted; sediment drying would be done at a rate that would provide enough sediment for vitrification and to assess the efficiency of the drying operations (energy required to dry the sediment and the quantity and quality of the off-gas); both tests would include extensive off-gas sampling and analysis, and a comprehensive site-wide air monitoring program.

The costs presented in Table 5 were developed by Foster Wheeler based on the use of vitrification on sediments with a relatively high moisture content. According to Geosafe, the estimate for treating dry sludge using the GeoMelt vitrification process is less than $400 per ton. In addition, Geosafe noted that, based on the company's experience, costs for dewatering can be less than $200 per ton.

Observations and Lessons Learned [1,6]

The results of the vitrification pilot test showed that PCB concentrations in the melt were reduced from an average of 2,085 mg/kg in the Hot Spot feed sediment to below detectable levels. The DRE for the vitrification process was 99.9905% for total PCBs. While the TCLP concentrations of metals in the feed sediment were below regulatory levels, the concentrations in the vitrified product indicate that vitrification reduced the mobility of arsenic, cadmium, chromium, and lead.

According to Geosafe, vitrification technology desorbs water, organics, and other materials as a normal part of the process, with pyrolyzation of PCBs occurring as the vapors pass to the surface. In the case of the Hot Spot sediments, the high water content of the sediments resulted in such a rapid removal of PCBs from the volume near the melt (by steam stripping) that there was insufficient time available for the normal pyrolyzation to be accomplished. Geosafe indicated that dewatering the sediment to a moisture content of 10% prior to treatment would address this problem, with Foster Wheeler indicating that a thermal dryer would likely be the most effective means of reducing the moisture content to that level.

Data from the pilot test indicated that organic by-products, including dioxins and furans, were present in the off-gas, requiring treatment. Foster Wheeler indicated that additional testing would be needed prior to full-scale implementation to evaluate the level of off-gas treatment that would be required to meet emissions criteria. According to Geosafe, their experience in using ISV on drier soils has not resulted in the formation of dioxins and furans.

Geosafe provided the following additional observations and lessons learned about this pilot test:

- Full-scale ISV technology is not the technology of choice for treating soils/sediments with a high moisture content (i.e., fluid media). The first test was performed on sediments that contained standing water. While the water was decanted from the sediment for the second test, the moisture content of the sediment tested was above 50 percent. Geosafe indicated it would have been helpful to have had a better understanding of the properties of the sediment before the testing was conducted.

- Based on Geosafe's experience in using ISV, the costs for treating dry sediment is about $400 per ton, rather than the $1,000 per ton estimated by Foster Wheeler. In addition, the cost for dewatering sediment can be less than $200 per ton.

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