

**Phase I Bench-Scale Testing Report  
Decontaminating Dredged Estuarine  
Sediments: The Westinghouse  
Plasma Vitrification Process**

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March 13, 1997



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# TABLE OF CONTENTS

<b>1. EXECUTIVE SUMMARY.....</b>	<b>1</b>
1.1 PHASE I BENCH-SCALE PROGRAM HIGHLIGHTS.....	2
1.2 PHASE II PILOT TEST PROGRAM .....	2
1.3 THE WESTINGHOUSE PLASMA VITRIFICATION SOLUTION .....	3
1.3.1 Process Raw Materials .....	5
1.3.2 Process Output Streams.....	5
1.4 PHASED APPROACH TO THE INTEGRATED TREATMENT TRAIN.....	7
1.5 REPORT ORGANIZATION.....	9
<b>2. CONCLUSIONS AND RECOMMENDATIONS .....</b>	<b>11</b>
<b>3. SEDIMENT CHARACTERIZATION .....</b>	<b>14</b>
3.1 GENERAL SEDIMENT CHARACTERISTICS .....	14
3.2 SEDIMENT MORPHOLOGY .....	16
3.3 ELEMENTAL ANALYSIS.....	16
3.4 MINERALOGICAL ANALYSIS.....	19
3.5 CONTAMINANT ANALYSIS .....	20
3.6 MICROBIOLOGICAL ANALYSIS.....	22
3.7 THERMAL ANALYSES .....	22
3.7.1 Thermal Gravimetric Analysis.....	22
3.7.2 Differential Thermal Analysis.....	24
<b>4. BENCH-SCALE TESTING.....</b>	<b>26</b>
4.1 GLASS RECIPES SELECTION.....	26
4.1.1 Glass Product Requirements .....	27
4.1.2 The Soda-Lime-Silica Phase Diagram .....	28
4.1.3 Viscosity Modeling.....	30
4.1.4 Target Glass Recipes .....	32
4.2 BENCH SCALE TEST PROCEDURES .....	32
4.2.1 Sediment Screening .....	34
4.2.2 Sediment Drying .....	35
4.2.3 Rinsing and Dewatering for Chloride Removal .....	35
4.3 COUPON MELT TESTING.....	38
4.3.1 Coupon Melt Test Description.....	38
4.3.2 Coupon Melt Results .....	40
4.3.3 Selection of Optimal Glass Formulation.....	41
<b>5. BENCH-SCALE GLASS PRODUCTION .....</b>	<b>43</b>
5.1 PROCEDURE FOR PRODUCTION OF 10 KG GLASS.....	43
5.2 CHEMICAL ANALYSIS OF PRODUCT GLASS.....	44
5.3 TESTING OF PRODUCT GLASS.....	45
5.3.1 Organic Contaminant Destruction Efficiency .....	45
5.3.2 RCRA Metals Analysis .....	46
5.3.3 TCLP Leach Testing.....	47
<b>6. THE PLASMA VITRIFICATION TREATMENT TRAIN.....</b>	<b>49</b>
6.1 DETAILED PROCESS DESCRIPTION AND MATERIAL BALANCES.....	49
6.1.1 Sediment Size Segregation .....	50
6.1.2 Salt Rinsing and Dewatering .....	53

6.1.3 Plasma Vitrification .....	54
6.1.4 Glass Product Manufacture.....	54
6.1.5 Gas Cleaning.....	55
6.1.6 Scrubber Water Treatment.....	56
6.1.7 Oversize Material Vitrification .....	57
6.1.8 Rinse Water Treatment .....	58
6.1.9 Optimum Water Content for Dredged Materials.....	58
6.1.10 Intellectual Property.....	59
<b>6.2 ENERGY BALANCE.....</b>	<b>59</b>
<b>6.3 PLANT CONFIGURATION .....</b>	<b>60</b>
<b>6.4 PRODUCTION REQUIREMENTS .....</b>	<b>61</b>
6.4.1 Site Requirements .....	61
6.4.2 Utility Requirements .....	61
6.4.3 Personnel Requirements.....	62
<b>6.5 ESTIMATED SEDIMENT PROCESSING COST .....</b>	<b>62</b>
<b>6.6 ENVIRONMENTAL, HEALTH, AND SAFETY IMPACTS.....</b>	<b>64</b>
6.6.1 Retention of Metals in Glass is a Waste Standard .....	64
6.6.2 Organic Destruction Has Been Extensively Verified.....	65
6.6.3 Fate of Sediment Contaminants .....	65
<b>7. PHASE II PILOT TESTS .....</b>	<b>68</b>
<b>7.1 DESCRIPTION OF PILOT TEST FACILITY .....</b>	<b>68</b>
7.1.1 Pilot Unit Throughput.....	69
7.1.2 Materials and Slurry Handling Capabilities .....	70
7.1.3 Plasma Melter Design .....	70
7.1.4 Plasma Torch Design .....	71
7.1.5 Offgas-Handling Capabilities .....	72
7.1.6 Sampling, Instrumentation, and Test-Monitoring Capabilities .....	73
7.1.7 Process Control Equipment .....	74
<b>7.2 PHASE II PILOT TEST PLANS .....</b>	<b>74</b>
<b>7.3 TECHNICAL APPROACH TO OPERATIONS.....</b>	<b>76</b>
7.3.1 Quality Assurance.....	76
7.3.2 Sample Acquisition and Handling .....	76
7.3.3 Site, Utility, and Personnel Requirements .....	76
7.3.4 Pilot Test Permitting .....	77
7.3.5 Pilot-Scale Test Waste Disposal .....	77
7.3.6 Site Security.....	78
7.3.7 Observation of Testing.....	78
<b>7.4 PILOT-SCALE TEST PROCEDURES .....</b>	<b>78</b>
7.4.1 Sediment Pretreatment.....	78
7.4.2 Vitrification Testing.....	79
7.4.3 Data Analysis.....	82
<b>7.5 PILOT TEST SCHEDULE AND DELIVERABLES .....</b>	<b>83</b>
<b>8. REFERENCES .....</b>	<b>84</b>
<b>APPENDIX A. CELS SEDIMENT ELEMENTAL ANALYSIS</b>	
<b>APPENDIX B. X-RAY DIFFRACTION ANALYSIS OF HARBOR SEDIMENT</b>	
<b>APPENDIX C. BNL SEDIMENT CONTAMINANT AND PARTICLE SIZE</b>	
<b>ANALYSIS</b>	
<b>APPENDIX D. BNL ANALYSIS OF VITRIFIED SEDIMENT PRODUCT</b>	
<b>APPENDIX E. TCLP TESTING OF GLASS PRODUCT</b>	

## ABSTRACT

Westinghouse Science and Technology Center successfully completed Phase I bench-scale testing of the integrated Plasma Vitrification process for converting contaminated New York/New Jersey Harbor sediment into useful and environmentally benign glass product. The Phase I Program demonstrated that:

- A glass product can be made from Newtown Creek sediments using a simple recipe including the addition of low-cost glassformers.
- The range of operating conditions for glass manufacture can be broad enough to accommodate variations in sediment feed that will likely occur.
- The glass product will retain metals in the matrix and not allow leaching of hazardous components into the environment.
- Organic destruction will be complete. Even though bench-scale tests did not subject the sediments to plasma melter temperatures, no detectable dioxins were measured in the product glass.
- The glass can be manufactured at reasonable operating temperatures, 1400°C, conditions that can be obtained in plasma vitrification systems at estimated costs of \$64 to \$84/ton.
- Glass products of composition and durability compatible to high-value products can be made, for example, rock wool valued at \$200/ton. This can offset treatment costs by up to \$60/ton.

Based on the Phase I results, a Phase II Pilot Test of the process is proposed.

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# 1. EXECUTIVE SUMMARY

The Westinghouse Science and Technology Center has successfully completed Phase I bench-scale testing of the integrated Plasma Vitrification process for converting contaminated New York/New Jersey Harbor sediment into useful and environmentally benign glass product. Phase I Bench-Scale Program objectives were to:

- Characterize the Newtown Creek sediment, determining its mineralogy, chemical, and physical properties.
- Identify an acceptable glass composition that can be made using the sediment as the primary feedstock.
- Produce a 5 kg of the product glass that successfully passes all leaching tests showing that the material is nonhazardous.
- Develop plans for proceeding with Phase II pilot tests of the integrated Plasma Vitrification Treatment Train.

Building on the results obtained in Phase I bench-scale tests, Westinghouse proposes to develop an integrated Plasma Vitrification Treatment Train to decontaminate New York/New Jersey Harbor sediments. The treatment train being developed is illustrated schematically in Figure 1.1.

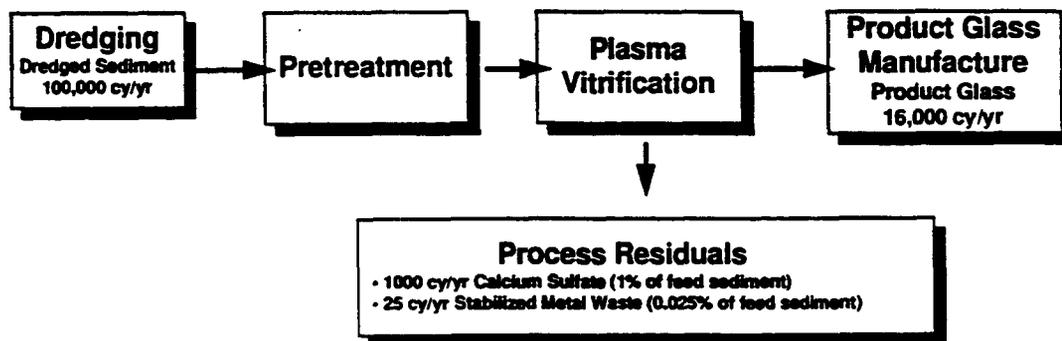


Figure 1.1 The Integrated Westinghouse Plasma Vitrification Treatment Train

The driving engine of Westinghouse's Treatment Train is the plasma melter. The sediments will be melted in the plasma melter using glassformers to produce a target glass product. The molten glass can be quenched to produce a glass aggregate or directly fed to glass manufacturing equipment to provide a salable commercial glass product. In the plasma melter, all organics are dissociated into elemental species which form clean gases that meet environmental release standards. Hazardous metals are incorporated in the product glass where they are environmentally benign. The dredged sediments can

be directly fed into the plasma melter, but the system will be designed to pretreat the sediments to optimize the integrated treatment train's economics and control the glass product quality. The integrated treatment train will be designed to minimize all process residuals, and ensure that they are environmentally benign.

## **1.1 PHASE I BENCH-SCALE PROGRAM HIGHLIGHTS**

The Phase I Bench Scale Program provides a convincing demonstration that high-value glass products can be manufactured using primarily Harbor sediment with low-cost glassformers. The Phase I Program demonstrated that:

- A glass product can be made from Newtown Creek sediments using a simple recipe including the addition of low-cost glassformers.
- The range of operating conditions for glass manufacture can be broad enough to accommodate variations in sediment feed that will likely occur.
- The glass product will retain metals in the matrix and not allow leaching of hazardous components into the environment.
- Organic destruction will be complete. Even though bench-scale tests did not subject the sediments to plasma melter temperatures, no detectable dioxins were measured in the product glass.
- The glass can be manufactured at reasonable operating temperatures, 1400°C, conditions that can be obtained in plasma vitrification systems at estimated costs of \$64 to \$84/ton.
- Glass products of composition and durability compatible to high-value products can be made, for example, rock wool valued at \$200/ton. This can offset treatment costs by up to \$60/ton.

The Phase I Bench Scale Program indicates that the Westinghouse Plasma Vitrification Process is a viable solution to the New York/New Jersey Harbor Sediment problem.

## **1.2 PHASE II PILOT TEST PROGRAM**

Building on the results of the Phase I bench-scale tests, a planned Phase II pilot-scale program will define an economic, integrated system design and validate the ability to produce glass using a plasma torch fired system at a scale that is representative of demonstration and commercial operations. Westinghouse will demonstrate the integrated plasma vitrification treatment train at the Westinghouse's Plasma Test Facility located at the Waltz Mill Site near Madison, Pennsylvania. The Phase II program will:

- Define the design base for the integrated Plasma Vitrification Treatment Train including a pretreatment system involving simple size segregation, desalinating, and dewatering, preprocessing steps that improve the integrated system economics and simplify the vitrification process.
- Demonstrate the integrated plasma process for glass making at a scale that can be used to develop demonstration and commercial design information.
- Determine the characteristics of all process streams to provide material balance information and allow all streams to be characterized, defining design specifications for auxiliary units.

The technical approach selected for Phase II Pilot Tests is described in detail in the Section 7. Phase II will demonstrate the key process elements of the integrated plasma vitrification process, process elements for which pilot testing of sediment is required to develop design information for a demonstration plant design. The Phase II tests will produce both a glass aggregate and cast glass product.

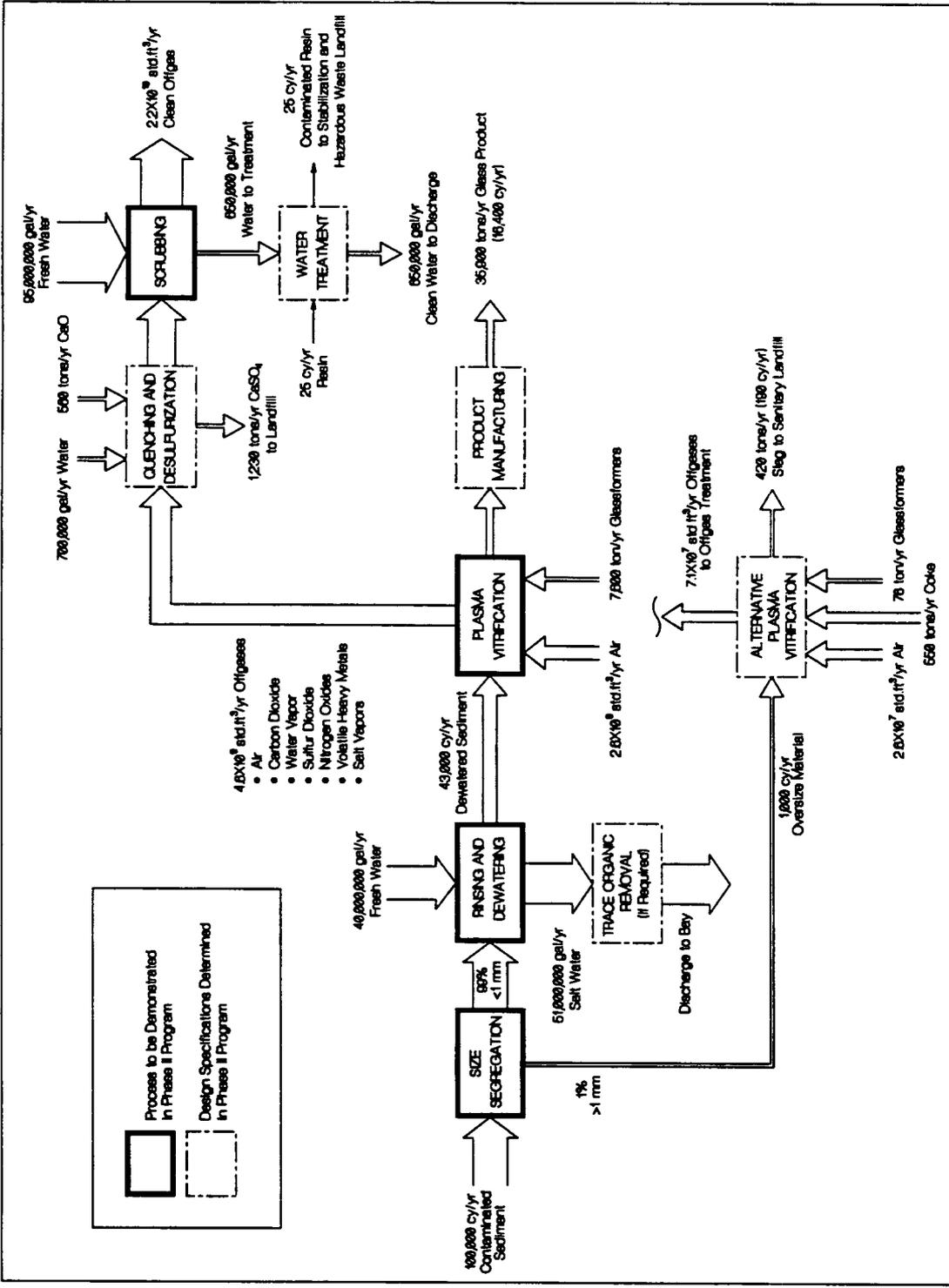
### 1.3 THE WESTINGHOUSE PLASMA VITRIFICATION SOLUTION

Westinghouse Science and Technology Center (WSTC) is developing an integrated process for converting contaminated Harbor sediments into useful glass materials using a Plasma Vitrification Process. The process is designed to economically provide a solution to Harbor sediment decontamination problems, eliminate the need for disposal or containment of dredged sediment, operate in an environmentally sound manner, and integrate municipal operations of dredging, decontamination, and production of materials for end use.

Figure 1.2 shows basic operations of the integrated plasma vitrification process. The central engine of the treatment train is the plasma melter. The other major components of the treatment train (i.e., sediment pretreatment, glass manufacture, and waste stream processing) need to be designed in synergy with the plasma melter in order to provide a cost effective solution that minimizes the production of any waste from the integrated Plasma Vitrification System.

The as-dredged sediment will be initially screened to remove large particles with minimal contamination, rinsed and partially dewatered to improve process economics, and then vitrified in the Plasma Melter to destroy the hazardous organics, and convert the contaminated fines to a low-leachability glass product suitable for reuse for construction aggregate, roofing granules, or glass fiber insulation material. Process offgases are treated with conventional gas cleaning technology (lime desulfurization and wet scrubbing) to remove contaminants before discharge. The major operations in the integrated system are:

- *Sediment Size Segregation:* The as-dredged sediment will be screened to remove large particles and debris. The oversized material, about 1 to 3% of the feed, is stored for batch vitrification into a low quality glass or slag. We recommend this disposal option since the material is oil coated. The remaining sediment is processed as follows.
- *Salt Rinsing and Dewatering:* Although the plasma melter could accept the sediment as is, process economics improve by desalinating and dewatering the sediment. Commercially proven sediment dewatering and rinsing operations will be specified and demonstrated in Phase II.
- *Plasma Vitrification:* The dewatered sediment is injected into the plasma melter, along with glassformers, to produce a molten glass stream and offgases.
- *Glass Product Manufacture:* The molten glass is feed directly into a glass manufacturing system, or quenched to produce a simple glass aggregate.
- *Gas Cleaning:* The gases are cleaned to remove entrained particulates, sulfur, and some trace metals that are too volatile to be captured in the molten glass. Clean gases are released to the atmosphere.



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Figure 1.2 The Westinghouse Plasma Vitrification Process Reduces the Volume of Processed Materials by a Factor of Six

- *Scrubber Water Treatment:* Water from the gas cleaning system is treated by commercial processes such as ion exchange to remove any metals before discharge. Mercury is the primary metal expected in the scrubber water.
- *Oversize Material Processing:* Oversized materials and debris from the feed sediment screening step can be plasma vitrified to produce a low grade glass or slag. To obtain the most controllable glass products we recommend not feeding oversized material with the bulk sediment.
- *Rinse Water Treatment:* Rinse water from the feed sediment desalination and dewatering step is not expected to require any treatment. If treatment is required to remove suspended solids or any organics, the steps will be defined after examining the water generated from the Pilot sediment pretreatment process.

### 1.3.1 Process Raw Materials

The process uses inexpensive, readily available glassformers, soda ash and lime, along with the feed sediment to make commercial glass products. The raw materials used in the integrated Plasma Vitrification treatment train are summarized in Table 1.1 Other raw materials consumed are water to rinse the sediment and scrub offgases, additional lime as a desulfurization agent, and a small amount (25 cy/year in a 100,000 cy/year sediment processing plant) of resin to remove any metals that are not encapsulated in the glass and report to the scrubber water. The plasma torch also uses air as the ionizing gas to produce the high temperature plasma.

**Table 1.1 Raw Material Used in the Integrated Plasma Vitrification Process**

Raw Materials	Flow for 100,000 cy/year plant
Feed Sediment	105,832 tons/yr
Lime	
• Dewatering Agent	999 tons/yr
• Glassformer	3,344 tons/yr
Soda Glassformer	3,505 tons/yr
Resin	25 cy/yr
Lime Desulfurizing Agent	500 tons/yr

### 1.3.2 Process Output Streams

The major stream leaving the process is the product glass.; the process achieves a volume reduction factor of glass relative to the original sediment of greater than six. Less than 1/60 of the original sediment feed result in solids that need to be land filled. A summary of all process streams leaving the integrated Plasma Vitrification System is given in Table 1.2. The process is environmentally sound, producing clean air and water discharges, non-contaminated calcium sulfate suitable for sanitary landfilling, and a small amount of stable slag.

There are a total of seven streams exiting the Westinghouse sediment vitrification process, as shown in Figure 1.2. Each of these streams and their environmental impact is discussed below.

**Table 1.2 Waste Minimization is Achieved with the Integrated Plasma Vitrification Process  
(Sediment Feed of 100,000 cy/year)**

<b>Output Streams:</b>	<b>Amount</b>	<b>Deposition</b>
Glass Product	36,664 tons/yr	Sell as commercial product
Calcium Sulfate	1,230 tons/yr (1% of sediment feed)	Nonhazardous Landfill
Oversized Material	373 tons/yr	Plasma vitrify in batches
Rinse Water	52.2 Mgal/yr	Clean water returned to Bay
Scrubber Water Bleed	0.65 Mgal/yr	Treat for removal of heavy metals; clean water discharged to the Bay
Contaminated Ion Exchange Resin	~25 cy/yr (0.025% of sediment feed)	Encapsulate and dispose of in hazardous waste landfill, or recover heavy metals
Clean Offgases	$1.73 \times 10^{10}$ std cu ft/yr	Discharge to stack

*Glass Product*

The glass itself is a useful product rather than a waste, and will be sold; the particular form of the final product will be determined by a market analysis. Since the potentially hazardous contaminated sediments are to be vitrified into a reusable product, the Westinghouse Plasma Vitrification Process alleviates the need for ocean dumping the processed material, eliminating a major public relations concern and possible environmental hazard. In addition, it eliminates the need for disposal in offshore mud dumps, space which is becoming limited. Conversion of contaminated sediments into a product avoids the environmental impact of opening further dumping grounds.

*Calcium Sulfate*

Sulfides, the largest contaminant in the feed sediment, will be converted quantitatively to SO<sub>x</sub> during the vitrification process. The sulfur oxides will then be cleaned from the offgas stream to produce an uncontaminated calcium sulfate waste stream. This waste will be generated in any thermal process (In thermal desorption systems, sulfur can be condensed for later incineration. The incinerator will then produce the calcium sulfate.). It is possible to dispose of the calcium sulfate as nonhazardous landfill material. The size of this stream is dependent on the amount of sulfur in the feed sediment. With high sulfur Newtown Creek sediment, the input sediment feed contains about 1% sulfur, a 100,000 cy/year plant will generate 1200 tons/year of calcium sulfate for disposal.

*Oversized Material*

Because this Newtown Creek sediment is oil soaked, we do not believe that water washing for disposal will be practical. For this reason, we recommend that the oversized material be plasma vitrified in a separate batch operation to produce a inert slag or lower quality glass.

*Rinse Water*

The rinse water from chloride removal and dewatering of the initial sediment is not expected to be contaminated, and will be discharged back to the Bay. If residual organic or particulate content is found in this water stream, it will be treated with commercial

processes before discharge. The Phase II pilot test will determine the rinse water's characteristics.

#### *Scrubber Water Bleed*

The scrubber water bleed will be treated by ion exchange to remove hazardous metals, and discharged as clean water.

#### *Ion Exchange Resin*

The scrubber bleed system from the plasma vitrification process will contain a small amount of volatile metals (particularly mercury) that are not encapsulated in the glass. The water will be treated to remove these trace metals, producing a small hazardous metal stream. Here again, any thermal process will result in this volatile metal carryover (primarily mercury) into the gas phase. Gas cleaning will result in a small hazardous metal stream.

The small quantity of volatile heavy metals which cannot be retained in a glass matrix (primarily Hg, but including lesser quantities of Cd, Pb, and Cr) will be removed in the scrubber bleed stream. This small but highly contaminated liquid stream will be treated by ion exchange using highly efficient chelated resins optimized for mercury removal. The heavy metal concentrates will eventually be disposed of in a hazardous waste landfill. The decontaminated water stream will be discharged to the Bay. The contaminated resin removed from the ion exchange system could either be (1) stabilized and disposed of as hazardous waste, or (2) a process could be developed for recovery and separation of the various heavy metals bound on the resins.

The exact amount of this stream will depend on the metal partitioning obtained in the plasma reactor. We estimate, based previously measured metal partitioning ratios obtained using different feed streams, that a stabilized hazardous resin stream equivalent to 0.025% of sediment feed (25 cy/year in a 100,000 cy/year plant) will result.

#### *Clean Offgases.*

The offgases leaving the plant will consist primarily of steam, air, and carbon dioxide. The scrubber system will have removed sulfur and nitrogen oxides, heavy metal vapors and salts, and entrained particulates; the bulk of the salts and particulates will be recycled to the melter and eventually incorporated in glass product. Sulfur in the sediment will report almost quantitatively to the CaSO<sub>4</sub> stream leaving the offgas desulfurizer.

## **1.4 PHASED APPROACH TO THE INTEGRATED TREATMENT TRAIN**

The information needed to design the integrated plasma vitrification process is being developed in several phases. The three major phases for developing the design information are the Phase I Bench-Scale Testing completed in the last quarter of 1995, the proposed Phase II Pilot Tests, and the Conceptual and Preliminary Design Phase that will follow the Phase II Pilot Program to develop specific designs for demonstration or production scale operations. Table 1.3 summarizes the design objectives for each processing unit in each of three phases of the treatment train development.

**Table 1.3 Westinghouse's Phased Approach to Design of an Integrated Treatment Train**

<b>Treatment Unit</b>	<b>Objectives</b>
<b>PHASE I BENCH-SCALE TESTS</b>	
Plasma Melter	<ul style="list-style-type: none"> <li>• Characterize sediment</li> <li>• Define a glass melt recipe</li> <li>• Demonstrate ability to make target glass</li> <li>• Demonstrate that glass is nonleachable</li> </ul>
Sediment Pretreatment	<ul style="list-style-type: none"> <li>• Pretreat sediment to supply feed for melting</li> <li>• Confirm that chlorine is readable rinsed from sediment</li> <li>• No testing to define pretreatment equipment</li> </ul>
<b>PHASE II PILOT TESTS</b>	
Size Segregation	Demonstrate with pilot/commercial equipment
Sediment Rinsing and Dewatering	<ul style="list-style-type: none"> <li>• Define specific process design</li> <li>• Select dewatering technique (centrifugation, filtration)</li> <li>• Determine what additives will be used, if any (lime, polymers)</li> <li>• Define performance obtainable</li> <li>• Demonstrate with pilot equipment</li> <li>• Determine rinse water characteristics and treatment requirements, if any</li> </ul>
Plasma Melter	<ul style="list-style-type: none"> <li>• Determine metal partitioning</li> <li>• Demonstrate organic dissociation</li> <li>• Define plasma melter design (feedrate, torch power, residence time,)</li> <li>• Establish melter performance as a function of feed water content</li> <li>• Demonstrate with pilot scale, scaleable equipment</li> <li>• Determine scrubber water characteristics and treatment requirements, if any</li> </ul>
Gas Scrubbing	<ul style="list-style-type: none"> <li>• Meet pilot emission standards</li> <li>• Capture metals to define metals carryover</li> </ul>
Glass Manufacture	Demonstrate composition of a viable commercial product
Integrated System Issues	<ul style="list-style-type: none"> <li>• Define optimum feed moisture content</li> <li>• Define optimum recycle rate of water quench stream</li> <li>• Produce flow diagram including recommended equipment for integrated system</li> </ul>
<b>CONCEPTUAL/PRELIMINARY DESIGN PHASE</b>	
Integrated System	Perform design study to identify plant goals (capacity, load follow)
Offgas Desulfurization	Design desulfurization system
Offgas Cleaning	Design gas cleaning system, scrubber
Scrubber Water Treatment	Design scrubber water treatment system
Rinse Water Treatment	Design rinse water treatment system ( if needed)
Glass Manufacture	Identify glass product; Test and design manufacturing

In Phase I Bench-Scale Program, tests were designed to provide the feasibility testing needed to determine that a glass product could be made using the sediment as a feed-stock. Sediment characteristics of importance to the process development were determined. Phase I testing was designed to test the possible glass compositions obtainable on a bulk level. The Phase I bench scale tests did not, however, use a plasma torch to ensure dissociation of organics.

The Phase II Pilot Test Program will demonstrate the formulation of this glass product in a pilot plasma unit that is readily scaleable to demonstration and commercial scales. Those operations deemed essential to test in the Phase II pilot program are indicated in bold in the process flow schematic presented in Figure 1.2. The remaining treatment train items are either commercially available to be specified without pilot testing or they require samples from the pilot tests to define their design requirements. The Phase II pilot test program will provide the information needed to set design parameters on the auxiliary operations in the treatment train, the pretreatment and gas cleaning system. The complete treatment train design basis will be defined from the Pilot Tests. Several components of the treatment train are commercially available. The specification of some of the auxiliary components, however, will not be complete until pilot tests provide some of the test data on input stream characteristics. Once specified input streams are identified, the treatment units can be designed and quotes obtained by commercial vendors. Any difficulties in the auxiliary designs will also be determined, once the stream data is obtained from the Phase II pilot tests.

If we proceed to provide conceptual and preliminary plant designs for demonstration and production-scale operations, Westinghouse will specify auxiliary design specifications based on the results of the Phase II program, and obtain vendor designs and quotes on auxiliary equipment.

## **1.5 REPORT ORGANIZATION**

This report is organized to provide all the information specified in the Bench-Scale Test Plan. As an aide to the reader, the following compliance matrix is supplied, indexing each item requested by BNL to its location in the report.

Section 2 summarizes Phase I conclusions and recommendations.

Section 3 presents the sediment characterization work performed. Section 4 describes the bench-scale testing performed to select a glass recipe for production tests. The batch production tests are then described in Section 5.

In order to relate the bench-scale test results to the overall process Treatment Train demonstration, Section 6 provides a comprehensive description of technical approach Westinghouse is taking to sediment decontamination. Section 7 then provides the requested update on the Phase II Pilot Test Program planned.

**Table 1.4 Report Compliance Matrix**

<b>Information Requested by BNL</b>	<b>Report Section</b>
1. Bench Scale Work • Procedures • Results	3. Sediment Characterization 4. Bench-Scale Testing 5. Bench-Scale Glass Production
2. Potential for Pilot Operations • Scale Up Plans	7. Phase II Pilot Tests 6. The Plasma Vitrification Treatment Train 6.1 Detailed Process Description/Material Balances 6.2 Energy Balance 6.3 Plant Configuration
• Pilot-Scale Processing Rates	7.1.1. Pilot Unit Throughput
• Pilot-Scale Resources Needed	7.3.3. Site, Utility, and Personnel Requirements
• Environmental Impact of Scale Up	6.6 Environmental, Health, and Safety Impact
• Licensing, royalties, etc.	6.1.10 Intellectual Property
• End products management	7.3.5 Pilot Test Waste Disposal 1.3.3 Process Output Streams
• Pretreatment Recommendations	7.4.1 Sediment Pretreatment 6.1.1 Sediment Size Segregation 6.1.2 Salt Rinsing and Dewatering
• Updated Costs for Pilot Unit	Phase II Cost Proposal
• Pilot-Scale System Plans	7. Phase II Pilot Tests

## 2. CONCLUSIONS AND RECOMMENDATIONS

The Phase I Program — Technology Evaluation and Bench-Scale Testing successfully achieved its objectives:

**Objective 1: Sediment Characterization** The Newtown Creek Harbor sediments were successfully characterized in terms of mineral composition, moisture content, and organic and sulfur content, allowing development of a process description and product formulation to successfully decontaminate the sediment and convert it to a useful glass product material.

- As-dredged Newtown Creek Harbor sediment consists of approximately 66% moisture and 34% solids, with a density of  $1.2 \text{ gm/cm}^3$ . The solids are predominately of small particle size (97% less than 2 mm), with the great bulk consisting of silts and clay with particle sizes below  $50 \mu\text{m}$ . This small "native" particle size lends itself readily to plasma vitrification using direct injection of the sediment-glassformer slurry into the plume of the plasma torch.
- The composition of the sediment solids consists of two phases. The mineral phase, comprising 90% of dry solids, is composed of silicate minerals including quartz, mica, aluminum silicates, and complex iron silicates. The remaining 10% of the dry solids consists of an organic phase, presumably a mixture of petroleum hydrocarbon materials and sewage overflow, which also contains significant concentrations of sulfur.
- The high organic content of the sediment provides a substantial heating value on the order of  $1.5 \text{ MJ/kg}$  of as-dredged sediment, for which credit may be taken in the overall energy balance of the vitrification process.

**Objective 2: Product Applications** A range of product compositions was defined based on the sediment analyses whereby readily processable glass may be economically produced from the sediment which (1) uses only low cost glassforming fluxes and high sediment loading, and (2) will be sufficiently flexible to permit decontamination of sediments having a wide range of compositions.

- Detailed elemental analysis of the rinsed solids reveals a mineral composition consisting of roughly 65%  $\text{SiO}_2$ , 14%  $\text{Al}_2\text{O}_3$ , and 8%  $\text{Fe}_2\text{O}_3$ , with the balance comprised of oxides of K, Na, Ca, Mg, Ti, Cu, and Zn. This composition lends itself readily to formulation of a soda-lime-silica glass with reasonably low melting point ( $\sim 1400^\circ\text{C}$ ), high sediment loading (75 to 85%), and inexpensive glassforming fluxes (lime or limestone plus soda ash).
- Well-established models for glass and slag viscosity as a function of composition and temperature have been used to predict a range of vitrified product composi-

tions (sediment plus glassformer additives) which can be readily processed in a plasma melter, and use only these limestone and soda ash fluxing agents.

- The reference glass composition produced in Phase I provides a sediment loading of 83.2%, and uses CaO and Na<sub>2</sub>O glassformers in a 2:1 ratio, with both species provided as carbonates. This formulation is predicted to exhibit a 200 Poise viscosity typical of commercial glass melting pour viscosities at a temperature of 1370°C, within the range of optimal operating temperatures established in the Test Plan.

**Objective 3: Bench-Scale Production** Melt tests yielded in excess of eleven kilograms of vitrified glass product from Harbor sediment, having good homogeneity, low leachability, and good processing characteristics for a variety of potential commercial products.

- Small crucible batches and coupon melts of the various glass compositions predicted from viscosity and phase diagram considerations confirm that the reference glass formulation is easily vitrified from Harbor sediment and glassformer powder, producing a very dark green-gold glass with good pour properties at 1400°C.
- Samples of this glass have been quenched directly into water, forming granulated aggregate material, glass “wire”, and flake glass. Glass fibers formed are very strong, indicating that the reference composition should be readily formed into fibrous products such as rock wool.

**Objective 4: Process Basis Update** Information from the Phase I Bench Tests was used to update the plans for Phase II Pilot Scale Testing, including estimates of the processing cost per ton of sediment. None of the results obtained during Phase I testing were at variance with the predictions made prior to the testing. The glassformer composition, process operating temperatures, overall sediment loading, and product quality were all close to what was anticipated based on prior Westinghouse vitrification experience. Those parameters which have been identified as a result of Phase I testing and engineering design are refinements to the original concept, and have resulted in a reduced overall processing cost prediction and a high degree of confidence.

Westinghouse is ready to take the plasma vitrification process forward through the Phase II pilot tests to demonstration and full-scale operation. In summary, the Westinghouse Plasma Vitrification Process will be designed to:

- Provide an economically feasible solution to the Harbor sediment decontamination problem.
- Convert the sediment waste into a useful material for the Harbor Area (e.g., construction aggregate, roofing granules, or glass fiber products such as rock wool insulation).

- Eliminate the need for Harbor disposal or containment of any dredged waste that the system processes.
- Operate using proven technology that produces no negative environmental impact on the Harbor area.
- Process all existing contaminants in the Harbor sediments.
- Integrate operations of dredging, sediment pretreatment, decontamination, and production of materials for local use.
- Produce no waste streams that transfer the contamination problem to another source.

Detailed plans for Phase II are presented in Section 7. Revised Phase II program cost estimates are provided in a separate proposal document. The Phase II Pilot Program will demonstrate the critical elements of this Plasma Vitrification Treatment Train and provide the design basis needed in order to proceed with a conceptual and preliminary integrated treatment train design.

### 3. SEDIMENT CHARACTERIZATION

Sediment characterization was performed in order to determine glass formulation options and define sediment processing characteristics for the integrated plasma vitrification system. This section describes the sediment characterization work performed. General sediment characteristics such as appearance, density, organic content, heating value and settling rate are presented in Section 3.1. Sediment morphology as determined by SEM imaging is presented in Section 3.2. Section 3.3 provides detailed elemental analysis of the sediment as reported by Corning Engineering Laboratory Services (CELS). The mineralogical analysis of the sediment is discussed in Section 3.4, as determined by XRD analysis at Westinghouse Science and Technology Center. Section 3.5 presents results of detailed contaminant analysis for organics and heavy metals provided by Brookhaven National Laboratory. Microbiological analysis performed is summarized in Section 3.6. Finally, Section 3.7 reports results of thermal gravimetric analysis (TGA) and differential thermal analysis (DTA), mapping phase changes and chemical reactions occurring in the sediment during heating.

#### 3.1 GENERAL SEDIMENT CHARACTERISTICS

Brookhaven supplied WSTC with 70.2 kg of as-dredged Harbor sediment, roughly 20 gallons in four containers. Upon opening, this material was found to be jet-black and viscous, with a strong creosote-like odor. After drying, the material exhibited a gray-black color, but still retained a strong organic odor which was now more characteristic of sewage.

General physical and chemical properties of the sediment measured are presented in Table 3.1. Note that the sediment contains a significant hydrocarbon content and heating value. The plasma vitrification process will use this heating value as an net energy source.

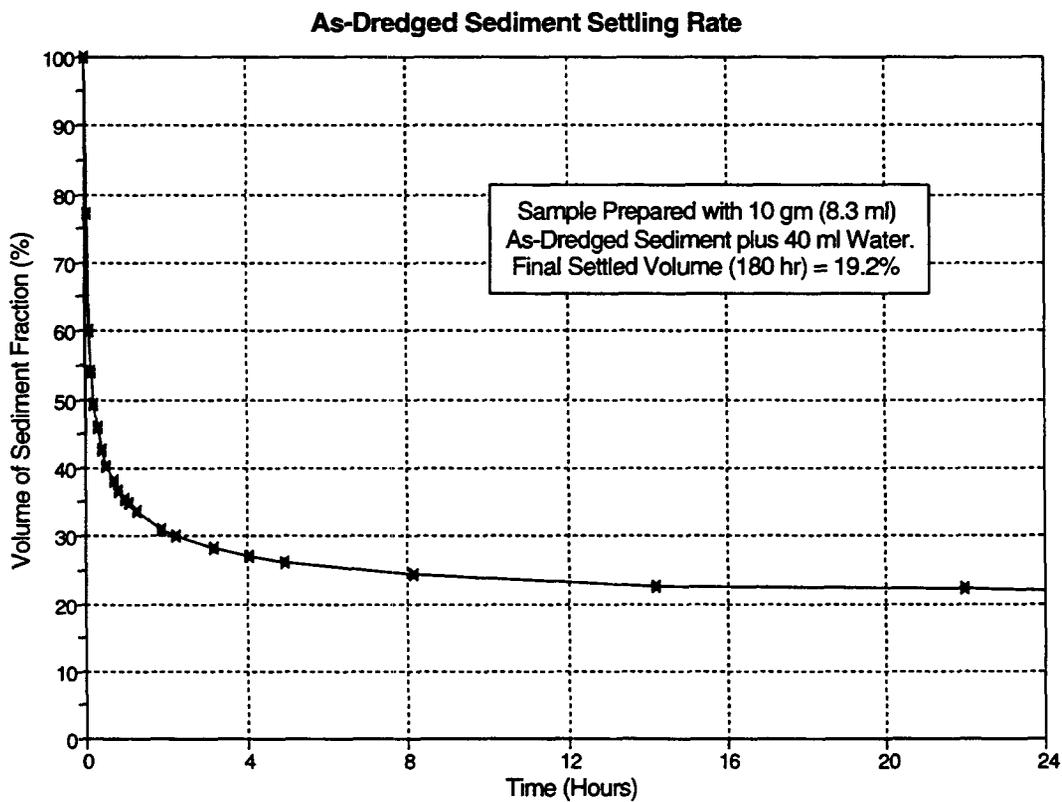
**Table 3.1 General Sediment Properties**

Property	Measured Value
<b>As-Dredged Sediment:</b>	
Density	1.206 gm/cm <sup>3</sup>
Viscosity	38,000 cp
Moisture Content	66 % weight
Hydrocarbon Content	2.88 to 3.50 wt. % C <sub>n</sub> H <sub>2n+2</sub>
Heating Value	1.26 to 1.52 MJ/kg
<b>Dry Rinsed Sediment:</b>	
Hydrocarbon Content	8.47 to 10.3 wt. % C <sub>n</sub> H <sub>2n+2</sub>
Heating Value	3.71 to 4.47 MJ/kg

Because of the large unreported organic fraction in the sediment, a sample was sent to Antech Laboratories for oil and grease analysis. The dry screened solids were reported to contain 2.3% oil and grease, and exhibit a heating value of 1600 Btu/lb. The organic content of 2.3% is a factor of four below the value of 10.3% based on the TOC. It is be-

lieved that the oil and grease analysis is, in fact, in error. Note that dry sediment containing 10.3% fuel oil would have a heating value of  $(18,750 \text{ Btu/lb oil})(0.103 \text{ lb oil/lb sediment}) = 1930 \text{ Btu/lb}$  ( $4.48 \text{ MJ/kg}$ ), in reasonably good agreement with the measured Antech value of  $1600 \text{ Btu/lb}$  ( $3.71 \text{ MJ/kg}$ ). Use of the BNL value for TOC (7.3%) rather than the CELS value (8.9%) would reduce the anticipated heating value to  $(1930 \times 7.3/8.9) = 1580 \text{ Btu/lb}$  ( $3.66 \text{ MJ/kg}$ ), in very close agreement with the Antech thermal analysis.

The nominal settling rate of the sediment was also measured. Ten grams of as-dredged sediment was blended with 40 ml of water and vigorously agitated to produce a uniform slurry. This was then poured into a graduated cylinder, and the position of the sediment-supernate interface monitored with time. The results are plotted in Figure 3.1. It is seen that the sediment settles readily without need for any flocculating agent. The final settled volume after 180 hours is 19.2%, in good agreement with the initial mixture containing a calculated theoretical 17% volume of sediment. Allowing the slurry to settle for 24 hours would give settling to 22%, allowing 78% of the volume to be decanted off and yielding about 81% chloride removal efficiency per rinse.



**Figure 3.1 - Settling Rate of As-Dredged Sediment in Fresh Water**

### 3.2 SEDIMENT MORPHOLOGY

During the course of the EDS analysis, electron micrographs were also taken of the sediment, both before and after the drying-rinsing processes. Presumably, if the drying process had resulted in some degree of low-temperature sintering responsible for the difference in filtration behavior, this would appear in the SEM images. Micrographs of the powder before and after rinsing are presented in Figures 3.2 and 3.3, respectively. Although the appearance of the two images are somewhat different, there is no obvious agglomeration present in the post-rinse material. The "native" particle size in both cases appears to be roughly 1 to 10  $\mu\text{m}$ , consistent with the particle size analysis.

### 3.3 ELEMENTAL ANALYSIS

Given the semiquantitative nature of EDS analysis, a sample of the dry rinsed sediment was sent to Corning Engineering Services Laboratory (CELS) for detailed elemental analysis. Sediment samples were chemical solubilized, and then analyzed by a variety of techniques including flame emission spectroscopy, plasma emission spectroscopy, and titrimetry. Results of the complete CELS analysis are provided as Appendix A, reported variously as weight percent metals and metal oxides. Table 3.2 presents these same analyses converted to both elemental weight and atom percents; results of the WSTC semiquantitative energy dispersive spectroscopy for the same material are also shown for comparison. Note that the oxygen data from the CELS are back-calculated from the equivalent oxygen associated with each of the reported metal oxides.

**Table 3.2 - Elemental Analyses of Dry Rinsed Solids**

Element	Corning Analysis (NYBASE 1-1)		WSTC EDS Analysis (NYBASE 1-1)	
	Weight Fraction	Atom Fraction	Weight Fraction	Atom Fraction
Oxygen	39.54 <sup>a</sup>	40.95 <sup>a</sup>	49.68	58.91
Silicon	24.97	31.50	20.71	13.99
Carbon	8.90	12.29	10.36	16.36
Aluminum	5.72	6.64	5.53	3.89
Iron	4.56	1.94	5.03	1.71
Chlorine	0.74	0.57	0.79	0.42
Sodium	1.28	0.77	1.30	1.07
Potassium	1.68	0.86	2.06	1.00
Sulfur	N/A	N/A	1.81	1.07
Calcium	1.38	0.79	1.20	0.57
Magnesium	1.27	1.43	1.07	0.83
Titanium	~0.50	~0.10	0.48	0.19
Copper	~0.20	~0.05	N/A	N/A
Zinc	~0.20	~0.05	N/A	N/A
Total	92.67	100.00 <sup>b</sup>	100.00 <sup>b</sup>	100.00 <sup>b</sup>

a. Oxygen associated with metal oxides only.

b. Arbitrarily normalized to 100%.

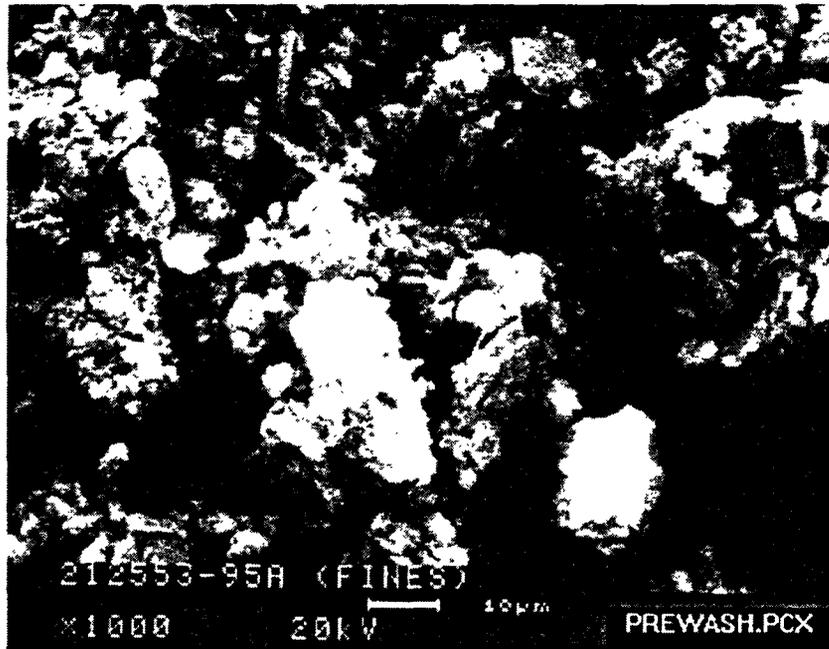


Figure 3.2 Electron Micrograph of As-Received Sediment

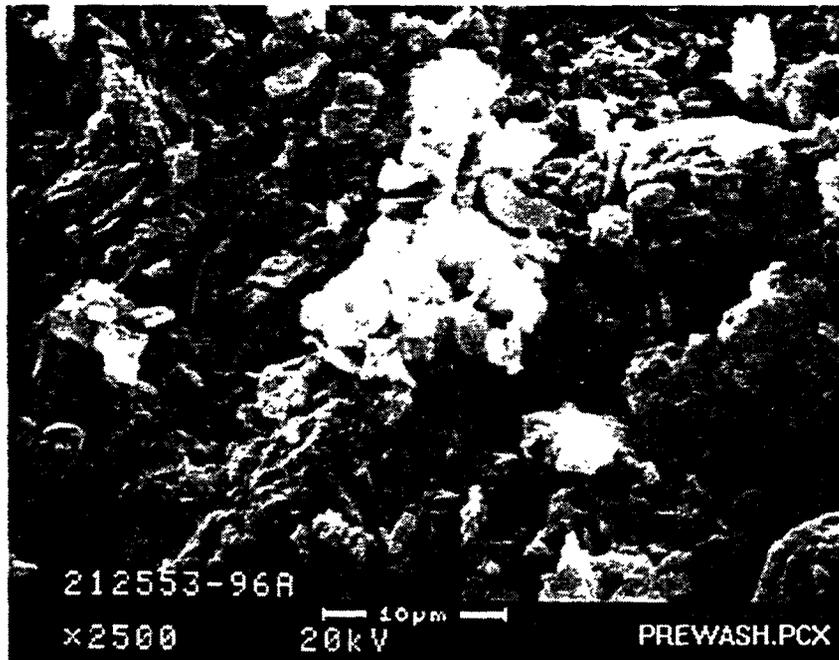
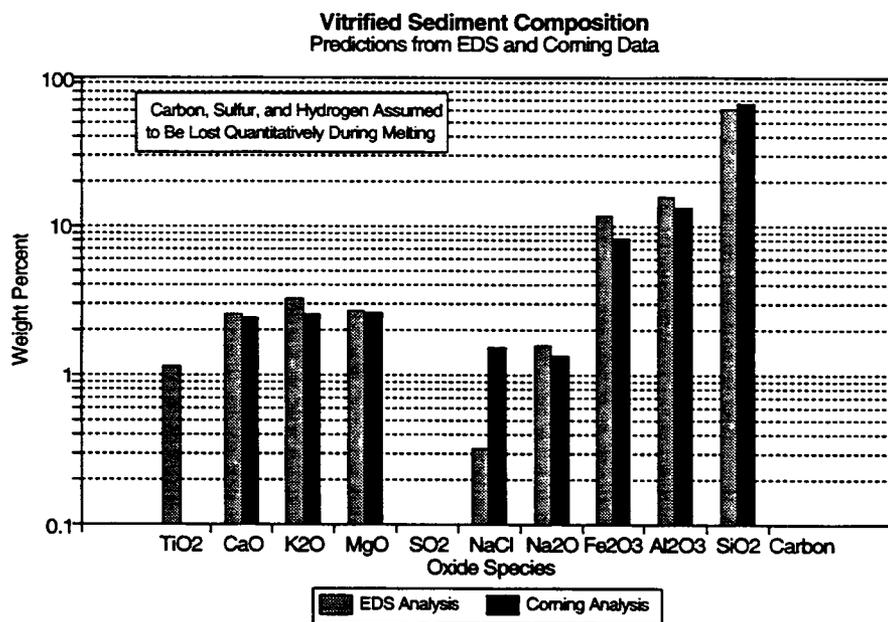


Figure 3.3 Electron Micrograph of Dried and Rinsed Sediment

Most of the elements with the exception of silicon, oxygen, and carbon show very good agreement between the CELS and the EDS analyses, confirming the quality of the data used to determine the rinsing efficiencies; comparison of the two is shown graphically in Figure 3.4 on a metal oxide basis. Silicon is notoriously difficult to analyze accurately in a glass or mineral matrix, although plus-or-minus a few percent Si is not expected to have any significant impact on the properties of the vitrified glass product. It is also notable that the CELS analysis does not sum to 100%; discussions with both the laboratory and with Ferro indicate that an analysis of this type summing to only 93% is not unusual for glass and mineral matrices, but that there is not simple rule of thumb to determine the nature of the missing 7%. The discrepancy in the oxygen analysis is of less concern, since CELS did not analyze specifically for oxygen; the data in the table are derived from consideration of the stoichiometric oxygen expected with each of the metals.



**Figure 3.4 Comparison of Elemental Analysis and Semiquantitative EDS**

The carbon analyses also differ by several percent. Analysis of carbon by EDS is often difficult, since powder samples are typically cemented down with carbon paint. *No carbon paint was used in the WSTC analyses, however, specifically for this reason.* Once again, the carbon content will not impact the final glass composition significantly, since all organic and inorganic carbon will be fully decomposed in the plasma plume.

Note that the CELS copper, zinc, and titanium analyses are semiquantitative. Copper and zinc were reported to be present at 0.1 to 0.3 weight percent (as metals), consistent with the Brookhaven analyses of 0.17 and 0.12 percent, respectively (see Section 3.5). Titanium, unlike Cu and Zn, was identified in the EDS analysis at 0.48%; the CELS analysis confirms the presence of Ti at between 0.3 and 1.0%.

Final determination of the glass formulation was based on the CELS analysis shown in Table 3.2, with the exception of sulfur which is taken from the Westinghouse EDS results.

### 3.4 MINERALOGICAL ANALYSIS

In addition to the elemental analysis, X-ray diffraction analysis (XRD) was also carried out at WSTC on the sample to determine the mineralogy of the sediment solids. The XRD summary report is attached as Appendix B. Table 3.3 presents a summary of the XRD analyses, with semiquantitative estimates of the weight fraction of each phase. Five mineral species are identified, with quartz being the dominant phase (66 to 75 weight percent). An additional 11 to 15% consists of a potassium-aluminum silicate phase, which is difficult to positively match, but is probably a muscovite mica species. The formula presented in the table represents the common muscovite species known as *magnesian*, represented as  $\text{KMgAlSi}_4\text{O}_{10}(\text{OH})_2$ , while the actual sediment species may be more generally written as  $(\text{K,Ca,Na})(\text{Al,Mg,Fe})_2(\text{Si,Al})_4\text{O}_{10}(\text{OH})_2$ ; these minerals are widely distributed in the New York/New England area.<sup>1</sup>

Table 3.3 - Sediment Mineralogy by X-Ray Diffraction Analysis

Mineral Species	Chemical Formula	Weight Percent
Quartz	$\text{SiO}_2$	66 to 75
Muscovite (Mica)	$\text{K}_2\text{O} \cdot 2\text{MgO} \cdot \text{Al}_2\text{O}_3 \cdot 8\text{SiO}_2 \cdot 2\text{H}_2\text{O}$	11 to 15
Amorphous Phase	Organics	3 to 13
Kyanite	$\text{Al}_2\text{O}_3 \cdot \text{SiO}_2$	6 to 7
Hydrated Aluminum Silicate	$19\text{Al}_2\text{O}_3 \cdot 173\text{SiO}_2 \cdot 9\text{H}_2\text{O}$	5 to 6
Cronstedtite	$4\text{FeO} \cdot 2\text{Fe}_2\text{O}_3 \cdot 3\text{SiO}_2 \cdot 2\text{H}_2\text{O}$	4 to 6

*Kyanite* (aluminum silicate) is also found at levels of 6 to 7 percent, one of the three trimorphous forms of  $\text{Al}_2\text{SiO}_5$ ; this species is also found in the New England area. This mineral is known to decompose above  $1200^\circ\text{C}$  to mullite ( $3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$ ) plus silica. A hydrated aluminum silicate of complex formula is identified as well at 5 to 6 weight percent, but does not have any simple mineralogical identification. Finally, a mixed-valence iron silicate known as *cronstedtite* is present at 4 to 6 percent. This dark green to black species is closely related to micas, and is commonly found in association with them, and probably represents the bulk of the iron present in the sediment. High-temperature oxidation may convert the ferrous iron ( $\text{FeO}$ ) to ferric iron ( $\text{Fe}_2\text{O}_3$ ), with a resulting phase and color change. An unidentified amorphous phase is also present in the XRD spectra at between 3 and 13 weight percent. Thus is undoubtedly the organic phase of the sediment, composed of hydrocarbons and sulfur-containing species.

Figure 3.5 presents a comparison of metal oxide composition from the EDS and XRD analyses. It is seen that substantial discrepancies exist between the two, emphasizing the fact that the XRD is semiquantitative at best. The XRD does identify several features of the composition that would not otherwise be available, however, notably the presence of two valence state of iron, a major phase transition occurring at 1200°C (the kyanite-mullite transition), and the presence of several hydrated minerals the decomposition of which will represent an endothermic reaction at elevated temperature.

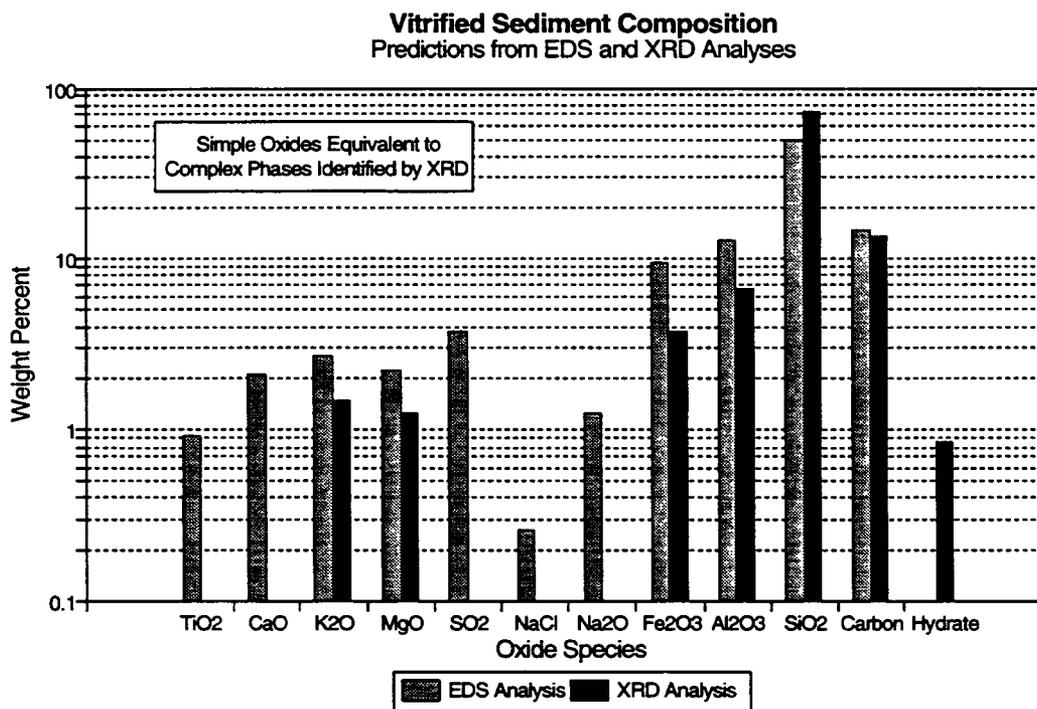


Figure 3.5 - Comparing Sediment Composition by XRD and EDS Analyses

### 3.5 CONTAMINANT ANALYSIS

Brookhaven has provided detailed contaminant analysis of the Newtown Creek sediment, as shown in Appendix C. Organic contaminant analysis is summarized in Table 3.4. Since it is anticipated that the intense heat of the plasma torch will fully destroy all of the various chlorinated biphenyls (PCB's) polyaromatic hydrocarbons (PAH's), dioxins, furans, pesticides, as well as aliphatic hydrocarbons, the discussion of these analyses will be limited here.

BNL analysis for total organic carbon (TOC) is roughly 7.32% on a dry basis, while the CELS analysis of the dry rinsed sediment indicates 8.9% total carbon. Although not identified in the XRD, this suggests that some inorganic carbon may be present in the sediment in the form of carbonates. Organic carbon associated with the various PCB's, pesticides, PAH's, dioxins, and furans only sum to 0.01% of the total organic carbon in

the sediment. The other 99.99% of the TOC is present as other organic species, most likely spilled marine fuel oil (judging from the odor and physical appearance of the as-dredged sediment). As discussed in Section 3.1, this carbon content would correspond to between 8.5 and 10.3% hydrocarbon on a dry solids basis, depending on which carbon analysis is used.

**Table 3.4 - Organic Contaminant Analysis of As-Dredged Sediment**

Analysis	Weight Fraction (Dry Basis)
Total Sulfides	$7.83 \times 10^{-3}$
Total Organic Carbon (TOC)	$7.32 \times 10^{-2}$
Total Polychlorinated Biphenyls (PCB)	$5.26 \times 10^{-6}$
Total Chlorinated Pesticides	$4.62 \times 10^{-7}$
Total Polyaromatic Hydrocarbons (PAH)	$1.17 \times 10^{-4}$
<i>bis</i> -2-ethylhexylphthalate	$4.86 \times 10^{-5}$
Fluoranthene	$1.03 \times 10^{-5}$
Phenanthrene	$0.65 \times 10^{-5}$
Others (24 analyzed over detection limit)	$5.16 \times 10^{-5}$
Total Dioxins	$6.45 \times 10^{-9}$
Total Furans	$1.65 \times 10^{-8}$

The analysis also indicates 7800 ppm of sulfide. The nature of the Harbor sediment sulfur content is somewhat speculative. Using the concentration expressed as a weight fraction of apparent hydrocarbon would yield a fuel oil sulfur content of 7.6%. This is very high for either a bunker fuel oil or crude petroleum; typical Bunker C sulfur contents range from 1% to a maximum of about 4%, while high-sulfur Venezuelan crude is rarely greater than 3%.<sup>3</sup> A total sulfur analysis of 0.78% (BNL) is, in fact, less by a factor of two as compared to either the CELS analysis (1.72%) or the Westinghouse EDS analysis (1.81%). Some of the additional total sulfur may be present as sulfate (present in seawater), although  $\text{Na}_2\text{SO}_4$  is water soluble and should have been largely removed by the rinsing process. Additional sulfide may arise from sewage outfall.

The BNL metals analyses are shown in Table 3.5. As indicated above, the analyses for Zn and Cu agree with those reported by CELS. Chromium and nickel at 300-400 ppm should be readily incorporated into the glass matrix along with the zinc and copper. Mercury will not be encapsulated in the glass matrix due to its high volatility, and will be recovered in the offgas system; collection of this quantity of Hg will be accounted for in the design of both pilot and production scale systems. Of the remaining metals present at significant quantities (Pb, Ag, As, Cd, and Sb), antimony and lead are quite soluble in glass and should be readily captured. Arsenic and cadmium both exhibit significant volatility, but also good glass solubility; the capture efficiency of these two species cannot be readily predicted. Some As and Cd are expected in the offgas scrubbing system, and will be dealt with accordingly.

**Table 3.5 - Trace Metals Analysis of Harbor Sediment (BNL)**

Metal	Concentration (mg/kg)
Ag	18.42 ± 0.72
As	33.48 ± 2.69
Be <sup>a</sup>	<0.56 ± 0.02
Cd	37.05 ± 1.44
Cr	367.67 ± 16.02
Cu	1171.67 ± 41.60
Hg	1.29 ± 0.06
Ni	297.17 ± 32.79
Pb	617.00 ± 37.39
Sb	10.29 ± 1.38
Se <sup>a</sup>	<3.24 ± 0.81
Tl <sup>a</sup>	<2.77 ± 0.09
Zn	1725.00 ± 81.80

a. Below detection limit.

### 3.6 MICROBIOLOGICAL ANALYSIS

Because of the high probability of the presence of sewage in the sediment, a sample was subjected to microbiological analysis to determine the presence of viable pathogens. No viable organisms of concern (*pseudomonas*, *fecal coliform*, *streptococcus*, *clostridium*, *salmonella*, or *enterobacter* Ac.) were observed above the detection limits. Total facultative anaerobes were found to be present at 34,000/gm, which is a count typical of normal soil and is actually low for marine sediment containing sewage treatment outflow; this suggests that other sediment components such as hydrocarbons may represent toxins to anaerobic bacteria.

### 3.7 THERMAL ANALYSES

The Harbor sediment samples were subjected to three thermal analyses. Thermal gravimetric analysis (TGA) was carried out at WSTC to observe the loss in weight of the sample during heating in helium as a function of time and temperature, tracking the processes of drying and volatile species evaporation. The offgases from the TGA test were also analyzed by mass spectrometry to identify the volatile components. The differential thermal analysis (DTA) follows internal temperature changes in the sample as it is heated in air, monitoring endothermic and exothermic chemical reactions and phase changes in the sediment; this analysis was done by Harrop Industries. Finally, a heating value analysis of the dry sediment was done by Antech Laboratories.

#### 3.7.1 Thermal Gravimetric Analysis

The results of the TGA study are shown in Figure 3.6. Both the sample weight (relative to its initial weight of 100%) and the temperature are recorded as a function of time. Initial loss of moisture is seen over 45 minutes, following a programmed heatup of the sample to 150°C over 25 minutes. After 50 minutes, no further loss in weight is ob-

served, with a final weight loss of 68.5%. Note that this is somewhat greater than the 66.0% loss in weight upon drying at 105°C. The discrepancy is believed to be the result of additional loss of volatile organic material at the higher TGA temperature. A variety of aliphatic hydrocarbon peaks are observed in the mass spectrometer during this initial heatup, with molecular weights ranging from 126 to as high as 490. (It is difficult to understand these very high molecular weight species being volatile; the 19-carbon trace species identified in the rinse water only exhibits a molecular weight of 268). Some carbon dioxide is also observed during water loss, although this too is difficult to understand. No oxidation can be occurring in helium, and the temperature is too low for carbonate decomposition; decomposition of organic alcohols or acids may be the source of CO<sub>2</sub>.

As the temperature is elevated further, a small amount of ammonia is observed, along with organic esters. The final weight loss after heating to 600°C is 71.7%, equivalent to 66.0% drying plus an additional 5.7%; the additional loss represents 8.6% of the weight of the dried material. The TGA process, carried out in helium, allows for pyrolysis of organic species but not oxidation. In the absence of oxygen a process similar to the production of coke takes place, releasing a variety of volatile species (the 8.6% weight loss) but leaving carbon behind. In air, the carbon is allowed to oxidize to CO<sub>2</sub>, and provide for an additional weight loss of the dry sediment.

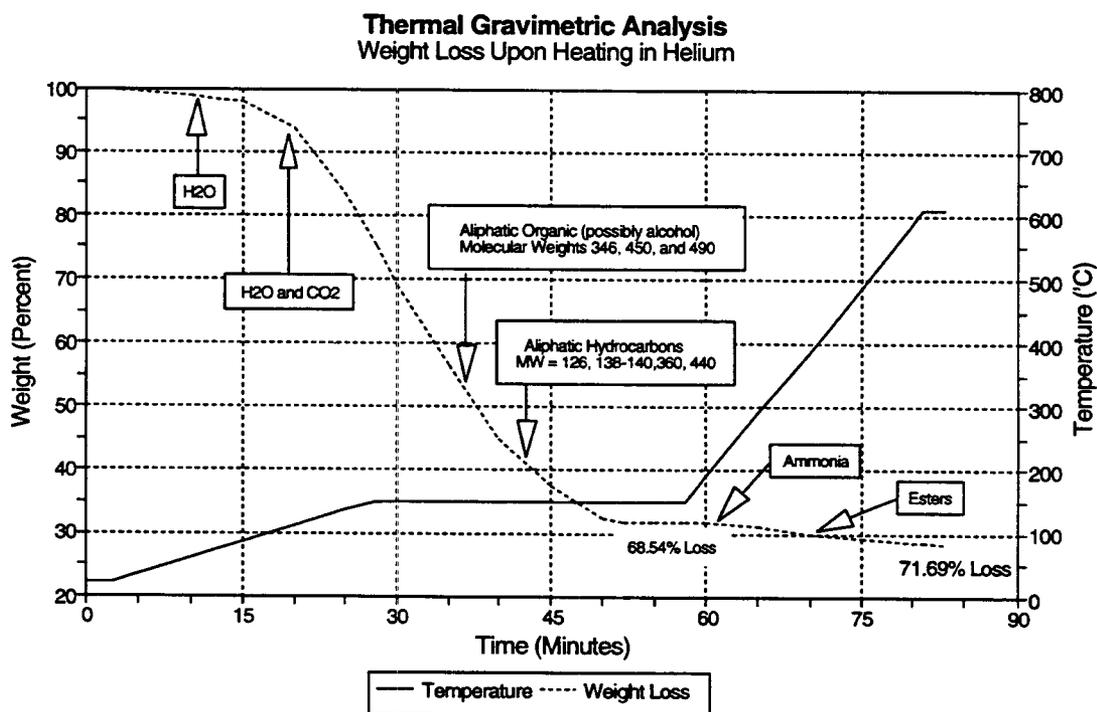


Figure 3.6 Thermal Gravimetric Analysis of Harbor Sediment

This observation was important to the conduct of the Phase I bench testing. All glass produced during Phase I was prepared in crucibles of various sorts. Although all heating was done in air, the bed of sediment powder in a deep crucible does not allow for either mixing or free circulation of air. Pyrolysis of organics thus occurs near the bottom of the pile, converting relatively flammable organics into relatively nonflammable carbon. Early coupon samples contained some dusty free surface carbon as a result. While the low-density carbon would eventually float to the top of the melt if the viscosity were sufficiently low, this transport process and the surface oxidation which followed are slow processes, so that incomplete destruction of TOC resulted.

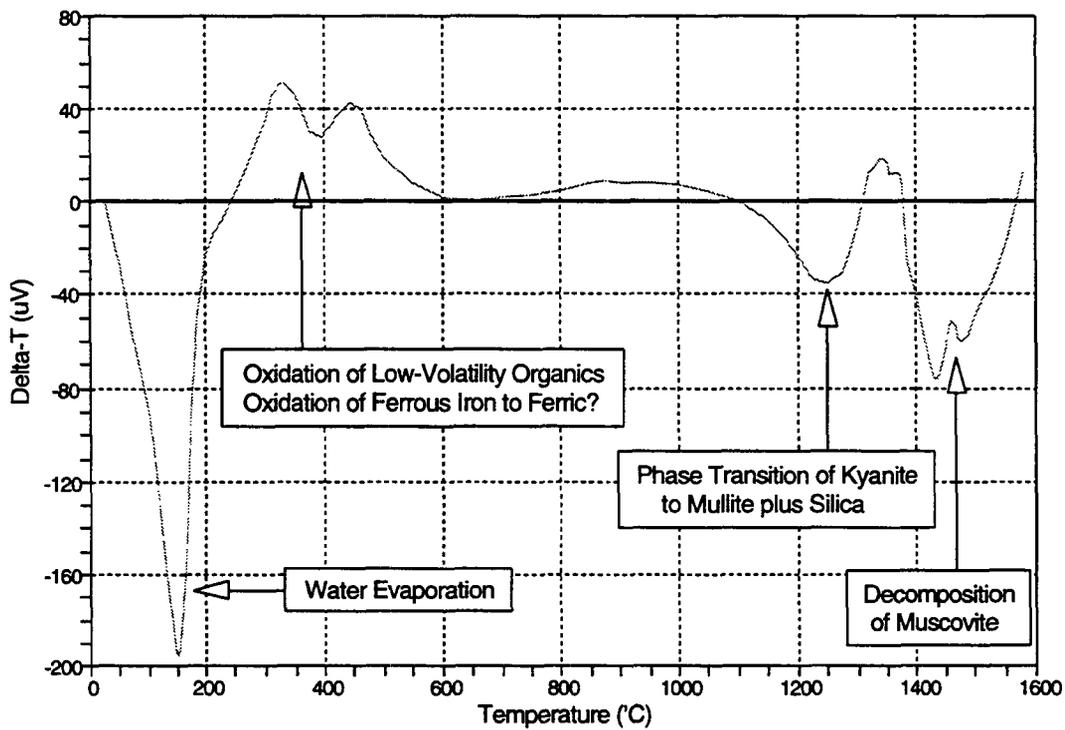
Since the issue of pyrolysis versus oxidation is related to the geometry of the crucible and is not expected to be an issue in the much hotter, well mixed plasma process, it was decided to pre-calcine the sediment powder before preparing the glass. Sediment was accordingly heated over many hours in shallow trays at 700°C to oxidize as much of the TOC as possible. Well-calcined sediment was found to change color from gray-black to a pink color, revealing the natural color of the white silicates and iron-containing minerals. This calcined powder was then blended with glassformers and melted into glass, greatly speeding up the crucible vitrification process.

### 3.7.2 Differential Thermal Analysis

The results of DTA are shown in Figure 3.7. The internal temperature difference as measured in thermocouple microvolts is plotted as a function of temperature as the sample is heated in air. The large initial negative  $\Delta T$  corresponds to the endothermic evaporation of water and volatile organics from the sample. At temperatures above 200°C, oxidation of organics and carbon take place, leading to exothermic reaction and heating of the sample. The heating value of the hydrocarbons in this sediment will therefore result in an energy credit to the process, and will be taken into account in design of the Phase II process.

Further heating gradually eliminates the organic oxidation peak. Some exothermic conversion of Fe(II) to Fe(III) may also be taking place near 400°C, analogous to the conversion of the mixed valence iron oxide magnetite ( $\text{FeO}\cdot\text{Fe}_2\text{O}_3$ ) to hematite ( $\text{Fe}_2\text{O}_3$ ) between 220 and 550°C. A large endothermic peak is observed above 1200°C, corresponding to the transition from kyanite to mullite plus silica. An additional large endothermic peak is observed above 1400°C, corresponding to dehydration and decomposition of the muscovite; this endothermic reaction would not contribute directly to the vitrification process, since the muscovite species will have already melted with the fluxing agents and dissolved in the glass matrix at temperatures below this point.

**Differential Thermal Analysis**  
Heating Rate 10°C/min in Air



**Figure 3.7 Differential Thermal Analysis of Harbor Sediments**

## 4. BENCH-SCALE TESTING

The objective of the bench-scale tests were to define a target glass composition that would make viable glass product using Harbor sediment as the raw material. As a guideline for planning tests, we developed specifications for the final glass product. Using the target specifications and the sediment characterization results, we developed a range of recipes for glassforming additives which were expected to yield a low-leachability glass product with reasonable melting point and pour viscosity.

Coupon melts were used to initially test the various glass formulations, evaluating glass homogeneity, pour viscosity, quench behavior, leachability, and physical properties. The coupon melt tests were used to select an optimum recipe for larger scale testing. Using the selected recipe, we generated roughly 10 kg of glass product in larger batch melts, with 7.5 kg scheduled for delivery to Brookhaven and further analyses.

The bench scale coupon melting and batch melting tests were selected as inexpensive methods to develop and make a glass melt. It is important to recognize that these small scale tests do not simulate the plasma reactor temperature exposure, and therefore, do not simulate organic dissociation that will be obtained at high temperature plasma reactor conditions. Phase II testing will be carried out using the plasma melting system rather than batch melting.

This section reports on the bench-scale testing for glass recipe development. The glass recipe selection process is described in Section 4.1. Next, Section 4.2 describes the bench-scale test procedures followed in melting the sediment and reports on the material balance for the bench-scale tests. Sediment pretreatment processes used in the bench scale tests are detailed. It should be noted, however, that the bench-scale pretreatment procedures were not representative of those to be developed for the full scale plant. Finally, coupon melting tests and their results are described in Section 4.3. The coupon melt tests were used to select a glass recipe for production of the batch samples.

### 4.1 GLASS RECIPES SELECTION

Target glass recipes were selected for coupon testing based on the desired glass product specifications developed in Section 4.1.1, and a theoretical assessment of glass properties expected using the Harbor sediment as a feedstock. Thermodynamic and viscosity models were used in the assessment. Section 4.1.2 examines the soda-lime-silica phase diagram used to select a glass composition and evaluate the flexibility of this composition to variability in the sediment analysis. Section 4.1.3 describes viscosity-temperature modeling as a function of composition, and establishes the predicted optimal formulation of glassforming flux and sediment.

#### 4.1.1 Glass Product Requirements

The following specification for the targeted glass product was developed.

- **Melting Point:** The melting point should be no greater than about 1425°C (2600°F), from considerations of process energy input and maximizing refractory lifetime. Note that glass does not have a well-defined melting temperature, but rather exhibits a continuously decreasing viscosity as the temperature is elevated. The vitrification temperature is defined as the temperature where the viscosity is equal to  $10^{13.7}$  Poise (Pascal-seconds); this is still extremely viscous and essentially solid. For practical purposes, the melting point is defined as that temperature where the glass exhibits a viscosity of approximately 200 Poise, at which point the molten material may be readily poured.
- **Homogeneity:** The glass should be fully vitrified and homogeneous, with minimal non-vitreous (crystalline) inclusions. This requirement is somewhat flexible. If the final product were to be construction aggregate, the presence of non-vitreous inclusions ("devitrite") would have little or no deleterious impact. For spinning of the molten product into fibers for rock wool insulation material, small quantities of devitrite heterogeneity would be acceptable whereas larger quantities would not; spinning into fiberglass requires essentially zero levels of devitrite. Establishing a Phase I goal of complete vitrification allows maximal flexibility in defining the product form.
- **Leachability:** To be useful, the glass should have very low leachability for potentially toxic heavy metals. Although the sediments are expected to be non-RCRA materials and thus contain very low levels of toxic heavy metals, a homogeneous vitrified product is expected to provide extremely low leach rates for nearly any heavy metal that might be found in the Harbor sediments.
- **Heavy Metal Capture:** The glass should exhibit good capture efficiency for potentially toxic heavy metals. Nearly all metals of concern (Be, Cr, Cu, Ni, Pb, Sb, Tl, Zn, Ag, Cd, Se) have good glass solubilities at low concentration. Mercury is an exception, being essentially insoluble in glass, and highly volatile at glass melting temperatures. Some volatility losses of cadmium and arsenic would also be anticipated. Efficient scrubbing of the offgases is therefore required, and the offgas cleaning system must be designed with internal recycle for capture of volatile toxic metals which will accumulate over time.
- **Glassformers:** The glass should be formulated using only low-cost glass-forming flux materials, since the volume of material to be processed is so large. Calcium and sodium are considered "network modifiers" in the structure of glass, opening up the molecular structure by creating non-bridging oxygen atoms in the lattice and consequently reducing the melting temperature and viscosity of the product. Sodium and other alkali metals (Li, K) are better network modifiers than calcium and other alkaline earths (Mg, Sr). Although good quality glasses suitable for fiberglass manufacture can be formulated using other additives (including boron, lithium, and zir-

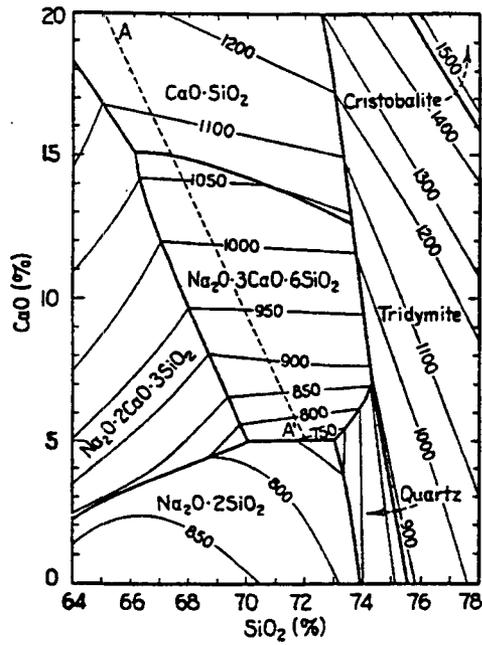
conium), sodium borate, lithium carbonate, and zircon are expensive glass-forming agents, and were therefore not considered. In summary, to minimize cost only sodium as soda ash ( $\text{Na}_2\text{CO}_3$ ) and calcium as either limestone ( $\text{CaCO}_3$ ) or lime ( $\text{CaO}$ ) were selected as candidate flux additives, yielding soda-lime-silica glasses as the product.

- **Physical Properties:** The glass product should have reasonable physical strength characteristics. The requirements for physical strength are again highly dependent on the final product form. Construction aggregate would presumably require greater physical strength than resin filler, while cullet destined for remelting into glass beads would have no physical strength criteria at all. It is also important to note that the physical strength of a sample of glass is determined by the details of the cooling and annealing process to at least as great an extent as by the chemical composition of the glass. Inherently strong glass which has been flash-quenched will typically contain large amounts of internal stress, which may lead to shattering if the glass is exposed to thermal shock or mechanical loading.

#### 4.1.2 The Soda-Lime-Silica Phase Diagram

Soda-lime-silica glass is the most common class of glass in commercial usage, formulated from  $\text{Na}_2\text{O}$ ,  $\text{CaO}$ , and  $\text{SiO}_2$ . The components, initially combined as "batch" chemicals sodium carbonate ( $\text{Na}_2\text{CO}_3$ ), limestone ( $\text{CaCO}_3$ ), and quartz ( $\text{SiO}_2$ ), are blended and melted; the carbonates decompose to form oxides, which fuse and form a non-crystalline vitreous solution over a temperature range from 850 to 1500°C, depending of the ratio of the three species. To form a glass, the mixture must first exceed the melting point of the three-component mixture, called the liquidus. The triangular phase diagram shown in Figure 4.1 presents the liquid temperature as a function of the three species weight fractions. The rectangular phase diagram plots liquidus versus lime and silica mass fractions, with soda being inferred as the difference  $100 - \text{CaO} - \text{SiO}_2$ . If the soda, lime, and silica mass fractions are such that the composition lies within the glass-forming region shown in the upper rectangular phase diagram, then formation of a good quality glass is straightforward.

Soda, lime, and silica are not the only components in the mixture, however. Of the remaining sediment components, only aluminum and iron pose additional concern. The potassium in the sediment will behave as sodium. Both magnesium and zinc will act similarly to calcium. Aluminum oxide and  $\text{Fe}_2\text{O}_3$  will have more significant effects; while not necessarily affecting the ability of the system to form a vitreous melt at temperatures above the liquidus point, both will impact the viscosity of the melt. The iron oxide will act in general as a fluidizer, reducing the melt viscosity. The solubility of ferric oxide in the glass may be limited, however, and result in crystalline  $\text{Fe}_2\text{O}_3$  inclusions in the glass. High alumina concentrations may also lead to precipitation of  $\text{Al}_2\text{O}_3$  crystals. Dissolved alumina will in general increase the melt viscosity. Selection of a glass composition must therefore consider not only the liquidus temperature of the mixture, but also the melt viscosity.



Compounds	CaO	Na <sub>2</sub> O	SiO <sub>2</sub>	Temp.	
SiO <sub>2</sub>			100.0	1710	M
α-CaO·SiO <sub>2</sub>	48.3		51.7	1540	M
β-CaO·SiO <sub>2</sub>	48.3		51.7	1180	I
Na <sub>2</sub> O·SiO <sub>2</sub>		50.8	49.2	1088	M
Na <sub>2</sub> O·2SiO <sub>2</sub>		34.1	65.9	874	M
2Na <sub>2</sub> O·CaO·3SiO <sub>2</sub>	15.6	34.4	50.0	1141	D
Na <sub>2</sub> O·3CaO·6SiO <sub>2</sub>	28.5	10.5	61.0	1047	D
Na <sub>2</sub> O·2CaO·3SiO <sub>2</sub>	31.6	17.5	50.9	1284	M

M = Melting Point  
 D = Decomposition Point  
 I = Inversion Point

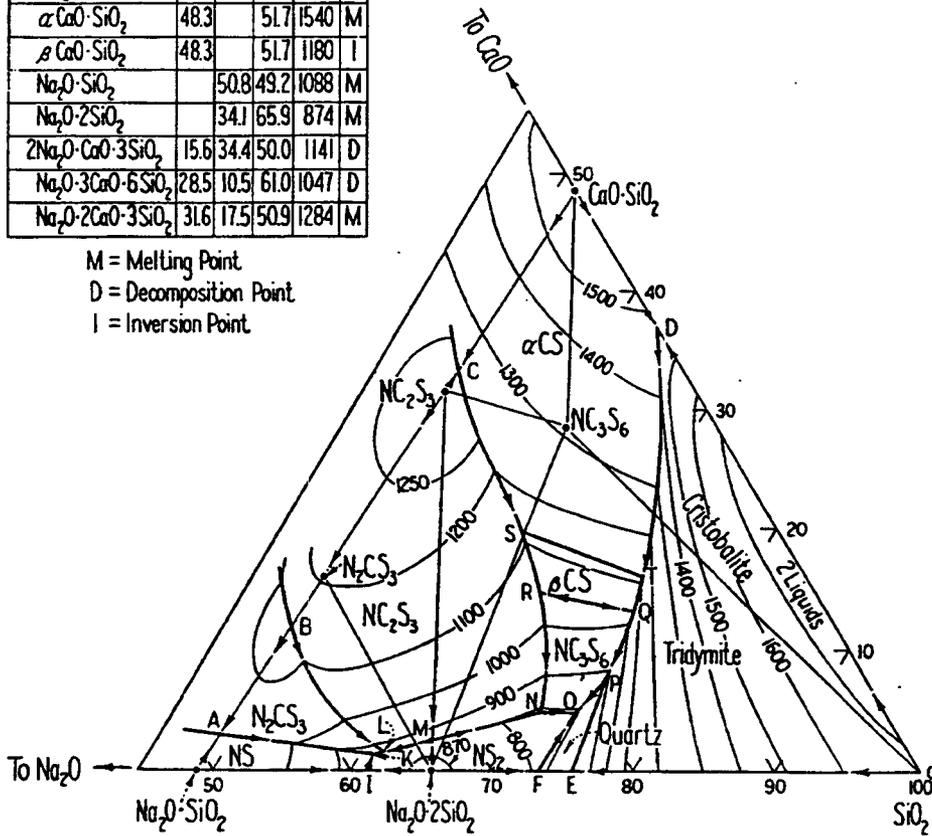


Figure 4.1 Phase Diagrams for the Soda-Lime-Silica System

### 4.1.3 Viscosity Modeling

Many melt components behave similarly when their effect on the melt viscosity is considered. This greatly simplifies development of an analytical model of melt viscosity as a function of composition. Alkali metal oxides, for example, will all have similar impact, such that the mole fractions of components  $\text{Na}_2\text{O}$  and  $\text{K}_2\text{O}$  may be summed as a single alkali metal oxide pseudospecies. Sulfides behave very similarly to oxides, so that  $\text{Na}_2\text{S}$  may also be combined as alkali metal oxide. Basic oxides, including  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{FeO}$ ,  $\text{PbO}$ ,  $\text{ZnO}$ ,  $\text{CuO}$ , and  $\text{MnO}$  may also be summed into a single pseudospecies. Similarly, aluminum and chromium oxides have comparable effects on viscosity. From Riboud et al.,<sup>4</sup> the melt viscosity  $\eta$  (Poise) may be determined as

$$\eta = A T \exp(B/T) ; \quad (4-1)$$

$$\ln(A) = -17.51 - 35.76 \sum x(\text{Al}_2\text{O}_3, \text{Cr}_2\text{O}_3) + 5.82 x(\text{NaCl}) \\ + 7.02 \sum x(\text{Na}_2\text{O}, \text{Na}_2\text{S}) + 1.73 \sum x(\text{CaO}, \text{MgO}, \text{FeO}, \text{MnO}, \text{PbO}, \text{ZnO}, \text{CuO}) \quad (4-2)$$

$$B = 31140 + 68833 \sum x(\text{Al}_2\text{O}_3, \text{Cr}_2\text{O}_3) - 46351 x(\text{NaCl}) \\ - 39519 \sum x(\text{Na}_2\text{O}, \text{Na}_2\text{S}) - 23896 \sum x(\text{CaO}, \text{MgO}, \text{FeO}, \text{MnO}, \text{PbO}, \text{ZnO}, \text{CuO}) \quad (4-3)$$

where  $T$  is the temperature ( $^\circ\text{K}$ ), and  $x$  is the mole fraction of each component. Silica does not appear in the viscosity equations; the mole fraction of  $\text{SiO}_2$  is assumed to be the difference of 1.0 and the sum of all other mole fractions. The correlations indicated here were derived for alumina concentrations up to 0.11 mole fraction; above this level, the accuracy of the Riboud model diminishes.

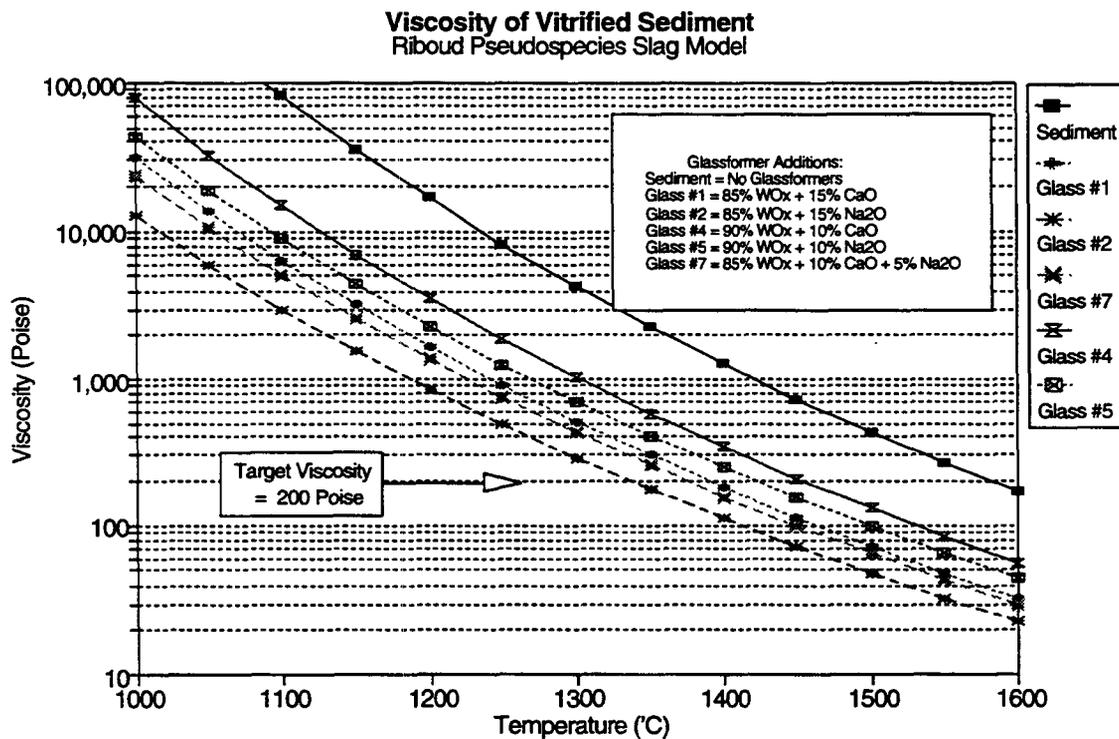
Another major component of Harbor sediment, ferric oxide ( $\text{Fe}_2\text{O}_3$ ), is also absent from viscosity modeling equations, although ferrous oxide ( $\text{FeO}$ ) is explicitly represented. This absence results historically from the development of these correlations from steel mill slag, which is always formed under reducing conditions. Ferric oxide is known to be a fluidizer; data presented by Mahan<sup>5</sup> indicate that addition of 4.5%  $\text{Fe}_2\text{O}_3$  to a slag having a 100 Poise viscosity at  $1350^\circ\text{C}$  will fluidize the melt such that the same viscosity is achieved at a temperature of only  $1310^\circ\text{C}$ . This level of ferric oxide is comparable to that expected in vitrified Harbor sediment, so that  $\text{Fe(III)}$  oxide may be expected to drop the effective melting point of the melt by 30 to  $40^\circ\text{C}$ . Conversely, Mahan indicates that a 1% addition of  $\text{TiO}_2$  (also present in Harbor sediment but absent in the Riboud model) will increase the 100 Poise temperature by  $10^\circ\text{C}$ .

Figure 4.2 presents viscosity curves computed from the above equations for the as-dredged sediment, plus five glass compositions formulated from sediment plus limestone and soda ash glassforming fluxes; the various formulations are discussed in detail in the next section. The graph shows the exponential decrease in viscosity with temperature. Sediment without glassformer addition is seen to be highly viscous; at the maximum desired vitrification temperature of  $1425^\circ\text{C}$ , the melt would exhibit a viscosity of 1000 Poise, a factor of five above the desired pour viscosity of 200 Poise. Note that

this latter value is the pour viscosity typically targeted in the commercial glass industry. At higher viscosities, the liquid head required to maintain a good pour stream becomes excessive, while at lower viscosities the wear rate in the pour spout increases.

Fluxed glass compositions are shown at two loadings of 85 and 90%, defined as the metal oxides derived from the sediment as a fraction of the total vitrified product weight. Glass #2, having 15% added Na<sub>2</sub>O (actually added as the equivalent amount of Na<sub>2</sub>CO<sub>3</sub>) is seen to have the lowest viscosity, emphasizing the fluidizing nature of alkali metals. Next in viscosity exhibiting roughly 1.5 times the viscosity of the 15% soda composition are Glass #7 and Glass #2, formulated with 10% CaO + 5% Na<sub>2</sub>O and 15% CaO, respectively. These two are very close in overall viscosity, with #7 being slightly more fluid. Increasing the loading to 90% with 10% added soda increases the viscosity another one-third (Glass #5), with a similar increase to formulation #4 containing 10% CaO.

The model would, therefore, predict that good melt and pour characteristics should be possible at loadings of 85-90%, using mixture of soda or soda-lime as glassforming fluxes. At the higher loading, soda is required to achieve low enough viscosity, which is relatively expensive as compared to calcia. Current chemical industry prices<sup>6</sup> for bulk



**Figure 4.2 - Predicted Viscosity of Vitrified Harbor Sediment Compositions**

CaCO<sub>3</sub> indicate that 9 to 17 μm fine powder sells for as low as \$87.50/ton (\$0.172/kg CaO); crushed limestone is closer to \$20/ton (\$0.04/kg CaO). Bulk Na<sub>2</sub>CO<sub>3</sub> sells for \$105/ton (\$0.198/kg Na<sub>2</sub>O), which is significantly more expensive. The tradeoff be-

tween high loading (smaller quantities of glassformer required and reduced total energy input) and the need for higher cost alkali flux is therefore one of process economics.

#### **4.1.4 Target Glass Recipes**

Using the sediment mineral composition reported in Section 3.4, we first examined the phase diagram literature, and identified a region of phase diagram space in which a vitreous product would be expected to form, ensuring that the product would exceed its liquidus temperature. The exact composition of the glass was then predicted based on modeling of the melt viscosity versus temperature and composition. A range of potential glass compositions were defined, and coupon melts carried for each.

## **4.2 BENCH SCALE TEST PROCEDURES**

Figure 4.3 presents a schematic material balance for Phase I bench test handling and processing of Harbor sediment, using as a basis 1000 grams of as-dredged sediment. The material was first screened to remove oversize material and then dried to establish the moisture content. The dry screened solids were then rinsed once with roughly two volumes of fresh water, and then filtered to partially dewater the sediment and remove chloride. The wet desalinated solids were again dried, and samples were taken for chemical analysis, coupon testing, and production of the 7.5 kg of glass requested by Brookhaven.

The remaining processing steps show calcination and vitrification separately, although these steps (as well as the final drying) would occur simultaneously in the plasma process. Calcination in the integrated plasma process accomplishes several chemical reactions, including oxidation of organic materials and sulfur, and decomposition of glassformer carbonates to oxides, although during Phase I bench testing sediment calcination was done before addition of the glassformers. The vitrification step accomplished decomposition of glassformer carbonates during Phase I processing, as well as melting of the resultant oxides with sediment oxides to form of a homogeneous glass product.

The preprocessing performed on the sediment for bench-scale melting tests is described in this section. Preprocessing provided vitrification feed material for the bench scale tests. There was no attempt, however, to develop an optimal preprocessing procedure or define commercial preprocessing steps. This was an offered, but not funded option for the Phase I Test Program.

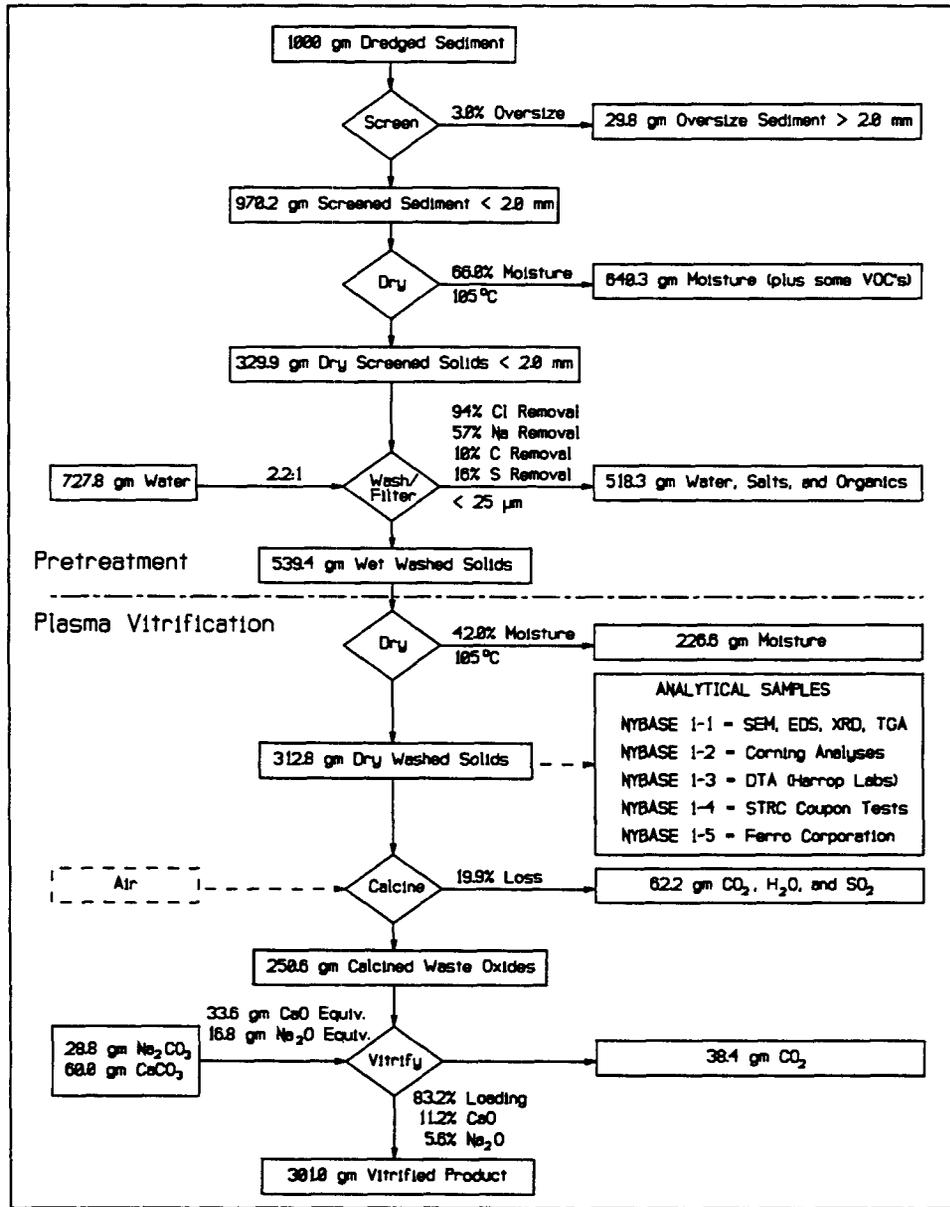


Figure 4.3 - Material Balance for Bench Testing of Harbor Sediment Vitrification

The following sections describe each of the bench-scale preprocessing steps shown in the Figure 4.3. Section 4.2.1. describes screening of the as-dredged material, while Section 4.2.2 describes the drying performed. Section 4.2.3 discusses sediment rinsing to remove chloride, and experience with filtering the resulting sediment for the purposes of dewatering.

#### 4.2.1 Sediment Screening

The first process to which the sediment was subjected was screening through a 10 mesh sieve, removing debris and particles having a nominal size greater than 2 mm. Sieving was accomplished by pouring the sediment through a 25 cm diameter sieve, and scraping it through with a paddle. Of the 70.16 kg of material sieved, the oversize fraction accounted for 2.97%. Most of the oversize fraction consisted of larger sediment particles (stones and gravel); a small fraction consisted of debris, both natural (sticks and bark) and artificial (fiber, wire and plastic foam).

**Table 4.1- Results of Coarse Screening with 2 mm Sieve**

Weight Fraction Retained on 2 mm Screen	2.97%
Composition of Oversize Material	Gravel, sticks, wire, foam, fibers

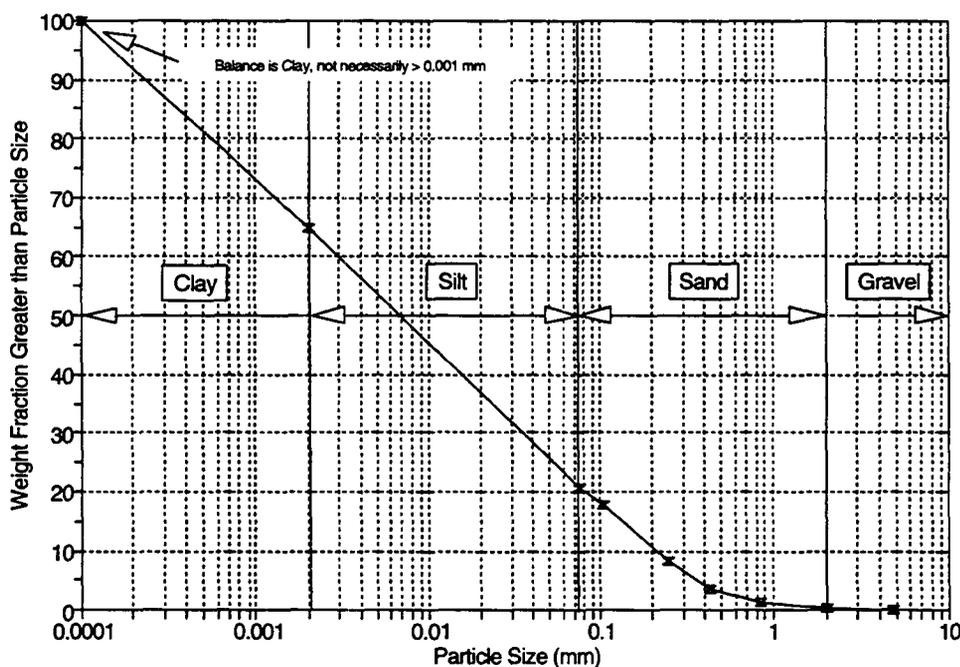
Brookhaven National Laboratory performed a particle size distribution analysis on the as-dredged Newtown Creek sediment, with the analytical results shown in Table 4.2 and the cumulative particle size distribution plotted in Figure 4.4. The complete BNL analysis is included in Appendix C.

**Table 4.2 Particle Size Analysis of Newtown Creek Sediment**

Classification	Size (mm)	Weight Percent of Total Dry Sediment						Mean
		Test #1	Test #2	Test #3	Test #4	Test #5	Test #6	
Medium Gravel	>4.75	0	0	0	0.18	0.04	0	0.04±0.07
Fine Gravel	2.00-4.75	0.12	0	0.67	0.18	0.58	0.74	0.38±0.29
TOTAL GRAVEL	>2.00	0.12	0	0.67	0.36	0.62	0.74	0.42±0.28
Very Coarse Sand	0.85-2.00	0.78	1.61	0.60	0.92	0.51	0.57	0.83±0.37
Coarse Sand	0.425-0.85	2.0	2.4	1.9	2.2	1.96	2.42	2.15±0.21
Medium Sand	0.25-0.425	4.9	5.0	4.9	4.7	5.9	4.9	5.05±0.39
Fine Sand	0.106-0.25	9.3	9.6	9.5	8.9	10.5	9.6	9.57±0.48
Very Fine Sand <sup>a</sup>	0.075-0.106	3.1	3.1	2.9	2.9	1.7	3.1	2.80±0.50
TOTAL SAND	0.075-2.00	20.1	21.7	19.8	19.6	20.6	20.6	20.40±0.69
Silt	0.002-0.075	41.7	43.8	40.8	43.1	44.3	56.0	44.96±5.08
Clay	<0.002	37.1	38.2	36.9	38.0	35.6	27.6	35.57±3.66
TOTAL		99.0	103.7	98.2	101.1	101.1	104.9	101.4

a. Note that lower limit of sand classification used by United States Soil Survey is 0.05 mm.

**Sediment Particle Size Analysis**  
Brookhaven National Laboratory Data



**Figure 4.4 - Particle Size Distribution of Newtown Creek Sediment**

**4.2.2 Sediment Drying**

Laboratory filtration of the rinsed sediment was difficult. We found, however, that the sediment was readily filterable in laboratory equipment if it was first dried. Although the dried sediment looks identical, some agglomeration or low-temperature sintering apparently takes place at 105°C which causes an increase in effective particle size and prevents blinding of the filtration medium. Predrying of the entire Phase I sample was carried out to aid in dewatering the material after rinsing.

Discussion with suppliers of commercial equipment and services for dewatering of fine, oil-contaminated sediments indicates that with proper commercially-available equipment and low-cost additives, dewatering of this sediment should not be difficult, and there will be no need to resort to expensive drying at the pilot or plant scale.

**4.2.3 Rinsing and Dewatering for Chloride Removal**

Following drying, the Phase I sample was slurried with fresh water, using approximately 2.2 volumes of water per 1 volume of dry solids. A total of 51 liters of water was added to the 23 kg of dry solids, in multiple 15-liter batches. The slurry was agitated manually, and then poured through a large laboratory filtration apparatus using 25 μm filter paper. A total of 38 kg of wet rinsed solids were obtained in this manner, collected from the filter medium. Drying of this material (again at 105°C) yielded 22 kg of dry rinsed solids, equivalent to a wet rinsed solids moisture content of 42%.

Chloride removal from the sediment is an important consideration in establishing the overall material balance in the offgas treatment system. Preliminary elemental analysis

was therefore carried out at WSTC using energy dispersive X-ray spectroscopy (EDS) to determine the chloride content before and after rinsing. Results are shown in Table 4.3.

**Table 4.3 - Impact of Water Rinsing on Sample Elemental Analysis**

Element	Before Rinsing (Sample 95A)		After First Rinse (Sample 96A)		After Second Rinse (Sample 96D)	
	Weight Per- cent	Atom Per- cent	Weight Percent	Atom Percent	Weight Percent	Atom Per- cent
Oxygen	48.43	56.58	50.14	58.41	49.47	56.97
Silicon	17.93	11.92	19.32	12.83	18.28	11.99
Carbon	12.75	19.85	12.14	18.84	14.01	21.49
Aluminum	5.39	3.73	5.67	3.91	5.47	3.73
Iron	4.90	1.64	5.52	1.84	5.96	1.97
Chlorine	2.08	1.10	0.14	0.07	<0.04 <sup>a</sup>	<0.02 <sup>a</sup>
Sodium	1.91	1.56	0.86	0.70	0.68	0.55
Potassium	1.84	0.88	1.84	0.88	1.94	0.91
Sulfur	1.77	1.03	1.56	0.91	1.33	0.76
Calcium	1.38	0.64	1.25	0.58	1.26	0.58
Magnesium	1.14	0.88	1.11	0.85	1.13	0.85
Titanium	0.48	0.19	0.45	0.18	0.44	0.17
Total <sup>b</sup>	100.00	100.00	100.00	100.00	100.00	100.00

a. Below detection limit.

b. Arbitrarily normalized to 100%.

A single water rinse reduced the chloride content of the sediment from 2.08% weight to 0.07% (a removal efficiency of 94%), while a second wash further reduces it to below 0.04% (the detection limit for chloride by EDS). This implies that the salt present is there simply as entrained seawater, rather than bound in some organic emulsion which would be much more resistant to simple rinsing. Note that calculating the removal efficiency is somewhat more complicated than comparing the composition before and after rinsing, since the rinsing process removes material; as seen in Figure 4.3; 100 gm of pre-rinse dry sediment actually leaves behind 94.8 gm of post-rinse dry sediment. Computing the fractional loss of six species for which some water-rinse removal would be expected, including renormalization for total losses, yields the results shown in Table 4.4.

As seen in Table 4.4, a single rinse is thus capable of achieving about 94 to 97% removal of chlorine and an accompanying 57% removal of sodium. Also lost are 10% of the total carbon in the system, 16% of the sulfur, 8% of the magnesium, and 5% of the potassium. Also shown in the table are expected weight losses, assuming the only mechanism being simple leaching of seawater out of the sediment; a typical seawater composition (29,400 ppm NaCl) is taken from Weast.<sup>7</sup> Good agreement is observed for Na and Cl, consistent with the assumption that essentially all of the chlorine present exists as dissolved NaCl. Significant losses for both carbon and sulfur are observed in excess of what would be anticipated from seawater leaching, assumed to be the result of some removal of organics containing both C and S. The numerical agreement between expected and observed losses for potassium and magnesium are not as good, with less loss of Mg than expected and greater loss of K; these discrepancies are probably a reflection on the fact that EDS is a semiquantitative analysis.

**Table 4.4 Sediment Rinsing Efficiencies**

Element	Cl	Na	S	C	Mg	K
gm/100 gm Dry Screened Solids	2.08	1.91	1.77	12.75	1.14	1.84
gm/100 gm Dry Rinsed Solids	0.14	0.86	1.56	12.14	1.11	1.84
gm/94.8 gm Dry Rinsed Solids	0.13	0.82	1.48	11.51	1.05	1.74
gm Lost/100 gm Dry Screened Solids	-1.95	-1.09	-0.29	-1.24	-0.09	-0.10
%Loss in Rinsing	-93.8	-57.1	-16.4	-9.7	-7.9	-5.4
gm/gm Cl in Seawater	1.000	0.556	0.047	0.002	0.067	0.020
Expected Seawater Loss	-1.95 <sup>a</sup>	-1.08	-0.09	-0.00	-0.13	-0.04
Expected Seawater %Loss	-93.8 <sup>a</sup>	-56.5	-5.1	0.0	-11.4	-2.2

*a. Basis for expected seawater loss is measured Cl loss.*

The rinse water collected from these samples was yellowish in color, consistent with leaching of some organic species from the sediment. *We do not believe that this rinse water is representative of rinse water from the commercial process because this rinse was performed on sediment that was dried at 105°C. Commercial experience on dewatering shows no indication of organic leaching from the sediment. This will be verified in the Phase II Pilot Test Program.*

An analysis of this water was carried out by acidification and organic solvent extraction, followed by analysis by GC/MS. Both phenylacetic acid and benzoic acids were detected at low concentration (actual concentration not determined), with additional traces of high molecular weight aliphatic hydrocarbons such as C<sub>19</sub>H<sub>40</sub>. None of these species readily accounts for the yellowish color. Additional inorganic analysis of the water indicates no colored metals in the rinse water, with only calcium and magnesium present above a few parts per million.

The yellow color is probably the result of ppm levels of polyaromatic hydrocarbons leached out of the sediment. These compounds are typically strongly colored, requiring only ppm levels to induce a yellow coloration to the water. Rinsing before drying yielded a clear colorless rinse water; the hydrophobic nature of the oil-contaminated sediment probably prevented leaching. After drying and some low-temperature decomposition of organics, the material became powdery and exhibited a higher surface area, allowing some leaching of PAH's into the rinse water.

The concentration, although enough to color the water, is probably not sufficient to cause the water to require significant treatment. Note that again, as indicated, the above rinse water chemistry results from *rinsing of dried sediment*, whereas the proposed pilot-scale and plant-scale operations would carry out rinsing of as-dredged sediment. The above trace concentrations of PAH's are not therefore expected in either larger scale test, nor would the rinse water discharge from the pilot or plant scale operation be expected to contain contaminant levels of regulatory concern.

## 4.3 COUPON MELT TESTING

### 4.3.1 Coupon Melt Test Description

Generation of Phase I batch glass product by coupon or crucible melting followed a procedure which included predrying of the wet sediment, heating in air to oxidize carbon and organic species (calcining), blending with dry glassformer powders, and slow melting (vitrification) in a furnace. This is quite different from the extremely rapid drying, calcination, and vitrification which take place simultaneously in milliseconds in the superheated plume of the plasma melter. The characteristics of the final molten glass product are the similar in either case, however, such that coupon and crucible testing can be used directly to ascertain the melt viscosity, operating temperature, and final glass physical and chemical properties. One difference is, however, expected in the coupon glass samples. The degree of organic destruction is expected to be better in the plasma-melted product than in the lower-temperature crucible material.

A total of nine glass compositions were evaluated in coupon testing, with overall final compositions as shown in Table 4.5. The formulation used to prepare each melt, expressed as gram of each glassformer added per kilogram of dredged sediment is given in Table 4.6. Table 4.6 also reports the temperature where the Riboud model viscosity equals 200 Poise.

All nine of the glass compositions shown were prepared as coupon crucible melts. In each case, the sediment was first dried and a 50 gram sample weighed out. This material was then pre-calcined for two hours at 700°C to speed the vitrification process.

**Table 4.6 Formulation of Coupon Glass Compositions Tested**

Formulation	Sediment Loading	gm CaCO <sub>3</sub> Added per kg As-Dredged Sediment	gm Na <sub>2</sub> CO <sub>3</sub> Added per kg As-Dredged Sediment	Predicted Pour Temperature (°C) with Viscosity of 200 Poise
Glass #1	85%	78.90	0	1390
Glass #2	85%	0	45.60	1336
Glass #3	85%	39.45	37.80	1364
Glass #4	90%	47.60	0	1455
Glass #5	90%	0	47.60	1423
Glass #6	90%	24.84	23.80	1439
Glass #7	83.2%	60.18	28.83	1347
Glass #8	85%	63.09	15.12	1380
Glass #9	81.5%	54.22	23.72	1374

Weight loss relative to the dry sediment was 5% as a result of pre-calcination, which is less than the 19.9% indicated in Figure 4.3. This calcination was therefore only partial, and the compositions were adjusted accordingly to put all formulations on a constant basis. Glassformers were then added, and the material melted in small crucibles. Part of each melt was cast into coupons for further analysis, while the balance was poured into water to assess its pouring behavior (a qualitative measurement of melt viscosity) and quenching.

**Table 4.5 Vitrified Sediment Formulations Evaluated in Coupon Melt Tests**

Component	Glass #1	Glass #2	Glass #3	Glass #4	Glass #5	Glass #6	Glass #7	Glass #8	Glass #9
	85% WO <sub>x</sub> 15% CaO	85% WO <sub>x</sub> 15% Na <sub>2</sub> O	85% WO <sub>x</sub> 7.5% Na <sub>2</sub> O 7.5% CaO	90% WO <sub>x</sub> 10% CaO	90% WO <sub>x</sub> 10% Na <sub>2</sub> O	90% WO <sub>x</sub> 5% Na <sub>2</sub> O 5% CaO	83.2% WO <sub>x</sub> 5.6% Na <sub>2</sub> O 11.2% CaO	85% WO <sub>x</sub> 3% Na <sub>2</sub> O 12% CaO	81.5% WO <sub>x</sub> 12.7% Na <sub>2</sub> O 5.8% CaO
SiO <sub>2</sub>	56.67	56.67	56.67	60.00	60.00	60.00	55.47	56.67	56.66
CaO	17.04	2.04	9.54	12.16	2.16	7.16	13.19	14.03	12.34
Na <sub>2</sub> O	1.14	16.14	8.64	1.20	11.20	6.20	6.71	4.14	5.84
Al <sub>2</sub> O <sub>3</sub>	11.46	11.46	11.46	12.13	12.13	12.13	11.22	11.46	11.46
Fe <sub>2</sub> O <sub>3</sub>	6.92	6.92	6.92	7.33	7.33	7.33	6.77	6.92	6.92
MgO	2.23	2.23	2.23	2.36	2.36	2.36	2.18	2.23	2.23
K <sub>2</sub> O	2.14	2.14	2.14	2.27	2.27	2.27	2.10	2.14	2.14
NaCl	1.29	1.29	1.29	1.37	1.37	1.37	1.27	1.29	1.29
TiO <sub>2</sub>	0.90	0.90	0.90	0.96	0.96	0.96	0.88	0.90	0.90
CuO/ZnO	0.21	0.21	0.21	0.22	0.22	0.22	0.21	0.21	0.21
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Total Na as Na <sub>2</sub> O	1.82	16.82	9.32	1.93	11.93	6.93	7.38	4.82	6.53

### 4.3.2 Coupon Melt Results

A summary of product properties obtained from the coupon melts is shown in Table 4.7. Two of the three coupons prepared at 90% sediment loading were incompletely vitrified, with observed crystals of both quartz and cristobalite  $\text{SiO}_2$ . A black film having a metallic appearance was also noted in all three of these glasses, which later was determined by XRD and magnetic behavior to be  $\text{Fe}_2\text{O}_3$  (magnetite), apparently the result of supersaturation of the glass matrix in iron oxide. All three high-loading products were also excessively viscous, "slaggy" in appearance, and contained trapped bubbles (another indication of excessive viscosity).

**Table 4.7 - Summary of Glass Coupon Testing Results**

Glass	Sediment Loading	Glassformer Composition	Properties
Sediment	100%	None	Very viscous at $T < 1450^\circ\text{C}$
Glass #1	85%	15% CaO	Slaggy at $1300^\circ\text{C}$ ; bubbly; too viscous to pour
Glass #2	85%	15% $\text{Na}_2\text{O}$	Fully vitrified; low viscosity at $1300^\circ\text{C}$ ; no bubbles
Glass #3	85%	7.5% CaO-7.5% $\text{Na}_2\text{O}$	Fully vitrified; low viscosity at $1300^\circ\text{C}$ ; no bubbles
Glass #4	90%	10% CaO	Viscous and slaggy at $1300^\circ\text{C}$ ; $\text{SiO}_2$ and $\text{Fe}_2\text{O}_3$ precipitation
Glass #5	90%	10% $\text{Na}_2\text{O}$	Fully vitrified; viscous at $1300^\circ\text{C}$ ; $\text{Fe}_2\text{O}_3$ precipitation
Glass #6	90%	5% CaO-5% $\text{Na}_2\text{O}$	Viscous and slaggy at $1300^\circ\text{C}$ ; $\text{SiO}_2$ and $\text{Fe}_2\text{O}_3$ precipitation
Glass #7	83.2%	11.2% CaO-5.6% $\text{Na}_2\text{O}$	Fully vitrified; fluid at $1350^\circ\text{C}$ ; no bubbles; $\text{Na}_2\text{SO}_4$ layer
Glass #8	85%	12% CaO-3% $\text{Na}_2\text{O}$	Low viscosity at $1350^\circ\text{C}$ ; $\text{SiO}_2$ crystal inclusions; bubbly
Glass #9	81.5%	12.7% CaO-5.8% $\text{Na}_2\text{O}$	Fully vitrified; fluid at $1350^\circ\text{C}$ ; no bubbles; $\text{Na}_2\text{SO}_4$ layer

All six of the lower loading formulations were essentially completely vitrified. A thin surface film of crystalline  $\text{SiO}_2$  was observed on Glasses #1, #7, and #8, but in all three cases iron was completely dissolved except for occasional  $2\ \mu\text{m}$  platelets of  $\text{Fe}_2\text{O}_3$ . Although surface silica was observed, no discrete inclusions of quartz or cristobalite could be located in Glass #7. In the cases of Glasses #7 and #9, a thin pool of molten  $\text{Na}_2\text{SO}_4$  was observed on the surface of the solidified coupon. Since the sulfur in the sample was calcined in the presence of excess carbon rather than oxidized to  $\text{SO}_2$ , this material was available to form sodium sulfate which has limited glass solubility. A small pellet several millimeters in diameter consisting of FeS was also observed in the bottom of the crucible from Glass #7, another indication of reduced sulfur. This phenomenon is not anticipated in the plasma processing.

In addition to the qualitative observations discussed above, chemical analysis was carried out of two of the coupon glasses having the best physical properties (Glasses #3 and #7). Dissolutions of the glass matrix were carried out by first HCl/ $\text{Na}_2\text{O}_2$  fusion/digestion, and second by microwave dissolution; the second technique provides the soda and potassa atomic absorption (AA) analysis which is not available after sodium peroxide fusion. The results are shown in Table 4.8. Good agreement is seen for both

**Table 4.8 Chemical Analysis of Optimal Glass Formulations**

Component	Glass #3 (7.5% CaO-7.5% Na <sub>2</sub> O)			Glass #7 (11.2% CaO-5.6% Na <sub>2</sub> O)		
	Predicted	Analyzed (HCl/Na <sub>2</sub> O <sub>2</sub> )	Analyzed (Microwave)	Predicted	Analyzed (HCl/Na <sub>2</sub> O <sub>2</sub> )	Analyzed (Microwave)
SiO <sub>2</sub>	56.7	53.3	53.5	55.5	53.4	52.5
Al <sub>2</sub> O <sub>3</sub>	11.5	10.8	12.0	11.2	11.9	12.5
CaO	9.5	8.5	9.6	13.1	13.4	14.1
Na <sub>2</sub> O	8.6	N/A	8.0	6.7	N/A	6.8
Fe <sub>2</sub> O <sub>3</sub>	6.9	7.2	8.0	6.8	5.6	6.0
MgO	2.2	1.9	2.1	2.2	2.1	2.1
K <sub>2</sub> O	2.1	N/A	2.0	2.1	N/A	1.9
TiO <sub>2</sub>	0.9	0.7	0.8	0.9	0.7	0.8
P <sub>2</sub> O <sub>5</sub>	N/A	0.5	0.5	N/A	0.5	0.5
Cr <sub>2</sub> O <sub>3</sub>	<0.03	0.3	0.3	<0.03	0.3	0.3
NiO	<0.03	0.2	0.2	<0.03	0.3	0.1
ZnO	<0.3	0.2	0.2	<0.3	0.2	0.2
MnO <sub>2</sub>	<0.1	0.1	0.2	<0.1	0.1	0.1
BaO	<0.1	0.06	0.06	<0.1	0.06	0.06
PbO	<0.1	0.05	N/D	<0.1	0.06	N/D
CuO	<0.3	0.02	0.3	<0.3	0.3	N/D
Total	100.00	84.22	99.26	100.00	88.53	98.46

glasses for all metals with the exception of Cr and Ni. These elevated levels result from use of a stainless steel crushing platen used for grinding the glass prior to digestion; similar elevated levels of iron are undoubtedly present, but masked by the already high Fe concentration.

Physically, the glass product is a dark greenish-gold color, appearing black in large masses. The material is physically strong, forming long fibers or "glass wires" if quenched into vigorously agitated water when molten; these "wires" are quite strong and resist breaking, and suggest that spinning of this product into fiberglass or rock wool should be successful. Density measurements of various samples ranged from a low of 2.495 gm/cm<sup>3</sup> for fine particles of Glass #3 to a high of 2.785 gm/cm<sup>3</sup> for large chunks of Glass #7, for an average over five samples of 2.61 gm/cm<sup>3</sup>.

#### 4.3.3 Selection of Optimal Glass Formulation

Glass #7 ( 11.2% CaO, 5.6% Na<sub>2</sub>O, 83.2% WO<sub>x</sub> ) was selected because it exhibited the following performance characteristics:

- It was fully vitrified.
- Negligible crystalline inclusions were observed.

- The melt had good pouring behavior at 1350°C.
- The mix achieves high sediment loading.
- A 2:1 ratio of lime to soda ash in the glassformer blend is economical.

This formulation was, therefore, selected for production of the 7.5 kg of material to be delivered to Brookhaven.

This composition in some ways pushes the limit of both sediment loading and Ca:Na ratio. If the sediment should exhibit variation in its composition and present higher levels of silica, iron, or alumina, it is quite possible that use of the formulation for Glass #7 shown in Table 4.8 could result in a product which was either incompletely vitrified (leaving crystals of  $\text{Fe}_2\text{O}_3$  or  $\text{SiO}_2$ ), or which resulted in a higher viscosity than anticipated, in which case the melter temperature would have to be elevated to compensate.

Flexibility to accommodate sediment variability is important to the overall process. The phase diagrams shown in Figure 4.1 indicate that a sediment having a nearly pure quartz composition (as is the case in the NIST Standard Sediment Sample at 85% silica) would be among the most difficult to vitrify. Combining quartz with a glassformer flux consisting of two parts lime to one part soda ash would yield a good glass composition (within the boundaries of the rectangular phase diagram) if the sediment loading were kept to below 76%. Such a glass would have a liquidus temperature of 1330°C and a 200 Poise pour temperature of 1360°C, and should be readily processable at 1400°C. Rather than increasing the melter temperature to compensate for excessively viscous product, the preferred strategy would be to maintain both the temperature and glassformer compositions constant, and simply increase the glassformer feed rate (decrease the waste loading).

## 5. BENCH-SCALE GLASS PRODUCTION

After establishing the conditions and composition for converting contaminated Harbor sediment to a vitrified glass product, 45 kg of as-dredged sediment were processed for conversion to glass at Ferro Corporation in Cleveland, Ohio. This material was processed by the same methods as shown in Figure 4.3.

### 5.1 PROCEDURE FOR PRODUCTION OF 10 KG GLASS

The sediment was initially screened through 2 mm sieves, with the 3% oversize material reserved. The fines were then dried in open pans at 105°C, and then washed by combination with two volumes of fresh water and agitation in buckets. The slurry was then passed through 25 µm filters for dewatering, reducing the material to roughly 50% moisture. To accelerate the vitrification process, the wet washed sediment was then calcined to burn out most of the carbon. This was again done in open pans in a large furnace in several batches at approximately 700°C for up to ten hours. The calcined solids were then shipped to Ferro, where they were blended with glassformers (lime and soda ash) using the formulation developed as Glass #7 (83.2% sediment loading, 2:1 ratio of added CaO and Na<sub>2</sub>O).

Ferro vitrified the material by loading the blended sediment and glassformer powders into 1 kg batch crucibles. The crucibles were fabricated from silica-alumina ceramic, and were capable of processing roughly 1 kg of glass per batch. A small amount of SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> may be expected to have leached from the crucible, yielding a glass slightly higher in silica and alumina than the Glass #7 formulation (prepared in platinum crucibles). Because of the low density of the feed mixture, filling the crucible initially with sediment and glassformer would yield only 1/3 of a crucible volume of molten product. Powder was therefore added gradually, "topping up" the crucible several times as the material melted down in the crucible.

Various batches were melted at several different temperatures from 1350 to 1450°C. Although in continuous production the viscosity of the melt was sufficiently low at 1350 to 1400°C to permit easy processing, when the crucibles were removed from the oven, rapid cooling occurred such that it was difficult to pour out the contents rapidly enough to prevent solidification of a significant quantity on the inside walls of the crucible. As a result, some glass was not recovered during each batch, and for later batches the temperature was increased to 1450°C to improve the glass fluidity, minimize the adherence to the walls, and hence improve the recovery efficiency. One full batch of nearly 1.5 kg was lost due to fracture of the crucible in the furnace, caused by a flaw in the ceramic which failed during heating.

Accounting for losses in batch recovery and failure of the one crucible, a total of 11.6 kg of glass product were produced and recovered during this operation, a yield of 86%. Most of the product was granulated by quenching into water, forming a fine gravely

aggregate with some fines. A smaller quantity was recovered as "wire," formed spontaneously during the quenching process as the melt cooled rapidly in agitated water. Several "pancake" samples were also poured onto steel platens, and then cooled slowly in an annealing oven to prevent fracture. As requested by Brookhaven, 7.5 kg were shipped to BNL for analysis, primarily aggregate but including some "wire" and "pancake" samples. The balance of 3.1 kg was retained by WSTC for archiving and potential further analysis.

Results of these various analyses are reported in the following sections.

## 5.2 CHEMICAL ANALYSIS OF PRODUCT GLASS

Samples of the product glass were forwarded to Savannah River Technology Center for X-ray diffraction and chemical analysis. XRD indicates nominally 1% total crystallinity (nonvitreous material), which is of negligible concern for most product applications with the sole exception of high-quality fiberglass. The only crystalline species observed were quartz and cristobalite (both forms of SiO<sub>2</sub>), which were undoubtedly due to incomplete dissolution of larger sand grains.

The chemical analyses are reproduced in Table 5.1. The actual analyses closely replicate the predictions based on sediment and glassformer analysis for most components. Elevated iron is observed, believed to be the result of grinding the glass product to 200

Table 5.1 SRTC Analysis of Product Glass

Species	Wt. Pct. (Predicted)	Wt. Pct. (Microwave Dissolution)	Wt. Pct. (Na <sub>2</sub> O/HCl Dissolution)
SiO <sub>2</sub>	55.6	55.96	56.56
CaO	14.2	12.71	12.44
Al <sub>2</sub> O <sub>3</sub>	11.2	11.06	10.29
Fe <sub>2</sub> O <sub>3</sub>	6.8	7.91	7.21
MgO	2.2	2.30	2.20
K <sub>2</sub> O	2.1	1.85	N/A
Na <sub>2</sub> O	7.9	7.28 (ICP)/6.74 (AA)	N/A
TiO <sub>2</sub>	N/A	0.75	0.68
P <sub>2</sub> O <sub>5</sub>	N/A	0.68	0.50
Cr <sub>2</sub> O <sub>3</sub>	N/A	0.30	0.29
ZnO	N/A	0.27	0.31
CuO	N/A	0.18	0.12
NiO	N/A	0.16	0.49
MnO <sub>2</sub>	N/A	0.11	0.11
ZrO <sub>2</sub>	N/A	0.10	N/A
BaO	N/A	0.06	0.05
PbO	N/A	0.05	N/A
SnO <sub>2</sub>	N/A	0.02	N/A
SrO	N/A	0.02	N/A

mesh on a stainless steel lined grinder prior to analysis; elevated Ni and Cr are also observed. Note that several potentially hazardous metals are found in the glass at nearly percent concentrations, including barium, lead, zinc, and copper.

### 5.3 TESTING OF PRODUCT GLASS

Samples of the glass product were analyzed by Brookhaven National Laboratory for metal and organic contamination, organic carbon and sulfide content, and TCLP leachability. Appendix D contains the complete set of analysis performed by BNL.

#### 5.3.1 Organic Contaminant Destruction Efficiency

Based on Brookhaven analysis of the organic content of the glass product, excellent destruction efficiencies were achieved for all organic species. Results of the organic contaminant analyses are summarized in Table 5.2. Organic analysis indicates that although the crucible melt procedure used for Phase I testing was not designed for highly efficient destruction of organic species, very high destruction was achieved. Total organic carbon (TOC) was below detection limits. Of particular concern are the dioxins, since presence of these compounds is central to the issue of ocean dumping of sediments. Dioxin analysis was also below detection limit. If all dioxins were present at the detection limit, the destruction efficiency would be 99.99%. This means our processing achieved an efficiency greater than this detectable limit.

Table 5.2 BNL Organic Analyses of Product Glass

Chemical Analyses	Product Glass	Untreated Dry Sediment	Destruction Efficiency (%)
Total Organic Carbon (%)	<Detection Limit	7.32	Not Measurable
Sulfide (mg/kg or ppm)	0.50	7800	99.994
PCB's (µg/kg or ppb)	1.28	5260	99.976
Chlorinated Pesticides (µg/kg or ppb)	<Detection Limit	462	Not Measurable
PAH's (µg/kg or ppb)			
Di-n-butyl phthalate	25.8	1,227	97.90
Butylbenzylphthalate	188	1,473	87.24
<i>bis</i> -2-ethylhexylphthalate	44.5	48,630	99.91
All Others (total)	<Detection Limit	65,670	Not Measurable
Dioxins (ng/kg or ppt)	<Detection Limit	6,440	Not Measurable
Furans (ng/kg or ppt)			
234678-HxCDF	0.41	184	99.78
All Others (total)	<Detection Limit	16,300	Not Measurable

Similar efficiencies are observed for sulfide, PCB's, chlorinated pesticides, and furans. Only four organic species were found at levels above detection limits, specifically three

polyaromatic hydrocarbons and the furan species 234678HxCd. The PAH's are observed at concentrations of 25 to 200 parts per billion. The ethylhexylphthalate compound was the PAH present at the highest concentration in the initial sediment, and still exhibits a 99.91% destruction efficiency. Lower efficiencies are seen for the other two PAH's, in particular butylbenzylphthalate (87%); it is not clear how a process which destroys in excess of 99% of total organic carbon and better than 99.99% of dioxins (which are notoriously refractory) would only destroy 87% of one particular PAH present at relatively low concentration. The furan species found in the glass sample also exhibits a high destruction efficiency (99.78%), and is only found at the 0.4 part per trillion level.

### 5.3.2 RCRA Metals Analysis

Metals analyses for the thirteen RCRA metals of concern were also done by Brookhaven, as shown in Table 5.3. It is of interest to compare the expectation metals concentration in the glass product, based on the bench scale material balance and the initial sediment metals analyses. The material balance indicates that 1000 gm of as-dredged sediment is equivalent to 312.8 gm of dry solids, the basis for the initial Brookhaven metals analyses. This quantity of dry solids in turn results in 301.0 gm of glass product, so that if no loss of heavy metals occurred, the concentration in the final product would be 1.04 times as great as in the initial dry sediment. A comparison of actual to expectation should therefore provide a measure of the fractional retention of the more volatile heavy metals in the glass matrix.

**Table 5.3 - Heavy Metals Material Balance in Product Glass**

Analyte	Analysis (mg/kg)				Ratio of BNL Final to Expected Glass Analysis
	Initial Sediment Analysis	Final BNL Glass Analysis	Final SRTC Glass Analysis	Expected Glass Analysis <sup>a</sup>	
Ag	18.42	2.47	N/A	19.1	0.129
As	33.48	5.18	N/A	34.8	0.149
Be	0.56 <sup>b</sup>	0.18 <sup>b</sup>	N/A	0.6	N/A
Cd	37.05	4.40	N/A	38.5	0.114
Cr	367.67	74.05	2000 <sup>c</sup>	382.1	0.194
Cu	1171.67	166.5	800	1217.6	0.137
Hg	1.29 <sup>b</sup>	0.07 <sup>b</sup>	N/A	1.3	N/A
Ni	297.17	50.1	4000 <sup>c</sup>	308.8	0.162
Pb	617.00	93.5	900	641.2	0.146
Sb	10.29	1.35	N/A	10.7	0.126
Se	3.24 <sup>b</sup>	0.89 <sup>b</sup>	N/A	3.4	N/A
Tl	2.77 <sup>b</sup>	0.89 <sup>b</sup>	N/A	2.9	N/A
Zn	1725.00	333.5	2400	1792.6	0.186
Average					0.149±0.025

a. Expected value assuming zero volatility loss.

b. Below detection limit.

c. High Cr and Ni levels from stainless steel grinding medium contamination.

All of the heavy metals analyzed show a glass concentration roughly 1/7 of the expectation value; in fact, the ratio of actual to expected concentration is consistent to within 2.5%. This result is very surprising, in that the metals considered vary substantially in volatility. Cadmium and lead, for example, could exhibit considerable volatility. Nickel and chromium, on the other hand, are almost entirely nonvolatile at 1400°C. Yet the results in Table 5.3 indicate the same apparent loss (6/7) of all four metals to within a few percent.

The only explanation which makes sense is a systematic error in one of the two analyses, more probably that of the glass product. Previous Westinghouse experience has indicated that obtaining good metals analysis from a glass matrix is difficult. A second set of glass product analyses carried out by Savannah River Technology Center, although of lower precision, are nominally consistent with the expectation values and suggest that the BNL data may be consistently low. For zinc, the SRTC analysis indicates 2400 ppm Zn as compared to the expected value of 1792, and the BNL value of only 333. Similarly SRTC reports 900 ppm Cu as compared to the expectation of 641 and the BNL value of only 93; SRTC Pb analysis indicates 800 ppm as compared to expectation of 1217 and BNL analysis of 166. In any case, enough concern exists about the reliability of the metals analysis to prevent any estimation about fractional retention in the product.

### 5.3.3 TCLP Leach Testing

Leach testing of the product glass performed by Brookhaven. Westinghouse also has TCLP tests performed by ANTEC (Appendix E). The results of TCLP analyses are shown in Table 5.4, along with the regulatory limit for each contaminant. The glass product exhibits no hazardous levels of any regulated substance. Of the potentially toxic metals known to exist in the sediment, only lead was observed above the detection limit. Lead was found in the extractant at 0.12 and 0.16 mg/L, whereas the Antech sample observed 0.23 mg/L of Pb. In all three analyses, the value was well below the 5.0 mg/L regulatory limit above which the material would be classified as hazardous. product exhibits no hazardous levels of any regulated substance.

Consistent with the high organic destruction efficiencies observed in Table 5.2, volatile organics, all PAH's, all dioxins, all PCB species, and all but one furan were also below detection limit in the extractant. Only one furan, the same 234678-HxCDF found above detection limit in the organic analysis, was reported in the TCLP extractant; note that the concentration of this compound was  $4.2 \times 10^{-9}$  mg/L, equivalent to only four parts in  $10^{15}$  in the aqueous phase. This is also orders of magnitude below the regulatory limit as set forth in 40CFR286.41 for landfill disposal of furan or dioxin contaminated materials. Again, the leach test results show the glass product to be highly stable with respect to leaching of toxic species and heavy metals.

Table 5.4 - TCLP Analyses of Product Glass

Contaminant	Antech TCLP Analysis(mg/L)	Brookhaven TCLP Analysis (mg/L)	Regulatory Limit (mg/L)
<b>Metals:</b>			
Silver	<0.10	<0.01	5.0
Arsenic	<0.10	<0.1	5.0
Barium	<10.00	<0.5	100.0
Cadmium	<0.10	<0.01	1.0
Chromium	<0.10	<0.01	5.0
Mercury	<0.010	<0.001	0.2
Lead	0.23	0.14	5.0
Selenium	<0.10	<0.10	1.0
<b>Organics:</b>			
Benzene	<0.050	<0.20	0.5
2-Butanone	<5.0	<5.0	200.0
Carbon Tetrachloride	<0.050	<0.20	0.5
Chlorobenzene	<1.00	<0.20	100.0
Chloroform	<0.50	<0.20	6.0
1,2-Dichloroethane	<0.050	<0.20	0.5
1,1-Dichloroethylene	<0.050	<0.20	0.7
Tetrachloroethylene	<0.050	<0.20	0.7
Trichloroethylene	<0.050	<0.20	0.5
Vinyl Chloride	<0.050	<0.10	0.2
1,4-Dichlorobenzene	<0.50	N/A	7.5
2,4-Dinitrotoluene	<0.050	N/A	0.13
Hexachloro-1,3-butadiene	<0.050	N/A	0.5
Hexachlorobenzene	<0.10	N/A	0.13
Hexachloroethane	<0.50	N/A	3.0
Nitrobenzene	<0.10	N/A	2.0
Pyridine	<0.50	N/A	5.0
PAH's	N/A	All <0.1	N/A
234678-HxCDF	N/A	$4.2 \times 10^{-9}$	$10^{-3}$
Other Furans	N/A	$<1 \times 10^{-9}$	$10^{-3}$
Dioxins	N/A	$<8 \times 10^{-9}$ (Typ.)	$10^{-3}$
PCB's	N/A	$<5 \times 10^{-7}$ (Typ.)	N/A

## 6. THE PLASMA VITRIFICATION TREATMENT TRAIN

Westinghouse's approach to the demonstration and design of the integrated plasma vitrification process is described in this section. Our technical approach to the Phase II Pilot tests, an integral part of the demonstration plan, is then detailed in Section 7.

Westinghouse's approach to solving the sediment decontamination problem is to provide an integrated plasma vitrification process which results in a complete treatment train to decontaminate the sediment, produce a useful commercial glass product, and minimize waste from contaminated sediment processing. Westinghouse has assessed alternative integrated system design options for sediment decontamination. The major factors that have lead us to select the integrated plasma vitrification process as our base technology are:

- a drive to minimize hazardous waste and maximize resource recovery
- process simplicity with flexibility to accept variable sediment feeds
- the need for low processing cost, \$ < 100/ton.

For the plasma vitrification process itself, we have evaluated system design tradeoffs such as:

- feed options to the plasma melter (e.g., pretreatment versus direct feed systems are possible)
- oversized material processing
- pretreatment options (e.g., desalination only versus contaminant separation)
- plasma melter design options (e.g., feed system options, reactor design specifics, glass removal methods)
- offgas treatment.

Our assessment of these options results in the following technical approach for the design of an integrated Plasma Vitrification Treatment Train.

Section 6.1 presents a detailed description of the integrated Plasma Vitrification Treatment Train's material balances and treatment units. Section 6.2 provides the system's energy balance. A description of the envisioned commercial plant configuration is given in Section 6.3. Production requirements are summarized in Section 6.4, and estimated production costs and their development basis is provided in Section 6.5. The environmental impact of the decontamination process is discussed in Section 6.6, where the fate of each sediment contaminant in the integrated Treatment Train is described.

### 6.1 DETAILED PROCESS DESCRIPTION AND MATERIAL BALANCES

Figure 6.1 presents an overall flowsheet for the integrated Plasma Vitrification process. Streams are numbered, where the numbers refer to material balance calculations in Tables 6.1 and 6.2. Material balances are computed for the production-scale operation of 100,000 cy/yr (assumed to be 100,000 ton/yr), and are based on actual sediment compositions and processing parameters as determined in the Phase I test program. The

overall process is segmented into two major operations in this material balance, namely sediment pretreatment (designed to size classify and desalinate the sediment) and vitrification. The six major elements of the integrated plasma vitrification treatment train are then described. In addition, the optimum water content for dredged materials and the intellectual property status of the Plasma Vitrification Process are discussed.

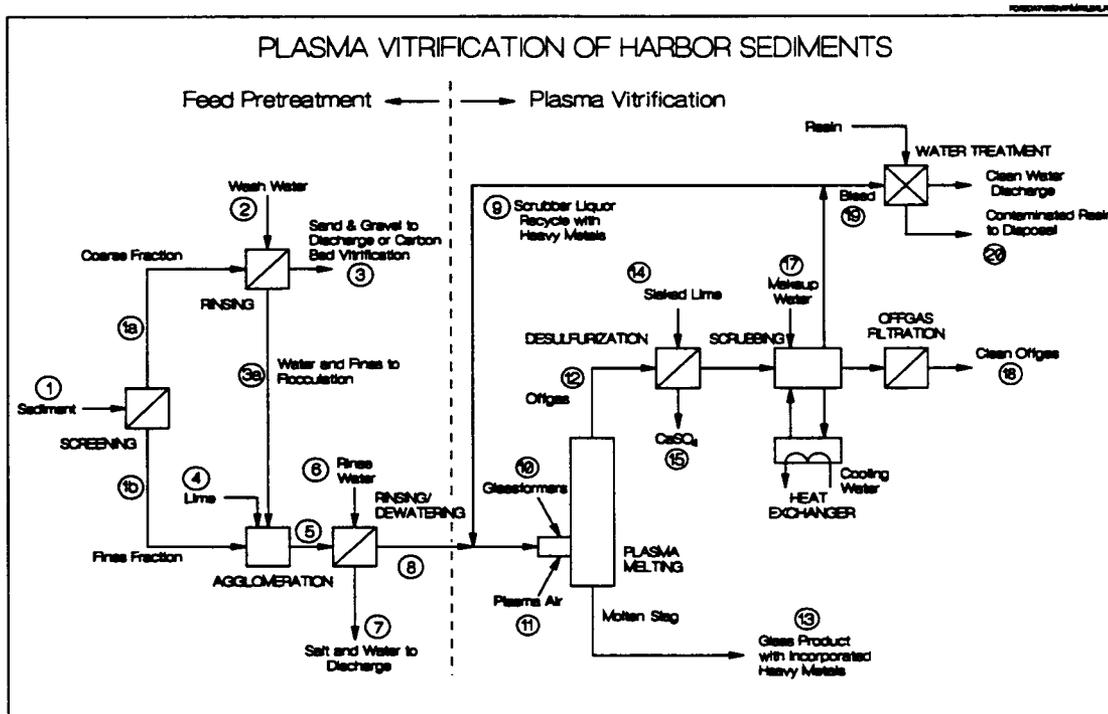


Figure 6.1 Integrated Plasma Vitrification Process Flow Diagram

### 6.1.1 Sediment Size Segregation

Although the plasma melter can be designed to process the as-received sediment, the most economical system will incorporate the removal of large particles. Incoming sediment (Stream 1) is first screened to remove particles larger than 100  $\mu\text{m}$ . Removal of larger particles ensures that the rapid heat transfer experienced later in the plasma melter will fully melt the sediment particles, forming a homogeneous glass product. Screening and particle size analysis indicates that roughly 1 to 3% of the total as-dredged sediment mass will be classified as oversized by the process (Stream 3).

Westinghouse soil washing experience indicates that the oversize particles could be inexpensively rinsed free of contaminants using only water as the rinsing agent, although this procedure was beyond the scope of Phase I testing. If it proves possible to adequately clean the hydrocarbons off of the oversize fraction, it may be possible to landfill or ocean dump this material as decontaminated sediment. If simple decontamination is

Table 6.1 Material Balance for the Sediment Pretreatment System

Stream tons/yr	1 Sediment	1a Oversize	1b Fines	2 Wash Water	3 Sand and Gravel	3a Oversize Rinse	4 Lime Filter Aid	5 Filter Feed	6 Rinse Water	7 Discharge Water	8 Dewatered Sediment
<b>Solids</b>											
Hydrate	346.3	3.8	342.5		3.8	0.0		342.5			342.5
C <sub>6</sub> H <sub>6</sub> n-1	2,868.4	31.5	2,834.9		31.5	0.0		2,834.9			2,834.9
S	264.6	2.9	261.7		2.9	0.0		261.7			261.7
Al <sub>2</sub> O <sub>3</sub>	3,127.8	34.4	3,093.4		34.4	0.0		3,093.4			3,093.4
SiO <sub>2</sub>	25,151.4	276.8	24,874.6		276.8	0.0		24,874.6			24,874.6
K <sub>2</sub> O	523.5	5.8	517.8		5.8	0.0		517.8			517.8
MgO	448.0	4.9	443.1		4.9	0.0		443.1			443.1
Fe <sub>2</sub> O <sub>3</sub>	630.6	6.9	623.7		6.9	0.0		623.7			623.7
FeO	567.4	6.2	561.2		6.2	0.0	3,018.8	561.2			561.2
Ca(OH) <sub>2</sub>								3,018.8			3,018.8
CaO											
CaSO <sub>4</sub>											
Na <sub>2</sub> CO <sub>3</sub>											
NaCl											
Na <sub>2</sub> O											
Heavy Metals	145.4	1.6	143.8		1.6	0.0		143.8			143.8
<b>Total</b>	<b>34,071.5</b>	<b>375.0</b>	<b>33,696.5</b>	<b>0.0</b>	<b>375.0</b>	<b>0.0</b>	<b>3,018.8</b>	<b>36,715.4</b>	<b>0.0</b>	<b>0.0</b>	<b>36,715.4</b>
<b>Liquids</b>											
H <sub>2</sub> O	69,787.4	768.0	69,019.3	2,496.2	1,493.3	1,772.8		70,792.1	168,404.2	215,597.3	23,598.9
NaNO <sub>3</sub>											
NaOH											
NaCl	2,119.2	23.3	2,095.9	2,496.2	10.7	12.7		2,108.5		1,897.7	211.9
<b>Total</b>	<b>71,906.6</b>	<b>791.4</b>	<b>71,115.2</b>	<b>2,496.2</b>	<b>1,504.0</b>	<b>1,785.5</b>	<b>0.0</b>	<b>72,900.7</b>	<b>168,404.2</b>	<b>217,495.0</b>	<b>23,810.9</b>
<b>Gases</b>											
N <sub>2</sub>											
O <sub>2</sub>											
Ar											
CO <sub>2</sub>											
SO <sub>2</sub>											
H <sub>2</sub> O											
NaCl											
NO <sub>x</sub>											
<b>Total</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>	<b>0.0</b>
<b>TOTAL</b>	<b>105,978.1</b>	<b>1,166.3</b>	<b>104,811.7</b>	<b>2,496.2</b>	<b>1,879.0</b>	<b>1,785.5</b>	<b>3,018.8</b>	<b>109,616.0</b>	<b>168,404.2</b>	<b>217,495.0</b>	<b>60,126.2</b>

Table 6.2 Material Balance for the Plasma Vitrification System

Stream tones/yr	9 Scrubber Recycle	10 Fluxes	11 Plasma Air	12 Plasma Offgas	13 Glass Product	14 Desulfurizer Lime	14 Calcium Sulfate	16 Desulfurizer Offgas	17 Scrubber Makeup	18 Clean Offgas	19 Scrubber Bleed	20 Resin
Solids												
Hydrate												
C <sub>2</sub> H <sub>4</sub>												
S												
Al <sub>2</sub> O <sub>3</sub>				92.8	3,000.6		92.8					
SiO <sub>2</sub>				746.2	24,128.3		746.2					
K <sub>2</sub> O				15.5	502.2		15.5					
MgO				13.3	429.8		13.3					
Fe <sub>2</sub> O <sub>3</sub>				37.4	1,209.9		37.4					
FeO												
Ca(OH) <sub>2</sub>						551.5	121.4					
CaO		1,813.8		129.0	3,978.2		1,114.9					
CaSO <sub>4</sub>												
Na <sub>2</sub> CO <sub>3</sub>		3,504.3										
NaCl					29.7							
Na <sub>2</sub> O				61.5	1,987.9		61.5					
Heavy Metals	0.0			37.9	105.9		22.3	15.6		15.6		15.6
Total	0.0	5,318.1	0.0	1,127.6	35,370.5	551.5	2,225.4	15.6	0.0	0.0	15.6	15.6
Liquids												
H <sub>2</sub> O	0.0								2,858.1		2,538.0	
NaNO <sub>3</sub>	0.0								151.8		322.6	
NaOH												
NaCl	0.0										182.3	
Total	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3,010.0	0.0	3,040.9	
Gases												
N <sub>2</sub>			51,251.4	51,148.9				51,148.9		51,183.5		
O <sub>2</sub>			15,769.7	5,668.5				5,668.5		5,565.6		
Ar			938.7	938.7				938.7		938.7		
CO <sub>2</sub>				10,459.2				10,459.2		10,459.2		
SO <sub>2</sub>				524.3				0.0				
H <sub>2</sub> O				28,273.3				28,234.3		28,624.8		
NaCl				182.3				182.3				
NO <sub>x</sub>				113.9				113.9				
Total	0.0	0.0	67,959.7	97,309.0	0.0	0.0	0.0	96,745.7	0.0	96,771.7	0.0	
TOTAL	0.0	5,318.1	67,959.7	98,436.6	35,370.5	551.5	2,225.4	96,761.3	3,010.0	96,771.7	3,056.5	

not possible, the oversize material will also be vitrified, and the rinse water removed from the oversized fraction will be mixed back with the undersize screen fraction.

### 6.1.2 Salt Rinsing and Dewatering

The next step in pretreatment of the sediment is removal of the bulk of the salt contained in entrained seawater. Removal of salt is desirable to avoid operating and maintenance problems in the plasma vitrification system. Salt removal and dewatering will be important to any thermal process. At plasma melter operating temperatures, much of the NaCl present in the sediment will be vaporized, with a fraction escaping into the offgas system. Heavy salt vapor loading in the offgas ducting may result in deposition on duct walls, and will accelerate corrosion of the offgas system refractory, as well as increase the dissolved salts loading in the scrubber. If the NaCl loading in the offgas is large, the scrubber water will rapidly become saturated with sodium chloride, requiring a larger bleed stream to be removed from the gas scrubber water. Since the bleed stream will probably need to be treated (depending on the actual heavy metal loading and local discharge regulations), liquid treatment costs will be lowest when a pretreatment step removes most of the salt.

Removal of NaCl is accomplished by simple rinsing and dewatering. Slaked lime (calcium hydroxide) is first added as a filtration aide (Stream 4), at a typical concentration of 0.1 lb/gallon. Operating experience by Severson Environmental indicates that addition of lime greatly simplifies the process of fine sediment filtration. Since lime will be added later in the process as a glassforming agent, lime is an obvious choice as a filtration aide. Lime added to dewater the sediment accounts for roughly two-thirds of the total calcium oxide required for vitrification.

The sediment is partially dewatered by processing with a high-throughput filter. Single-stage filtration dewateres the sediment to approximately 60 to 70 weight percent solids, removing roughly in excess of 90% of the dissolved salt from the sediment (initially 2 weight percent NaCl). Stream 8 then contains only 0.35% NaCl. If a second-stage filtration is needed, rinse water (Stream 6) is added to further desalinate the mixture, yielding a melter feed stream that is once again dewatered to 60 to 70% solids, but now contains less than 0.10% NaCl; a 95% removal of chloride has therefore been accomplished. The material balance shown in Figure 6.1 conservatively assumes that rinsing with two volumes of fresh water is required, and only 60% solids result in the dewatered sediment. Actual salt removal efficiency will depend on the results of flocculation and dewatering characterization to be carried out during Phase II with industrial-scale equipment.

Note that the saltwater discharge stream is not anticipated to contain contaminant concentrations of any hazardous species of regulatory concern. Experience at Severson Environmental has indicated that contaminated sediments containing both heavy metals and up to 30% oil may be dewatered successfully, yielding a water product which can be discharged within environmental regulatory limits. The most likely contaminant in the water stream is hydrocarbon. If necessary, this water stream may be passed through an activated charcoal bed to strip out minor quantities of organics. This water will be collected and analyzed during Phase II for determination of its organic and metal content, and evaluation of the need for treatment before discharge.

### 6.1.3 Plasma Vitrification

This pretreated stream (Stream 8) is then blended with scrubber recycle water (Stream 9) and injected into the mixing duct (known as a tuyere) with a slurry pump. Although dewatering can produce a product having a solids content as high as 60-70%, higher levels water may be desirable to (1) permit easier pumping of the slurry into the melting tuyere, and (2) better atomization of the feed in the plasma plume, caused by the extremely rapid flashing of the water content to steam. These two advantages are at the expense of the additional energy input requirement to evaporate and heat the water. Phase II testing will determine melter operating characteristics at different feed moisture contents and define the desired feed water content.

On contact with the intense heat of the plasma plume, the fine sediment-glassformer mixture is rapidly heated. The plasma plume consists of a jet of air which has been superheated to temperatures approaching 5000°C by passage through a DC arc. Additional air is injected into the tuyere, dropping the temperature and extending the lifetime of the tuyere refractory. On contact with this superheated air stream, the fine sediment particles are heated first to the point where the water content is flashed to steam, then to calcination temperatures (at which point glassformer sodium and calcium carbonates are dissociated to form  $\text{Na}_2\text{O}$  and  $\text{CaO}$ , and hydrated mineral species are reduced to anhydrous oxides), and finally to melting temperatures. Because of the extremely high temperatures and vigorous mixing conditions (assisted by the explosive evaporation of the sediment moisture content), the heat transfer coefficients in the tuyere zone are extremely large, and complete melting of refractory oxide particles takes place in time scales on the order of 10 milliseconds. A typical mixing temperature in the melting tuyere with slurry feed is 2200 to 2600°C, whereas the highest melting species in the sediment melts at only 2045°C (alumina); complete melting is therefore anticipated before the feed leaves the tuyere. Rapid melting is enhanced by the small particle size of the sediment, and the vigorous mixing and intense thermal radiation in the tuyere.

The liquid oxide mixture is then deposited in the crucible zone at the exit of the tuyere. The melt accumulates there for a residence time characteristic of the design pool depth and product throughput. In previous vitrification tests, the total residence time in the melter was less than 30 minutes, as compared to tens of hours in a large commercial glassmaking tank; the Plasma Melter product was nevertheless well vitrified and homogeneous.

### 6.1.4 Glass Product Manufacture

The molten glass/slag product is extracted via a bottom drain and collected. The flow-sheet in Figure 6.1 assumes water quenching to form a granular aggregate (Stream 17). In actual production processing, the molten product will be directly quenched into water to produce a shattered aggregate material, or otherwise collected for fabrication of alternate products. If manufacture of granules or rock wool were the final product, the molten material would flow from the Plasma Melter into a secondary glass tank heated by gas combustion torches, wherein the granule or fiber formation process would take place. To accomplish final product fabrication, the molten output of the plasma process will need to be interfaced with glass production equipment, which could be rock wool spinning wheels, a granulator, a prilling process, or roll casting, depending on the par-

ticular product of interest. Depending on the desired final product; glass manufacturing options include:

- Spinning into fibers with rotating wheels for rock wool insulation;
- Spinning into fibers with centrifugal drum spinners for fiberglass insulation;
- Granulating or prilling to form roofing granules for asphalt shingles;
- Coarse quenching to form construction aggregate for roadbed or cinder block;
- Fine quenching to form sandblasting grit ("Black Beauty");
- Crushing to form cullet for the manufacture of glass beads or other glass products; and
- Quenching to form filler material for artificial onyx resin bathtubs, etc.

Each of these product options produces a material having a different value, market demand, and production overhead. A market survey is required to identify which product or products would be most economical overall for the New York/New Jersey Harbor material.

### **6.1.5 Gas Cleaning**

The offgas cleaning system will be designed to remove nitrogen oxides, sulfur oxides, and any volatile metal components from the gas stream. The offgas handling system proposed for plant operation is comprised of components well established for handling contaminated offgases -- (1) a quench system, (2) a high temperature sulfur adsorption system, (3) a high efficiency scrubber and recirculation system, (4) a separator demister, (5) a heat exchanger, (6) offgas filters, and (7) regenerative blowers to maintain a negative pressure within the vitrification melter.

Most of the components of the sediment will rapidly be incorporated into the glassy melt. Some fraction of the more volatile heavy metals (e.g., Cd, Pb, Cr, and Hg) will report to the offgas stream and leave the melter. The partitioning of these metals during plasma vitrification will be measured in the Phase II Pilot Tests. This offgas is cleaned by:

- Partial quenching to reduce the temperature
- Lime injection to absorb sulfur dioxide
- Hot gas filtration to collect and remove calcium sulfate formed by sulfur gettering
- High-efficiency liquid scrubbing to complete the gas quenching and to remove and collect heavy metals and nitrogen oxides; and finally
- Low-temperature final filtration to eliminate entrained mist.

Testing at the Pilot Plant has demonstrated that complete (99.99999%) destruction of organics occurs in the melter, and that downstream treatment of the offgas for final organic destruction will not be necessary to meet air quality standards.

The scrubber liquor is circulated through a heat exchanger to remove excess heat, and makeup water is continuously added to account for water stripped out as steam by the hot offgases. Lime injection is an industry standard for removal of sulfur from the effluent of coal-fired power plants, and can be readily applied here. The high temperatures of the plasma offgas stream will prevent condensation of Hg and heavy metal

chloride vapors with the  $\text{CaSO}_4$ , so that this waste stream should be minimally contaminated. Westinghouse is also an industry leader in the development and application of hot gas filtration systems.

A fraction of the scrubber liquor is continuously withdrawn and returned to the melting tuyere. This recirculation is carried out for two purposes. As the heavy metal concentrations build up in the scrubber, eventually each will attain a concentration such that the fractional retention in the glass, multiplied by the concentration in the mixed sediment+recycle feed stream, is equal to the rate of addition with fresh sediment feed. At that point the net flow of that contaminant in the scrubber recycle stream reaches steady state. The total volume of the recycle stream is dominated by sodium chloride, which is known to have a low glass retention (measured at approximately 10% during vitrification testing). It is this retention efficiency which sets the volume of the recycle stream reported in the material balance, where the recycle water flowrate is roughly 2/3 of the water flow in the partially dewatered feed. Addition of this water also reduces the slurry solids density entering the tuyere, making pumping easier and reducing abrasive wear on the pump and injection system, and improves tuyere heat transfer.

#### 6.1.6 Scrubber Water Treatment

The purge stream from the scrubber water will need to be treated to remove a fraction of the heavy metals that are too volatile to be captured in the glass melt. While many toxic heavy metals such as nickel, copper, zinc, and silver have high retention efficiency in the plasma vitrification process, some are likely to report, at least in part, to the offgas. Although no data are presently available on the fractional retention of these metals in the glass phase, we made estimates based on our past pilot test experience using other feed streams. We estimate 85% retention for Pb, 80% for Cd, 65% for Cr, and 2% for Hg. Given these fractional retentions and sediment metal concentrations measured during Phase I testing, the following quantities of heavy metals will report to the offgas:

- The total Hg flowrate at 1.29 ppm in the feed is 85.6 lb/yr, or 83.9 lb/yr carried over at 2% retention;
- Cd is present at 37.1 ppm (2510 lb/yr feed, or 503 lb/yr carried over at 80% retention);
- Pb is present at 617 ppm in the sediment (41,800 lb/yr, or 6,270 lb/yr carried over at 85% retention); and
- Cr is found at 367 ppm in the feed (24,900 lb/yr, or 8,700 lb/yr carried over at 65% retention).

Note that these figures represent *conservatively low minimum retention efficiency estimates*, and are *not* based on actual data for sediment vitrification. In addition, the figures reflect once-through retention estimates at low concentrations of water-soluble (and hence relatively volatile) chemical species of each metal, whereas the scrubber water is partially recirculated, allowing multiple passes through the vitrification system. The contaminant carryover estimates are therefore maximum values that could be expected. Analysis of offgas and product streams during Phase II will quantify the actual retention efficiencies for the metals found in the sediment.

The volumetric flowrate of the scrubber bleed stream shown in Figure 6.1 (Stream 18) is only roughly 1.42 gallons/minute (2,850 tons/yr), based on maintaining the scrubber water at 20% of the saturation concentration of NaCl; this amounts to roughly 0.5% of the scrubber system makeup water. The *maximum* estimated contaminant levels in this stream based on the carryover rates indicated above would therefore be 15 ppm Hg, 76 ppm Cd, 1,500 ppm Cr, and 1,100 ppm Pb. Even if these estimates represent conservative maximum values, treatment of this water stream is clearly required. High-efficiency chelating ion exchange resins have been developed for extraction of mercury (in particular) from water streams; such a resin column would also remove cadmium, lead, and other heavy metals. The small size of this water stream and the relatively low total salt loading make this application straightforward. Assuming the resin to have a capacity of about 16 kg/ft<sup>3</sup> expressed as calcium carbonate, equivalent molar loading of the four heavy metals above would only generate 25 cy/yr of contaminated resin. This material could either be encapsulated and disposed of as hazardous waste, or additional process development could be done to recover and separate the heavy metals.

### 6.1.7 Oversize Material Vitrification

It was indicated above that disposal of the oversize material would be handled in a somewhat different manner from the fine sediment, assuming that washing of this material is not successful in reducing the contaminant level to the point where it may be dumped directly. Since injection of sediment into the tuyere requires a small particle size both for injection and for rapid heat transfer during the time-of-flight in the tuyere, a different strategy must be used for large material. This is particularly true of metallic debris, which would not necessarily melt at the 1400°C operating temperature of the sediment vitrification process. It would be possible to melt larger mineral and organic debris by directly dumping this material into the molten pool through a secondary feed.

A second approach for disposing of the oversize material is slag melting using the combined energy input of a plasma torch and a coke bed. Since two heat sources are present, the operating temperature can be much higher, exceeding the melting point of iron and steel. In addition, the presence of hot carbon creates a reducing environment, such that metal remains as molten metal rather than being oxidized. Slag and mineral species are melted and extracted as a separate, stratified molten stream floating above any molten metal that might be present.

Operation of such a coke-bed melter is straightforward. A mixture of lump coke (commonly used for blast furnace operation) and sediment debris is added at the top of the melter shaft. The plasma torch is used to ignite the coke bed, and continues to operation providing process heat. As the coke bed burns down, the sediment minerals are melted along with any metal content. Ash from the coke (primarily silica and alumina) is also incorporated into the molten oxide phase. Extraction of molten product from the bottom is done in the same way as the tuyere melting system, and most of the offgas cleaning system is identical. The reducing atmosphere introduces a few minor differences. A gas-fired afterburner is provided at the top of the shaft to combust carbon monoxide which is generated in the coke bed, introducing some additional heat into the scrubbing system. The chemistry of the minor contaminant metals will differ as well, in that lead and zinc may report to the offgas system as metals rather than oxides and

chlorides, depending of the specific gas chemistry. These materials would then be recovered from the scrubber water by filtration rather than ion exchange, simplifying the water treatment issue.

Because of the small volume of the oversize fraction (only 373 tons/yr), a small coke-bed melter could be used intermittently for processing of this material. The facility currently operating at the Westinghouse Pilot Plant has the capacity of processing several tons per hour, so that a one to two week campaign of a unit of this size would be sufficient to process all of the oversize inventory from the 100,000 cy/yr plant. A much shorter coke bed campaign would be required using a full size melting unit.

#### **6.1.8 Rinse Water Treatment**

We do not believe that the rinse water used on the feed sediment will require any treatment, The pilot test will generate samples of this stream to verify our assessment.

#### **6.1.9 Optimum Water Content for Dredged Materials**

Commercial sediment decontamination will benefit from dredging which minimizes water content because the salt concentration fed to the decontamination equipment will be reduced if the sediment contains less water. Lower salt content results in (1) improved system operability due to reduced risk of salt deposits in the offgas system, (2) lower maintenance costs due to improved refractory lifetime, and (3) reduced size of the scrubber bleed stream, providing a smaller and more concentrated heavy metal stream for water treatment.

The decontamination process will need to be designed to water rinse and then dewater sediment, regardless of the dredged materials water content. The sediment needs to be water rinsed in order to reduce the salt loadings to the plasma melter. If the dredged material contains less water and, therefore, less salt, our rinsing step will be more effective. This will reduce the plasma plant's maintenance and operating cost because less salt will be carried into the plasma system, corroding the materials of construction, and less salt will also build up in the recycle stream, and therefore, the recycle purge stream will be smaller, reducing the operating cost of the plant.

The optimum water content for the dredged material is, therefore, the lowest content obtainable because the lower the seawater content, the less salt will be present in the sediment. Obviously, the integrated treatment train should be designed to optimize the overall system economics. Any increases in dredging cost for reducing the raw sediment's water content will need to be paid back with a cost reduction in the decontamination processing steps.

We are expecting, however, that the dredged sediment will contain about 30% solids, as did the Phase I sample, and the anticipated pretreatment system is designed to remove NaCl from sediments having roughly this seawater content. The Phase II Program will define the sediment pretreatment system for the sediment materials received. The economically optimum pretreatment system will depend on the exact configuration of the plant and the cost basis for the plant such as the site's cost of electricity. Using our current assumed cost basis, for every weight percent increase in solids content achieved in

dewatering, the processing cost is decreased by about \$1/ton. In other words, changing the plasma feed material from a 50 weight percent solids material to a 60 weight percent solids material, decreases the operating cost by \$10/ton. Notice that the dewatering system must work on rinsed sediment, so water will be added to any as-dredged sediment.

### 6.1.10 Intellectual Property

There will be no licensing fees associated with Phase II Pilot Tests or scaleup of the process.

Westinghouse maintains 24 patents on the plasma torch and plasma processing technology. Additional patent disclosures and applications are pending, including the application of plasma technology to sediments and related wastes.

The know-how developed by Westinghouse to successfully apply plasma technology to the processing of materials for resource recovery, destruction, or volume reduction to meet specific application needs is a primary intellectual property resource.

## 6.2 ENERGY BALANCE

Table 6.3 summarizes the energy balance for the 100,000 cy/yr process, with 15 plasma torch tuyeres operating at 2.0 gpm feed each of the 50% solids slurry. Under these

**Table 6.3 - Energy Balance for 100,000 cy/yr Plasma Vitrification Processes**

Plant Capacity	100,000 cy/yr (106,000 ton/yr)
As-Dredged Sediment Solids Content	33.4 weight percent
Melter Slurry Solids Content	50.0 weight percent
Flowrate per Melter Tuyere	2.00 gallons/minute
Number of Melter Tuyeres	15
Individual Torch Operating Power	1,500 kW
Plasma Torch System Efficiency	90%
Total Power Requirement	22,500 kW
Power from Sediment Hydrocarbon Heating Value	5,000 kW
Vaporization of Water	1,400 kW (6.2%)
Heating of Product Gases	10,150 kW (45.1%)
Heating and Melting of Oxides	8,700 kW (38.7%)
Plasma System Heat Losses	2,250 kW (10.0%)
Tuyere Mixing Temperature	2,100°C

operating conditions, the total energy busbar consumption is 22.5 MW. Note that the sediment hydrocarbons provide a heating value equivalent to 5.0 MWe. Torch efficiency, heat losses, and melting energy are based on plasma system commercial experience applied to the sediment application. This energy consumption is equivalent to 19.5 MJ/kg of glass product. This figure is theoretically computed, but is nearly identical to the energy consumption rate of 19.4 MJ/kg measured during Pilot Plant production of glass from simulated high-level nuclear waste for Hanford. This figure is comparable to the energy requirement for production of container glass in a very large, highly optimized, combustion fired glass melter with no water vaporization (typically 8 MJ/kg),

and indicates that the plasma melting process is a cost-competitive technology for melting as well as destruction of hazardous components.

The total plant energy consumption is seen to be 22.5 MW. Each Plasma Torch is operated at 1,500 kW, which is well below the Marc-11 rating of 2,300 MW. Individual torch operating power is an economic tradeoff; at lower power the electrodes experience longer lifetime, but the operating efficiency is slightly lower. A feed slurry solids content of 50% is assumed, which is readily pumpable, and allows recycle of scrubber water while still only requiring a dewatering efficiency of 90% (60% weight solids). All of these figures are, therefore, conservative and readily achievable. Nearly 40% of the total energy is directed into heating and melting of the solids, while most of the balance is consumed by evaporating and superheating water. The sediment water content accounts for the factor of two higher energy requirement of this process as compared to commercial vitrification, where the glassmaking feed contains no water. Note further that the tuyere operating temperature after achieving thermal equilibrium is 1,800°C, which is 400°C above the glass melting temperature and accounts for the extremely rapid heat transfer.

### 6.3 PLANT CONFIGURATION

We assume that the current design concept is based on a fixed based sediment processing facility. Westinghouse is also able to develop a design for a barge-mounted system for plasma vitrification of the sediment, if desired. The scope of operations performed on any barge mounted system and the sediment throughput in a barge mounted system would need to meet the practically size constraints of any such unit.

The plant configuration for the production-scale (100,000 cy/year) design will consist of one plasma melter unit running multiple torches and its operation train. The plant configuration for the production-scale system will consist of one melter island. The melter will consist of a vertical circular shaft with a refractory-lined crucible bottom. A number of melting tuyeres will be arranged radially around the perimeter, each feeding into the common crucible. Figure 6.2 shows a representative configuration for the plasma

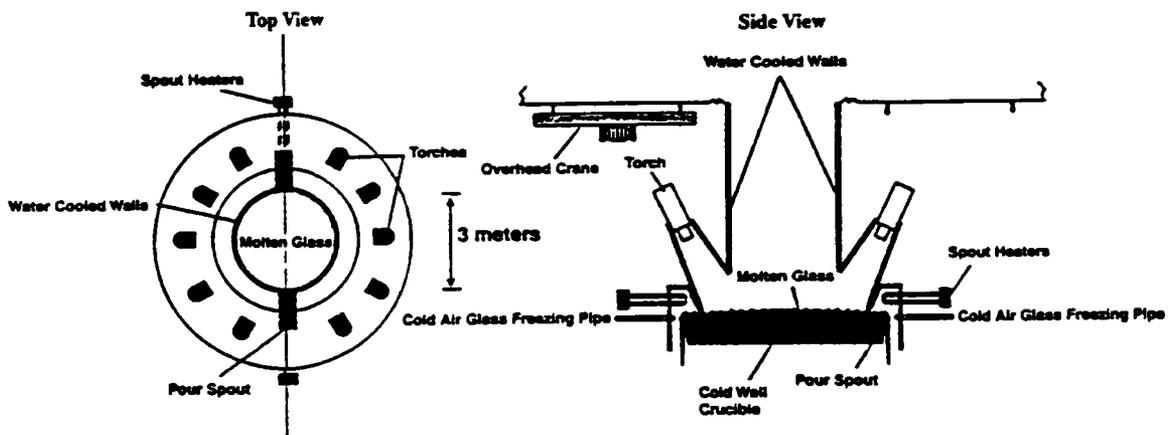


Figure 6.2 The melter island configuration consists of one melter with multiple plasma torches

melter with multiple torches. The full-scale 500,000 cy/year system will be composed of five 100,000 cy/year processing trains. The material balance shown in Section 6.1 indicates that the 100,000 cy/yr plant would produce molten product at a flowrate of 6,800 lb/hr. Vitrification tests with slurry feed of similar solids content generated about 650 lb/hr of glass with a single torch and tuyere; approximately ten torches will be required to meet the required throughput. Ten torches could be arranged on a single melter island. Westinghouse has similar melter island design in commercial operation at the General Motors Corporation plant in Defiance, Ohio. This plasma metal melter operates at a throughput of 90 tonnes/hr in a single melter operating with eight torch/tuyere assemblies, with an overall melter diameter of four meters.

One or two product extraction spouts would remove molten glass product from the melter. This material may fall directly into a water bath where it would shatter into a gravel-like material suitable for use as aggregate, or additional processing operations could convert the molten glass to insulating fiber or roofing granules.

## 6.4 PRODUCTION REQUIREMENTS

The site, utility, and personnel requirements for the production level and full-scale operations are presented in this section.

### 6.4.1 Site Requirements

A two-acre site size is envisioned for the production-scale plant. Ten acres will be required for the 500,000 cy/year full-scale plant. These estimates include sediment pre-processing operations as well as the integrated plasma vitrification process with a glass manufacturing operation. The plant layout will be developed more precisely when the integrated sediment treatment train is specifically designed.

### 6.4.2 Utility Requirements

The utility requirements for the production-scale facility are listed below in Table 6.4 are based on the material balances presented in Section 6.1.

**Table 6.4 Utility Requirements for Production Level and Full-Scale Plants**

Utility	100,000 cy/year	500,000 cy/year
Electrical Power	22.5 MWe	112.5 MWe
Water Usage		
Process Water:	40 gpm	200 gpm
Scrubber Makeup Water	12 gpm	60 gpm
Quench Makeup Water	18 gpm	90 gpm
Recycled Water:		
Torch Cooling Water	750 gpm	3750 gpm
Melter Cooling Water	280 gpm	1400 gpm
Compressed Air (Generated On-Site)	4,000 scfm	20,000 scfm
Glass Former	10,000 ton/year	50,000 ton/year
Raw Sediment	100,000 cy/year	500,000 cy/year
Glass Product	40,000 ton/year	200,000 tons/year

### 6.4.3 Personnel Requirements

Personnel requirements identified for each shift of plant operations are shown in Table 6.5

**Table 6.5 Labor Requirements for Production- and Full-Scale Plants**

Position	Number Needed per Shift	
	100,000 cy/year	500,000 cy/year
Yard Operator	2	4
Control Room Operator	1	1
Maintenance	1	1
Supervisor	1	1

## 6.5 ESTIMATED SEDIMENT PROCESSING COST

At this point in the process development, only estimated costs for integrated treatment trains can be provided. In order to provide accurate cost estimates, a conceptual design is required. The conceptual design needs to have design parameters specified such as the operation requirements (e.g., round the clock, year round), system design basis (e.g., fixed versus shipboard), and sediment supply characteristics (e.g., water content, oil content). Cost estimates for varied treatment systems also need to be based on standard project scopes (e.g., dredging, waste treatment, waste stream disposal) and standard assumptions as to important factors such as labor and utility rates.

In the Phase I proposal, a very rough estimate of sediment processing cost was provided, predicting operating costs in the range of \$80-120/ton. Based on more refined material balances and sediment composition data, the predicted processing cost was re-evaluated. The results of this study are shown in Table 6.6. The table documents principal processing assumptions that were made, consistent with the material balance shown in Tables 6.1 and 6.2, and based on the 100,000 cy/yr treatment facility. Whenever possible, processing data are taken from Phase I test results (sediment water and salt content, mineral composition, hydrocarbon content and heating value, size distribution, glassformer formulation, and operating temperature). Process heat requirements were derived from thermodynamic simulation of the sediment vitrification process, including prediction of the offgas composition and quench water requirements. Although the Westinghouse Plasma Torch is rated in excess of 2,000 kW, a conservative 1,500 kWe rating is assumed for extended electrode lifetime. Plasma system operating parameters (efficiency, air flow) are derived from plant operating experience in commercial systems. Price data are taken from catalogs (chemical prices) or actual utility quotations in the New York Harbor area (electricity rate). A conservatively low market value of only \$10/ton is assumed for construction aggregate.

The processing cost for as-dredged sediment is between \$64 and \$84/ton. Westinghouse believes that this cost is highly competitive as compared to other treatment train options examined during the Phase I proposal process, including soil washing, thermal desorption, and biological treatment. The largest fraction of the total cost (65%) is the cost of electricity. The electrical power rate is derived from actual quotation; even lower rates may be available for large fixed-base customer usage. An additional 20% of the total is labor, the rates for which are estimates; more details on actual labor rates for a plant situated in the New York Harbor area will be developed during Phase II.

**Table 6.6 Predicted Sediment Processing Costs Based on Phase I Test Data**

<b>As-Dredged Sediment Processing Cost</b>	<b>\$64 to 84/ton</b>
<b>Assumed Operating Parameters</b>	
Throughput	100,000 cy/year as-dredged sediment
As-Dredged Sediment Water Content	66.0% weight
Plant Factor (On-Line Fraction)	91.3%
Weight Percent Oversize Material >1 mm	1.1% weight
Volume of Water Used in NaCl Washing	2 sediment volumes
Lime Addition as Filtration Aid	0.1 lb/gallon
Water Content of Dewatered Sediment	30 to 40% weight
Sediment Loading in Final Glass Product	83.2% weight
Glassformer Composition	See Section 6.1
Water Content of Tuyere Feed Slurry	30 to 50 % weight
Tuyere Feed Rate per Torch	2.50 gallons/minute
Torch Electrical Power per Tuyere	1500 kW <sub>e</sub>
Torch Electrical-to-Thermal Efficiency	90%
Air Flow per Tuyere	275 std. ft <sup>3</sup> /minute
Offgas Quench Temperature	200°C
Lime Usage in Desulfurizer	1.2 × stoichiometric requirement
Scrubber Bleed Stream Salt Concentration	20% of saturation at 25°C
<b>Assumed Utility and Material Costs</b>	
Fresh Water	\$1.00/thousand gallons
Lime (Calcium Oxide)	\$50/ton + \$10/ton shipping
Soda Ash (Sodium Carbonate)	\$105/ton + \$10/ton shipping
Electricity	\$0.03/kWhr
Disposal Cost for CaSO <sub>4</sub>	\$100/ton
Product Market Value	\$10/ton as construction aggregate
Maintenance Parts Costs	5% of capital cost/year
Labor Needs	See Table 6.5

Because the greatest factor is the cost of electricity, process modifications which conserve energy will have a large impact on the overall processing cost. In particular, the water content of the melter feed has a major impact on processing cost, with a 1% reduction in water content yielding roughly a \$1/ton reduction in total operating cost (since it is no longer necessary for the plasma torch to evaporate and superheat this water). If dewatering to 70% solids could be accomplished (Sevenson believes this may be possible), at least a 10% reduction in water content could be realized, lowering the processing cost.

Note also that because the Plasma Melter process is highly modular, there is little economy of scale associated with moving from the 100,000 cy/yr plant to the full-scale 500,000 cy/yr facility. Increasing the throughput is essentially a matter of increasing the number of tuyeres. Some economy of scale will be derived from the use of a common

control system and labor pool. The bulk of the total cost is associated with energy cost and labor. The \$84/ton processing cost will, therefore, be reduced by some fraction at the larger plant scale.

## 6.6 ENVIRONMENTAL, HEALTH, AND SAFETY IMPACTS

The integrated plasma vitrification treatment train will be designed to produce minimal environmental impact while processing all sediment contaminants. Some nuisance odors will result from handling of dredged harbor sludge (marine decay, hydrogen sulfide), but will only occur during the mechanical handling of the sediment between barge and plant. No odors are expected from the cleaned offgases.

The process's proven ability to retain metals in a glass and destroy organic is discussed in generic terms. Evidence of the plasma system's ability to process the contaminants is provided. The fate of each expected sediment contaminants in the integrated Plasma Vitrification Treatment Train is then described.

### 6.6.1 Retention of Metals in Glass is a Waste Standard

Glass is perhaps the most stable known chemical form for incorporation and immobilization of heavy metals. Glass provides, by far, the most effective means of ensuring that metals will be immobilized and not leach into the environment. No cementation or encapsulation process ensures as low a leachability. Rather than simply encapsulating the waste mechanically in a matrix, the toxic heavy metals (as oxides) become part of the glass matrix in solid solution, and as such are exceptionally resistant to leaching. For this reason, glass has been selected by the Department of Energy for long-term storage and isolation of the complex radioactive metal mixtures found in high-level and low-level nuclear waste. A wide variety of metal oxides exhibit good solubility in glass, and will exhibit very low leachability from the final product.

Table 6.7 presents a brief summary of toxic metals of concern in the environment and their likely fate during vitrification. Metals with high glass solubility may be effectively incorporated into the glass matrix and immobilized. If the metal oxide volatility is high (as in the case of cadmium, for example), some fraction of the feed metal will report to the offgas stream and require recycle from the scrubber, but ultimately the metal will become encapsulated in the glass matrix. Certain metals with low glass solubility but low volatility may still be incorporated effectively if the concentration is limited, including nickel and chromium. In all cases, the leachability of the heavy metal will be low.

**Table 6.7 - Retention of Heavy Metals During Vitrification**

Difficulty of Vitrification	Easy		Recycle Required	Very Difficult
<b>Glass Solubility:</b>	High	Low	High	Low
<b>Metal Oxide Volatility:</b>	Low	Low	High	High
<b>Species</b>	Fe, Sb, Cu, Sn, Mn, Zr, U, Ba, Sr	Ni, Cr, Ag	Cd, As, Pb, Zn, Bi, Mo, Cs, Tc	Hg, Se

The few metals exhibiting both low glass solubility and high volatility (including mercury) present the greatest challenge. The concentration will gradually increase in the scrubbing system liquor. If the retention efficiency is low, the accumulation of heavy

metals may be avoided by a combination of scrubber water recycle and removing a bleed stream. from the scrubber, Some water re-addition to the dewatered sediment is anticipated to improve pumpability. With recycle, the concentration of each heavy metal in the scrubber will increase until the fraction retention per pass multiplied by the concentration in the mixed feed-recycle stream is equal to the total feed rate of that metal. For metals exhibiting very low retentions (for example Hg), excessive scrubber water concentrations are avoided by also maintaining a small bleed stream, which is subsequently treated by ion exchange to yield a small heavy metal concentrate.

### 6.6.2 Organic Destruction Has Been Extensively Verified

The intense heat of the plasma vitrification tuyere is capable of destroying even the most refractory organic species. Plasma pyrolysis of PCB-containing oils was tested by Westinghouse for the EPA and the New York State Department of Environmental Conservation at Love Canal. In these tests, 40,000 liters of various solvents and 4,700 liters of PCB-containing Askarel transformer fluid were processed in the plume of a Westinghouse Plasma Torch. Careful analysis of the offgas was carried out to ascertain the PCB destruction efficiency and look for dioxin or furan formation. In no case was a measurable quantity of dioxin found; PCB destruction efficiencies up to 99.999998% were measured, as shown in Table 6.8.

**Table 6.8 – Results of Plasma Pyrolysis Testing of PCB Transformer Fluids**

Test Number	Run Time (minutes) at 1 gpm	Destruction Removal Efficiency (%)*
1	60	99.999,997
2	60	99.999,994
3	60	99.999,96
4	150	99.999,998
5	300	99.999,999,8
6	300	99.999,999,8
7	300	99.999,999

\* DRE =  $100 \times [\text{PCB}(\text{input}) - \text{PCB}(\text{output})] / \text{PCB}(\text{input})$

Based on these results, it is expected that complete destruction of the organic component of the New York Harbor sediment will occur, and that no residual toxic organic species (PCB, dioxin, furan, polyaromatic hydrocarbon, or pesticide) will remain in the final product. To confirm this prediction, Phase II testing will include sampling of the offgas for both vapor-phase and particulate organic material to quantify whatever trace of TOC material might escape the plasma pyrolysis process.

### 6.6.3 Fate of Sediment Contaminants

A summary of the fate of contaminants to be processed in the Plasma Vitrification process is presented based on our current level of data and design information. Phase II Pilot testing will clarify many of the assumptions used in this data. The contaminants to be processed by the plasma vitrification system are summarized in Table 6.9, along with a description of end state of these contaminants in the integrated plasma vitrification system.

**Table 6.9 The Integrated Plasma Vitrification Treatment Train Minimizes Contaminant Impact**

Contaminant	Fate	Discharged As
<b>Organics</b>		
Hazardous Organics	Dissociated in Plasma Reactor	CO <sub>2</sub> and H <sub>2</sub> O in exiting gas
PAH's	Dissociated in Plasma Reactor	CO <sub>2</sub> and H <sub>2</sub> O in exiting gas
Pesticides	Dissociated in Plasma Reactor	CO <sub>2</sub> and H <sub>2</sub> O in exiting gas
Dioxins and difurans	Dissociated in Plasma Reactor	CO <sub>2</sub> and H <sub>2</sub> O in exiting gas
PCBs	Dissociated in Plasma Reactor	CO <sub>2</sub> and H <sub>2</sub> O in exiting gas
<b>Toxic Metals</b>		
Arsenic	Encapsulated in product glass (100%)	Vitrified glass product
Cadmium	<ul style="list-style-type: none"> <li>Encapsulated in product glass (&gt;80%)</li> <li>Removed from quench water onto ion exchange media and stabilized (&lt;20%)</li> </ul>	<ul style="list-style-type: none"> <li>Vitrified glass product (80%)</li> <li>Stabilized, concentrated hazardous waste stream (20%)</li> </ul>
Chromium	<ul style="list-style-type: none"> <li>Encapsulated in product glass (&gt;65%)</li> <li>Removed from quench water onto ion exchange media and stabilized (&lt;35%)</li> </ul>	<ul style="list-style-type: none"> <li>Vitrified glass product (&gt;65%)</li> <li>Stabilized, concentrated hazardous waste stream (&lt;35%)</li> </ul>
Copper	Encapsulated in product glass (100%)	Vitrified glass product
Lead	<ul style="list-style-type: none"> <li>Encapsulated in product glass (&gt;85%)</li> <li>Removed from quench water onto ion exchange media and stabilized (&lt;15%)</li> </ul>	<ul style="list-style-type: none"> <li>Vitrified glass product (&gt;85%)</li> <li>Stabilized, concentrated hazardous waste stream (&lt;15%)</li> </ul>
Mercury	<ul style="list-style-type: none"> <li>Encapsulated in product glass (&gt;2%)</li> <li>Removed from water quench onto ion exchange media and stabilized (&lt;98%)</li> </ul>	<ul style="list-style-type: none"> <li>Vitrified glass product (&gt;2%)</li> <li>Stabilized, concentrated hazardous waste stream (&lt;98%)</li> </ul>
Nickel	Encapsulated in product glass (100%)	Vitrified glass product
Silver	Encapsulated in product glass (100%)	Vitrified glass product
Zinc	Encapsulated in product glass (100%)	Vitrified glass product
<b>Other Components</b>		
Sulfur	<ul style="list-style-type: none"> <li>Dissociated in Plasma Reactor, forms SO<sub>2</sub> in offgas</li> <li>Captured in lime desulfurization system as CaSO<sub>4</sub></li> </ul>	Landfill CaSO <sub>4</sub>
Oils	<ul style="list-style-type: none"> <li>Dissociated in Plasma Reactor</li> <li>Heating value adds to thermal efficiency of the integrated system</li> </ul>	CO <sub>2</sub> and H <sub>2</sub> O in exiting gas

A summary of all output streams from the integrated system and their disposal was provided in Section 1.3.2. Note that two waste streams result from the sediments sulfur content and the sediments volatile metal content, primarily mercury. These two waste streams will be common to any thermal process, but the integrated plasma vitrification process minimizes the quantity of these streams.

Most heavy metals in the waste have good glass solubility and relatively low volatility, and will be incorporated easily into the product. For some metals (Cd, Cr, and Pb), a fraction will report to the offgas; recycle of the metal-laden scrubber water back to the

melter as slurry makeup water will result in the most of this material eventually becoming part of the glass product. A full steady-state analysis is required with actual fractional retention data to ascertain how much of each species will become glass, and how much will be removed in the scrubber water bleed stream for eventual extraction by ion exchange.

Mercury in the waste is the only metal oxide in the sediment for which the glass solubility is low, and which will be difficult to vitrify. The concentration of Hg is very low in the sediment (1.3 ppm), and depending on the retention efficiency which will be measured in Phase II, encapsulation of a large fraction of the Hg may be possible by recycle. Any mercury in the offgas will be effectively scrubbed in the aqueous scrubbing system, and accumulate there as Hg metal, soluble mercury salts, or a mixture of the two. It is assumed that most of the mercury in the system will eventually be extracted from the scrubber bleed stream.

## 7. PHASE II PILOT TESTS

The proposed Phase II testing will be carried out in the pilot-scale plasma melter located at the Westinghouse Plasma Center in Madison, PA. This facility has been used for vitrification of multi-ton quantities of simulated landfill material, municipal solid waste incinerator ash, and simulated radioactive tank waste. This Plasma Center pilot test facility is described in Section 7.1. The Phase II Pilot Test Work Scope is presented in Sections 7.2 to 7.5.

### 7.1 DESCRIPTION OF PILOT TEST FACILITY

The proposed location for carrying out the Phase II testing is the Westinghouse Plasma Center in Madison, Pennsylvania, roughly 30 miles east of Pittsburgh. This facility includes the Plasma Melter Pilot Plant, a multi-ton-per-day facility which is operated by the Westinghouse Science and Technology Center. This facility has been designed to be highly flexible and heavily instrumented, and is used for demonstration testing and process development in a wide range of plasma melting and processing applications.

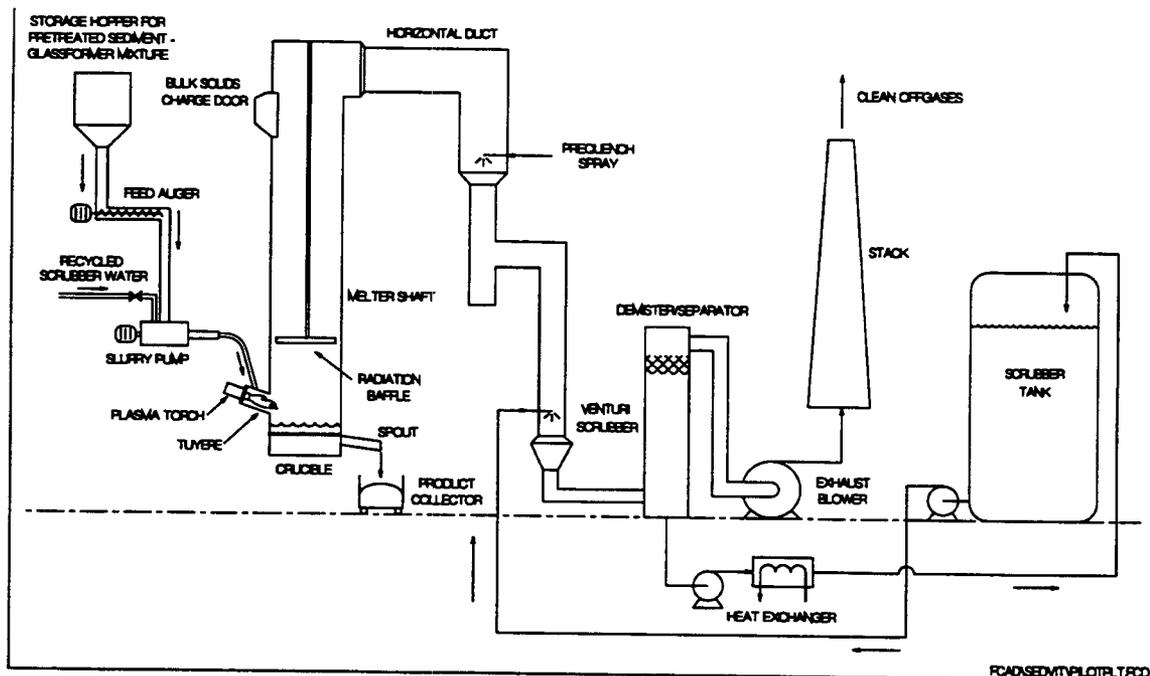
The plasma facility consists of a Plasma Melter including a Westinghouse Marc-11 plasma torch thermal source capable of 2.3 MW output, several feed supply systems for injecting metered quantities of aqueous/slurry chemical species and glassformers, a glass product collection system, a scrubber system for separating and collecting aerosols and volatiles, and a state-of-the-art process control and data acquisition system.

The overall vitrification pilot-scale process schematic is shown in Figure 7.1. Pretreated feed from the slurry tank is injected into the melter tuyere. A commercial sediment pretreatment system will be supplied by Severson and operated at the Plasma Center site. The exact configuration of the pretreatment system will be defined after pretreatment treatability tests are completed at the start of Phase II.

Glassformer powder is continuously blended with feed slurry in a hopper equipped with blending paddles, from which it is extruded by a progressing cavity slurry pump capable of pumping dense slurries. The sediment-glassformer mixture is injected into the plume of a non-transferred arc plasma torch in the vitrification tuyere, where melting and chemical decomposition of contaminant and glassformer species take place at extremely high temperature. The molten material exits the tuyere and is captured in the crucible zone, from which it is poured continuously into product collectors.

Process offgases and any entrained solids are carried up the shaft of the melter, and quenched by a water spray. Further quenching takes place in a venturi scrubber and demister system, after which the clean gas is discharged through a stack. The water used in the quench spray and scrubbing system is recirculated to the scrubber holding tank through a heat rejection system. Contaminants accumulate in the scrubber for eventual disposal following the test. Sampling ports are provided throughout for col-

lection of gas and scrubber water samples, enabling closure of the material balance for selected contaminants and demonstrating compliance with air quality regulations.



**Figure 7.1- The Westinghouse pilot-scale Plasma Melter facility provides the complete system needed to demonstrate vitrification of harbor sediments**

To minimize the possibility of shutdown due to the unlikely event of equipment failure, primary and backup plasma torches and power supplies will be available to supply thermal energy. Likewise, a standby injection system for simulant feed will be available. The Plasma Center control room facilities and data acquisition system will be dedicated to this program during testing. In addition, the Plasma Center provides a team of engineers and technicians intimately familiar with the operation of the melter, and skilled in handling a wide range of materials both hazardous and nonhazardous. The site is both secure and fully permitted to carry out the Phase II test operations.

### 7.1.1 Pilot Unit Throughput

The plasma melter has produced up to 8 metric ton/day of a vitrified glass product. Typical injection rates are between 1 and 2 gallons per minute processing feed slurries. Assuming feeding of a 50 weight percent slurry of dry solids in water at 1.5 gpm, the 25 cy sediment inventory could be processed in roughly 90 hours of melter operation, equivalent to a sediment processing throughput of 6.7 tons/day. Exact processing time will depend on the water content of Phase II feed sediment material obtained in the commercial pretreatment system and the actual sediment residence time obtained in the tuyere. If a longer residence time is required in the tuyere, the anticipated 1.5 gpm processing rate will be lowered to achieve good quality glass product from the melter.

### 7.1.2 Materials and Slurry Handling Capabilities

The feedstock supply capabilities for the Plasma Processing Facility consist of dry feed systems, liquid/slurry feed system, and a glassformer feed system. The system pumps at rates in excess of 11 liters per minute. A unique primary and secondary recirculation system, in combination with a mechanical agitator, maintains feed uniformity in suspension in the holding/mixing tank and throughout the injection system to ensure that the desired chemical composition is injected into the Plasma Melter. Flowrates of liquid/slurry feeds are monitored and metered by a flowmeter combined with a metering valve. Sampling ports are strategically located throughout the feed system for taking grab samples for analysis. Glassformers are injected into the Plasma Melter by an auger feeder equipped with vibratory capability to ensure a constant and desired feedrate into the tuyere.

### 7.1.3 Plasma Melter Design

The heart of the treatment process is the plasma-fired vitrification reactor, shown in Figure 7.2. The pilot-scale Plasma Melter is a vertical shaft design, refractory-lined to

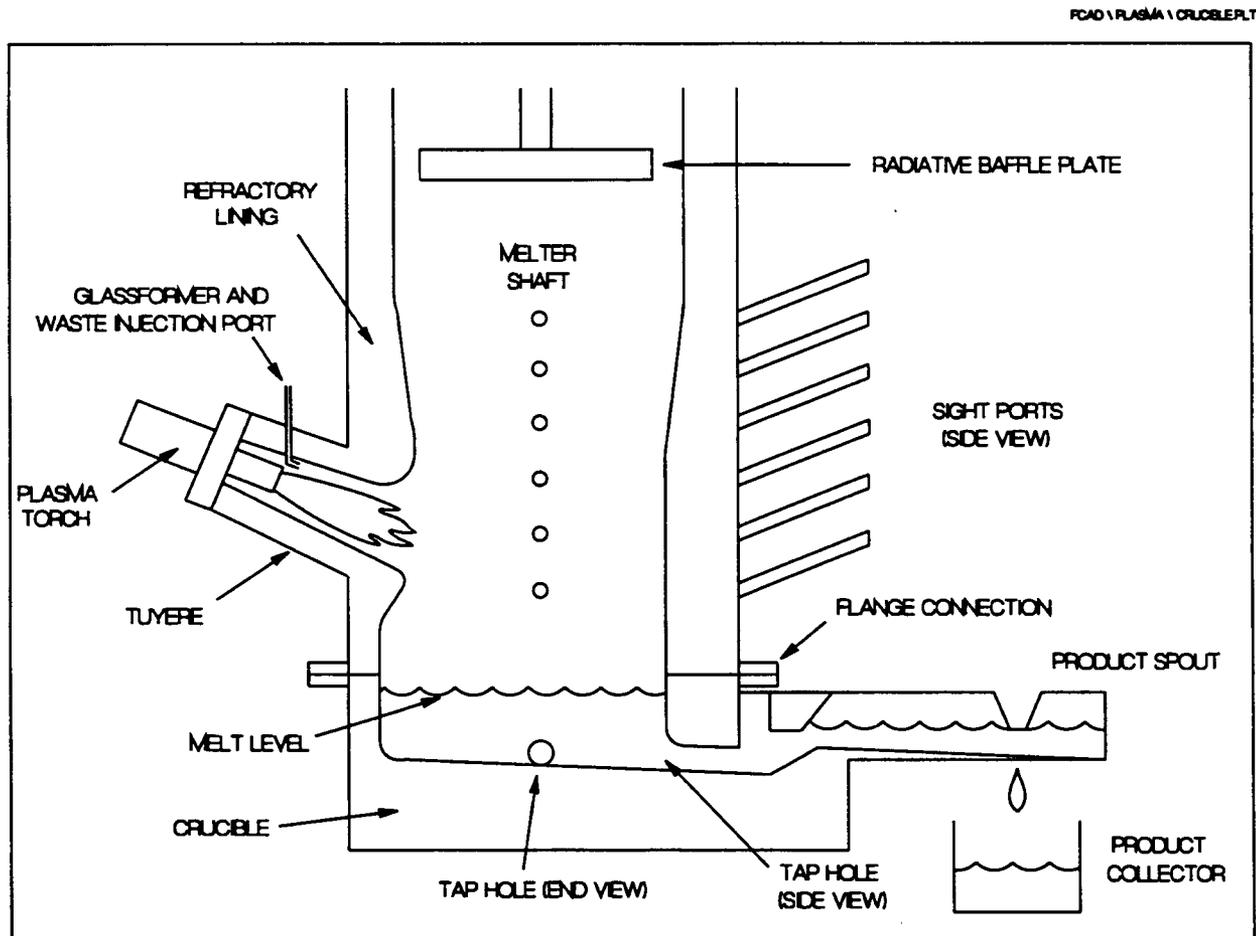


Figure 7.2 - The Plasma Melter crucible design is simple and easy to maintain

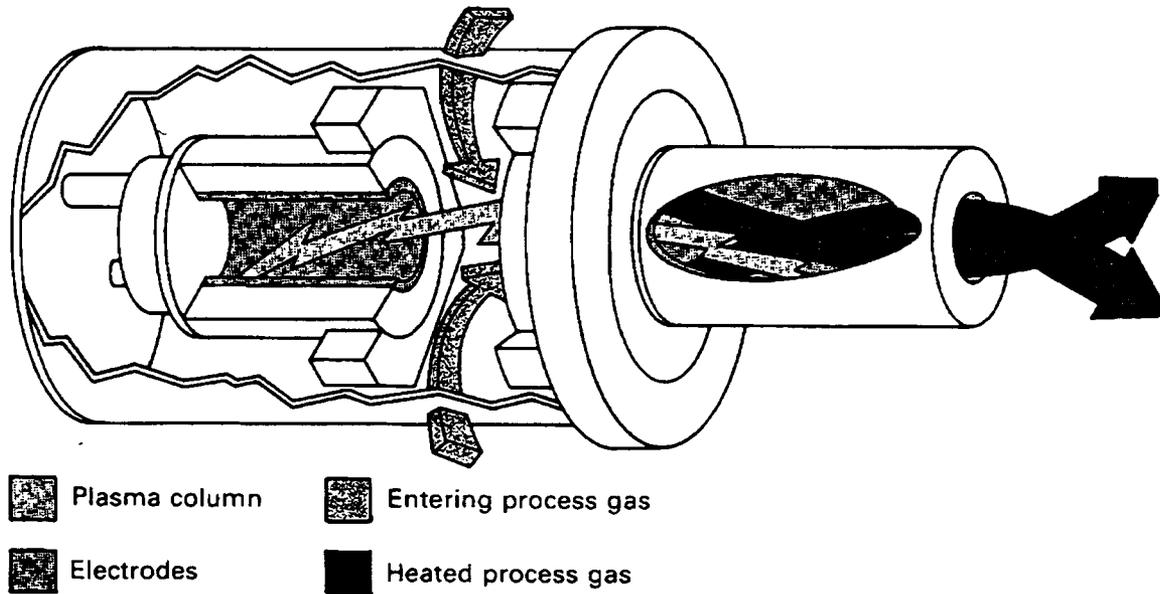
provide a 35-inch inner diameter. The shaft is lined with a high-alumina refractory material which has shown good resistance to vitreous slag materials in past melter testing. A refractory-lined crucible mounts to the bottom of the vertical shaft with a bolted flange for easy assembly and disassembly. A tap hole at the bottom of the crucible is integrated with a heated spout assembly to provide a flow path for molten, vitrified waste glass. During test operations the vitrified product is collected in steel mold boxes, supported by sand-lined steel containers mounted on rails for easy removal from the Plasma Melter.

In production operations, the molten product would be (1) directly quenched into water to shatter the glassy slag into aggregate, (2) granulated in a controlled manner to produce uniform roofing granules, or (3) centrifugally thrown into glass fibers for rock wool fabrication.

The Plasma Melter is designed for either solid or liquid feed, and may be operated either with or without a coke bed. In its application for stabilization of harbor sediment, the sediment will be processed without a coke bed (direct injection into the plasma plume), and the sediment will be fed to the reactor at a relatively low moisture content. The dewatered sediment will be combined with glassforming additives (lime and soda ash) and sufficient water to provide a pumpable dense slurry (about 50% weight solids), and the resulting mixture injected directly into the vitrification tuyeres through injection nozzles. The vigorous tuyere air circulation and rapid flashing of the sediment moisture content cause rapid mixing of the waste with the extremely hot (5000°C) plume generated by the plasma torch, producing a mixing temperature well in excess of 2200°C. Decomposition of even relatively refractory organic carbon compounds such as PCBs and dioxin is nearly instantaneous.

#### **7.1.4 Plasma Torch Design**

Process heat is supplied by a commercially available Westinghouse non-transferred arc Plasma Torch, mounted to one side of the crucible zone in an entry duct known as a tuyere. A production scale Westinghouse Marc-11 Plasma Torch (see Figure 7.3) supplies the thermal energy to the Plasma Melter. The Westinghouse non-transferred arc plasma torch is a rugged and commercially available technology. The torch is rated at 2300 kW input electrical power, with an overall torch-and-tuyere electrical-to-thermal efficiency between 80 and 90%. The torch design uses a pair of cylindrical, water-cooled electrodes to generate a DC arc, which is rotated by an electric field. Process gas is injected through the cylindrical electrode gap at typical flowrates of 100 to 150 scfm. The high velocity of the gas carries the arc into the throat of the torch, and heats the working gas to extremely high temperatures. Field coils rotate the electrically conductive plasma at high rotational velocities, such that the point of contact of the arc with the downstream electrode is constantly moving. This feature minimizes ablation of the electrode, and leads to electrode lifetimes which are the best in the industry. The superheated process gas is mixed with additional gas at the torch nozzle; this shroud gas flow blankets the superheated plasma plume and extends the life of the tuyere refractory.



**Figure 7.3 - The Westinghouse Marc-11 Plasma Torch is a rugged and commercially proven design having long life and minimal maintenance costs.**

Because of the simplicity of its construction, maintenance on the Westinghouse plasma torch is simple and requires little time. In typical industrial operations, the plasma torch is connected to the melter by simple flange connections, with all of the required utilities connected through the mounting flange. Disconnection of four bolts, two electrical connectors, and several quick-connect fittings supplying air and cooling water allows the torch to be changed out in less than fifteen minutes.

The electrodes within the torch eventually require replacement due to slow ablation. Typical electrode lifetimes are 750 to 1500 hours on the downstream electrode, and 1000 to 3000 hours on the upstream electrode. Replacement of the electrodes is a quick and inexpensive operation, however. In a commercial melter with several torches, the operation of melter need not be interrupted for torch electrode replacement. A single torch is disconnected from the tuyere and swapped out for a spare torch, a process requiring only 15 minutes time. Full electrode rebuilding can be accomplished by one individual in less than one hour.

### **7.1.5 Offgas-Handling Capabilities**

Offgas handling in the pilot demonstration test is shown in Figure 7.4. The Pilot Plant uses a venturi scrubber, and eliminates the filtration train downstream of the scrubbing system. No separate sulfur removal system is provided, with  $\text{SO}_2$  removal occurring in the scrubber. The two-stage quench and dry-sorption system is designed to cool the overall gas stream, remove sulfur oxides, and finally condense volatile salts (primarily  $\text{NaCl}$ ) which may be entrained in the melter offgases. The high-efficiency scrubber then removes condensed particulates from the exhaust stream. The separator/demister removes additional solid particulates and aerosols and thoroughly scrubs the exhaust stream, capturing water soluble offgas products and sending them to a holding tank for recycle to the scrubber. Environmentally acceptable  $\text{N}_2/\text{O}_2/\text{CO}_2$  offgases are ejected by the blower through an exhaust stack.

# PLASMA MELTER OFFGAS SYSTEM

FCAD \ PLASMA \ OFFGAS.PLT

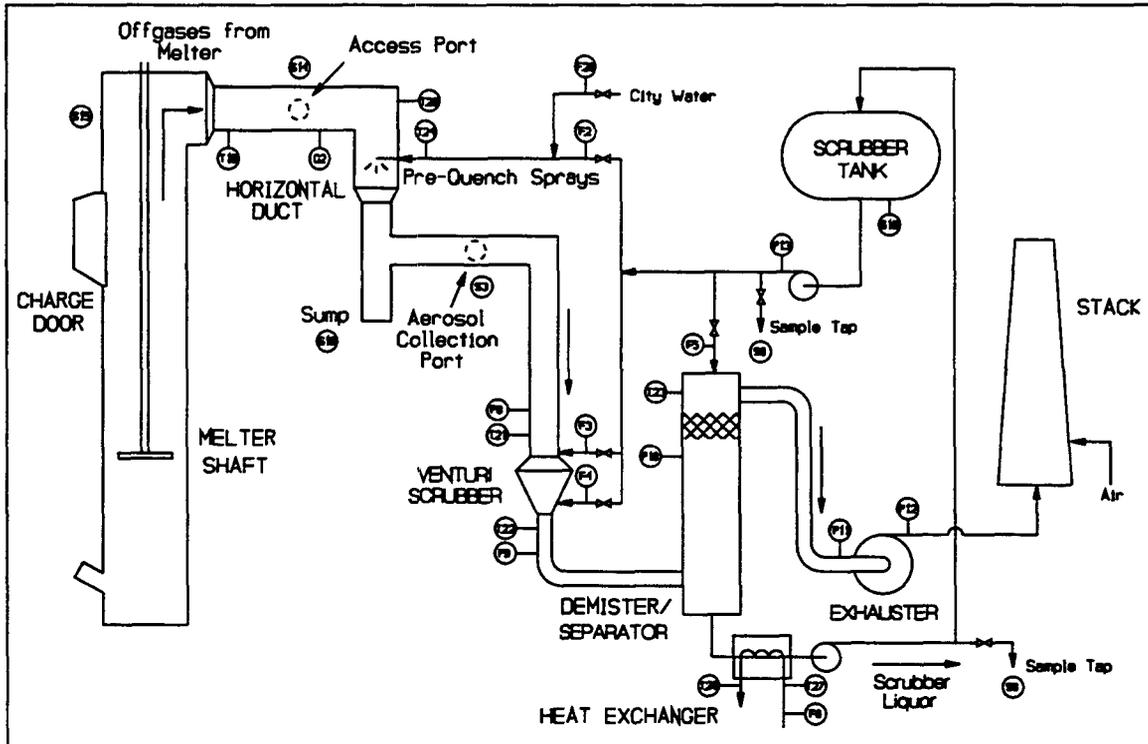


Figure 7.4 - The pilot plant offgas handling system

In the production plant, a secondary scrubber liquor-processing system provides for recycle of volatiles and entrained material. The heat exchanger in the scrubber tank removes thermal energy absorbed from the offgas stream by the scrubber system and prevents excessive temperature rise in the scrubber reservoir tank. To prevent continual accumulation of both water and volatile species in the scrubber water, a bleed stream is continuously removed and processed by an evaporator to remove water collected from waste steam condensation. This concentrated bleed stream is then reinjected into the melter feed, returning the volatile salts to the vitrification process. For all species which have a reasonable solubility in the glass product, steady state operation will result in which the feed entering the tuyere will be enriched in these species. In the case of the Pilot Plant, contaminants will be allowed to accumulate in the scrubber water, with samples taken periodically to track the rate of accumulation and hence the entrainment/volatility of the species involved.

## 7.1.6 Sampling, Instrumentation, and Test-Monitoring Capabilities

The Plasma Melter facility has a variety of sampling locations for removing feed, product, and offgas samples to aid in process monitoring and control and for performing the crucial overall mass balance analysis. The liquid/slurry feed system has sampling ports

on the primary and secondary recirculation loops and on the feed injection tube immediately upstream of the injection port. Product samples are removed from the molten product stream at the Plasma Melter spout.

The Plasma Melter System is equipped with on-line gas analyzers for obtaining off-gas concentrations of nitrogen oxides (NO/NO<sub>x</sub>), oxygen (O<sub>2</sub>), and hydrogen (H<sub>2</sub>). The NO/NO<sub>x</sub> analyzer is a multi-range Beckman, Model 951 H, with sensitivity of ±1 ppm and a maximum of 10,000 ppm. The O<sub>2</sub> analyzer is a multi-range Beckman instrument with sensitivity of ±0.5% by volume and a maximum of 25% by volume. The H<sub>2</sub> analyzer is a Thermocon instrument with a sensitivity of ±0.1% by volume and a maximum of 10% by volume. The outputs from the analytical instruments are constantly monitored and recorded by the control room data acquisition system. In addition to the on-line instrumentation monitors, bomb samples of offgas can be obtained for analysis of other gases of interest (such as sulfur dioxide). Locations are provided for EPA Method 5 particulate sampling as well.

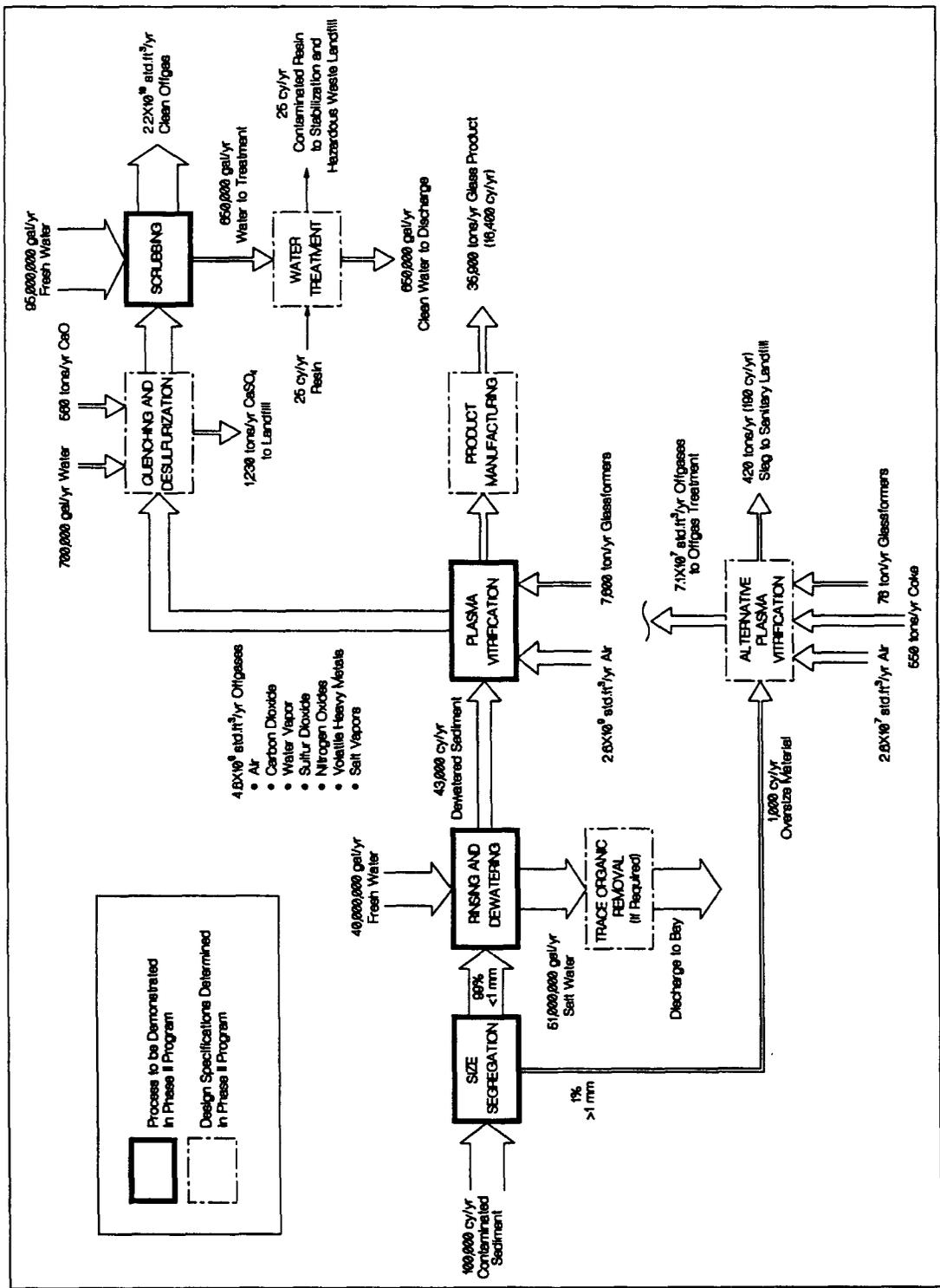
### **7.1.7 Process Control Equipment**

Process control equipment includes a process logic controller for monitoring critical process variables and alarming or activating system shut-down when alarm set points have been exceeded. The sediment flowrate, glassformer flowrate, torch input power, and process gas flowrate are operator controlled to obtain the desired product production rate, desired product composition, and Plasma Melter operating conditions.

The pilot-scale Plasma Melter is highly instrumented with temperature, pressure, and flow measurement devices to completely characterize the heat and material balances around the melter. System instrumentation includes strategically located thermocouples, pressure transducers, flowmeters, power meters, and voltmeters to control, monitor, and record torch power, feed streams, product stream, and offgas. Critical data are recorded on the computer data acquisition systems and chart recorders allowing real-time control of process parameters such as torch input power, feed flow, process gas flow, glassformer input rate, product formation rate, product stream temperature, and offgas temperature, flow rate, and composition. Data collection and process control are further enhanced by operator-maintained data reduction graphs and charts. A Hewlett Packard Model 3054A Automatic Data Acquisition/Control System interfaces with several personal computers for data archiving and data reduction.

## **7.2 PHASE II PILOT TEST PLANS**

The Phase II Pilot Test Program provides the most crucial design information needed to develop demonstration and production systems for plasma vitrification of the sediment. The Phase II pilot program will develop the information needed to size and design auxiliary equipment that is commercially available for the integrated system. Figure 7.5 provides a block diagram representation of the possible components of an integrated plasma vitrification system. The blocks indicated in blue are the crucial components for which design information will be obtained from the test program to design the integrated system. The remaining blocks will either be determined to be unnecessary by the stream analysis obtained in the test program, or they will be able to be commercially



FC\DATA\SED\VI\PROCESS.FDD

Figure 7.5 The Phase II Pilot Program will provide the design basis for crucial operations of the Treatment Train.

designed from the samples taken. Westinghouse offers to retain 55 gallon samples of the following streams for 6 months after the test program:

- Sediment rinse water
- Scrubber water
- Glass aggregate
- Oversized sediment material.

Retaining these samples will allow commercial treatability and design tests to be performed, if needed, on the actual product streams from Phase II testing.

The Phase II Pilot program will also provide the information needed to develop the glass manufacturing process design. Most of the melt will be cast in large glass blocks, but a fraction of the melt will be water quenched to produce a bulk aggregate glass. Once a target glass product is selected based on the local area's market needs, commercial glass manufacturing processes can be tested using the glass generated from the Phase II Pilot tests.

### **7.3 TECHNICAL APPROACH TO OPERATIONS**

The general operation procedures needed for the pilot testing are described below.

#### **7.3.1 Quality Assurance**

Westinghouse will prepare Quality Assurance procedures, along with its Pilot Test Plans, that will assure the testing and sampling will meet BNL requirements.

#### **7.3.2 Sample Acquisition and Handling**

Westinghouse will receive the dredged sediment at its Waltz Mill Site. The sediment will be stored at ambient conditions before pilot testing begins.

A 25 cubic yard sediment sample will be obtained from Newtown Creek by the U.S. Army Corps of Engineers who will also be responsible for arranging all needed dredging permits. Brookhaven/Rensselaer Environmental Partnership Multistate Alliance (BREP/MSA), in consultation with EPA and COE, New York District, will obtain any necessary permits for transportation and arrange for the delivery of sediments to participants by barge, rail, or truck.

Concentrations of contaminants in the untreated material will be determined by analysis of specimens obtained at the time of dredging by BREP/MSA.

#### **7.3.3 Site, Utility, and Personnel Requirements**

Westinghouse will provide all site, utility, and personnel requirements for the Phase II tests.

The site of the pilot-scale testing will be the Westinghouse Plasma Center in Madison, PA, roughly 30 miles southeast of Pittsburgh. The Plasma Center is located on the Westinghouse Waltz Mill site. The Science & Technology Center operates and is responsible for Plasma Center operations. This facility is designed to be a highly flexible

pilot plant for testing of plasma processing of various materials, and includes all of the required subsystems for large-scale testing (plasma torches, power supplies, control systems, offgas scrubbing system, feed delivery systems, 1000- and 4000-gallon slurry tank storage, cooling water systems). Typical utility requirements for testing in the pilot-scale Plasma Melter are shown in Table 7.1. The Plasma Center maintains a permanent staff of four engineers and six technicians, and draws upon additional engineering staff at WSTC and technician staff as needed for test operations.

**Table 7.1 Utility Requirements for Pilot-Scale Plasma Melter Operation**

Utility Parameter	Requirement
Typical Slurry Processing Rate	1 to 2 gallons/minute
Electrical Power Usage	1500 to 2000 kW 1600 to 2100 amps 900 volts DC
Process Temperature	1100 to 1600 °C
Plasma Torch Air Flowrate	250 to 500 scfm
Cooling Water Usage	60 gpm (vitrification tuyere) 15 gpm (plasma torch electrodes) 70 gpm (melter shell)

### 7.3.4 Pilot Test Permitting

We assume that the Newtown Creek dredged sediment for the Phase II tests will:

- not be classified as a hazardous waste
- not be bacteria laden, containing pathogenic contamination resulting from the presence of raw sewage.

Using these assumptions, the Plasma Test Facility possesses the required air-quality permit for gaseous and particulate emissions. The expected emissions for each proposed test are communicated to the Air Quality Office of the Regional PADEP office which results in a letter to Westinghouse giving permission to conduct the test.

Pennsylvania Department of Environmental Protection (PADEP) has indicated that the Newtown Creek harbor sediment will not be classified as hazardous waste if it passes PADEP's TCLP and reactivity criteria. In this case, no hazardous waste permits will be required to do the proposed work. The sediment, however, may be considered residual waste as defined and regulated under PA Code Title 25. A waste of this type is typically regulated on a case-by-case basis with specific conditions and limitations applied to any testing or processing of this material. Westinghouse will work closely with the regional PADEP office.

### 7.3.5 Pilot-Scale Test Waste Disposal

Westinghouse will dispose of all unused sediment and process waste. Disposal of waste and/or hazardous materials from the Plasma Center is managed through the site Environmental Compliance Coordinator. Only licensed sanitary waste, chemical waste, or hazardous waste disposal firms are used for disposition of waste materials, and all shipping and disposal is carried out in full compliance with all local, state, and federal regulations. Proof of such lawful disposition will be provided to BREP/MSA as required.

We anticipate that the residual solids and glass from the Phase II tests will meet all TCLP leaching test requirements, and will be able to be disposed of in a sanitary landfill. The conservative assumption is further made that the 5000 to 10,000 gallons of scrubber water will be contaminated with the maximum anticipated heavy metal carryover (see Section 6.6.3):

- 1.29 ppm Hg at 98% carryover = 2.2 µg/ml
- 37.1 ppm Cd at 20% carryover = 12.4 µg/ml
- 617 ppm Pb at 15% carryover = 155 µg/ml
- 367 ppm Cr at 35% carryover = 216 µg/ml.

This liquid will qualify as hazardous, and will be disposed of as such by a licensed hazardous liquid waste disposal contractor.

### **7.3.6 Site Security**

Westinghouse will supply a secure site for Phase II Pilot Tests. The Westinghouse Waltz Mill site, where the pilot-scale tests are to be conducted, is a fully guarded and fenced facility. All visitors must sign-in at the main gate guard house where badges and vehicle passes are issued. The Plasma Center is a secure building where only authorized Plasma Center personnel or escorted visitors are permitted.

The Plasma Center is fully staffed with the required personnel for each test in attendance. Typically this is about 5 engineers and 6 to 8 technicians per test. A fully equipped fire brigade and safety professionals are available in case of an emergency.

### **7.3.7 Observation of Testing**

As in the case of previous test programs, the interagency team and their contractors will be invited to observe any and all test operations, including feed pretreatment, plasma melter operations, and sample management. The interagency team may also be permitted to perform sampling or effluent monitoring, if prearranged with Westinghouse.

## **7.4 PILOT-SCALE TEST PROCEDURES**

Westinghouse will perform all pilot testing activities to process 25 cy of Newton Creek sediment. Pilot-scale testing will involve sediment pretreatment (consisting of size segregation, rinsing to remove salt, and dewatering) and sediment vitrification. The sediment pretreatment testing will be carried out largely by Severson Environmental, while the vitrification will be carried out by Westinghouse Electric.

### **7.4.1 Sediment Pretreatment**

Westinghouse is subcontracting Severson Environmental, an environmental company with extensive commercial experience in sediment dredging handling, and dewatering, in order to assure the most economical path to developing an integrated sediment treatment system. Severson will perform treatability tests on a small supply of sediment from Newtown Creek in order to select the optimum pretreatment train for the pilot test.

Sediment pretreatment testing will be performed in two stages, laboratory treatability studies and pilot scale pretreatment of 25 cy of sediment. Laboratory treatability tests

will be performed in Severson's treatability laboratory in Niagara Falls. Pilot demonstration will be performed at commercial feed rates at Westinghouse's Waltz Mill Site. Upon completion of the laboratory pretreatment testing, Severson will design the pretreatment train to be used in the 25 cubic yard pilot demonstration. The necessary equipment will be assembled, and the mobile sediment pretreatment design for pilot testing will then be used at the Waltz Mill Plasma Center to perform the following operations:

1. **Sizing:** Oversized sediment material exceeding 1 mm will be removed from the 25 cubic yard sample.
2. **Desalinating:** The sediment will be rinsed with fresh water to minimize input sodium chloride fed with the sediment.
3. **Dewatering:** The sediment will be dewatered, most likely with a filter press, using part of the lime glassformer as a dewatering additive. It is expected that a sediment feed stream with between 50 and 70% solids will be obtained to feed the plasma melter.

#### **7.4.2 Vitrification Testing**

Westinghouse will perform vitrification testing to process the 25 cy of pretreated sediment. Vitrification testing is planned to occur in 12 hour run periods. Samples will be taken during each run period, designed to obtain information at varied operation conditions.

Pretreated feed from the slurry tank will be injected into the melter tuyere at approximately 50% solids content. The plasma torch in this case is a Westinghouse Marc-11, having a rate power output of 2300 kW. Typical injection rates are between 1 and 2 gallons per minute processing feed sediment at glass production rates of 6 to 9 tons/day; roughly 75 to 100 hours of operating time are anticipated to completely process 25 tons of wet sediment. Exact processing time will depend on the water content of Phase II feed sediment material obtained with the commercial pretreatment system and the actual sediment residence time obtained in the tuyere.

Molten product produced in the Plasma Melter is extracted via a bottom tap hole, and leaves the melter via a heated spout system. The bulk of the product will be collected in sand-lined steel mold boxes. In actual production processing, the molten product will be directly quenched into water to produce a shattered aggregate material, or otherwise collected for fabrication of alternate products. To simulate the aggregate quench process and generate test samples, grab samples of the molten glassy product will be collected in ladles and added directly to water in a specially designed Slag Granulator; this unit allows production of tens of kilograms of quenched material for test purposes. The quenched product from the Slag Granulator will be collected at the end of the test for analysis.

One of the experimental parameters in Phase II testing will be the melter feed water content. Although introducing energy cost, some water addition is desirable, since (1) this re-addition provides recycle of scrubber heavy metals and reduces the load on the scrubber bleed stream metals removal process, and (2) additional water in the feed increases the mixing of sediment with the plasma plume in the tuyere due to violent flashing, as well as increasing the emissivity of the gas and enhancing the heat transfer

coefficient. The quantity of recycle scrubber water thus becomes an economic optimization problem. The impact of varied water content on the melting process will therefore be evaluated and quantified, allowing economic optimization of the overall recycle process.

#### **7.4.2.1 Data Collection**

Westinghouse will collect all data during the pilot tests to characterize the system's material and energy balance. The pilot-scale Plasma Melter is highly instrumented with temperature, pressure, and flow measurement devices to completely characterize the heat and material balances around the melter. Samples of the input slurry, glass product, scrubber water, and offgases will be taken at regular intervals to establish the fate of the various trace metals in the system and their retention efficiencies in the glass (see Section 6.6.3). Of particular interest will be retention of sodium chloride, the volatility of which will determine the required volume of the scrubber recycle stream.

To accomplish closure of the material and energy balances, the following data will be collected:

- Masses of all streams associated with pretreatment (feed, oversize material, undersize material, rinse water, lime filtration aid, discharge rinse water, dewatered sediment)
- Cumulative mass versus time of all components in melter feed (dewatered sediment, slurry makeup water, glassformers)
- Plasma torch power
- Plasma system cooling water temperatures and flowrates
- Air flowrates to plasma torch and melting tuyere
- Melter operating temperature
- Cumulative mass versus time of glass product collected
- Scrubber water inventory as a function of time, including makeup water additions
- Mass of particulate material accumulated in scrubber after the test is complete
- Inventory of deposits remaining in melter after the test is complete

#### **7.4.2.2 Sampling**

Westinghouse will supply samples of all major process streams to BREP/MSA. Westinghouse assumes, as specified in the RFP, the BREP/MSA will perform all necessary chemical analyses to analyze the pilot plant streams, including the glass composition analyses for which we will recommend a test laboratory. Westinghouse will submit a test plan specifying the exact number and type of analysis needed to BNL before proceeding with the pilot tests. Samples of the materials specified in Table 7.2 will be provided to BNL for testing. In order to define material balances at some varied operating conditions, we expect to have six test periods from which samples will be generated, that is six analyses will be required on each of the streams in Table 7.2. Westinghouse will provide the specified on-line gas analyses, but not the bomb or Method 5 gas assays.

**Table 7.2 Sampling during Pilot Tests**

Sample	Sample Size
Feed material (as-dredged sediment)	5 kg
Oversized material	5 kg
Pretreated/dewatered sediment	5 kg
Glass product (cast)	50 kg
Glass product (quenched)	20 kg
Rinse water	5 l
Scrubber water	1 l every 12 hours
Scrubber particulate material	1 kg
Offgases	On-line: CO <sub>2</sub> , CO, NO <sub>x</sub>
Offgases	50 ml Bombs: SO <sub>2</sub> (2) Method 5: Particulates (2)
Feed lime	1 kg
Feed soda ash	1 kg

Samples of each of the feed and solid product materials are taken. The offgas analysis is important to close the material balance around the melter and establish the carryover of species to the scrubber. While on-line analysis is available for carbon and nitrogen oxides, sulfur dioxide must be analyzed by gas bomb collection. Two samples are recommended, taken at widely spaced intervals. Similarly, EPA Method 5 testing for entrained particulates will be carried out at two time point, with sampling done by a contract laboratory. The particulate material collected will be forwarded to BNL for analysis. Finally, scrubber water samples are collected every 12 hours, for an anticipated inventory of six samples plus the pretest control over the expected 90 hours of operation. From these samples, the carryover of both metals and cations into the scrubbing system may be computed. As in the case of the bench-scale testing, TCLP and chemical analysis of the glass product materials are recommended, although biological viability testing would not seem to be appropriate given the anticipated use of the product.

#### **7.4.2.3 Measurement of Offgases for Emissions of Concern to BNL**

The plasma system is equipped with the following on-line monitoring systems that feed into the control room data collection. Shaft gases are continuously monitored for :

- Temperature
- Flowrate
- Pressure
- Nitrogen oxides (NO/NO<sub>x</sub>)
- Oxygen (O<sub>2</sub>)
- Hydrogen (H<sub>2</sub>)
- Carbon dioxide (CO<sub>2</sub>), and
- Carbon monoxide (CO)

In addition, the exhaust stack gas is continuously monitored for:

- Oxygen (O<sub>2</sub>)
- Carbon monoxide (CO)

Bomb samples of shaft offgases are also collected for off-line analysis, with particular interest in sulfur dioxide. Particulate analysis, as indicated above, will be done by collection of samples via EPA Method 5.

### **7.4.3 Data Analysis**

Westinghouse will perform the data analysis needed to evaluate the performance of the Phase II Pilot Test including:

- measurement of a global material balance on the sediment vitrification process
- characterization of all process streams to allow development of treatment train design specifications
- production of a glass with the target chemistry for product formation and non-leachable contaminants.

Here again, we assume that BNL will supply all product stream analyses required for these tasks, other than the on-line measurements taken by the Plasma Center that are identified above.

#### **7.4.3.1 Material and Energy Balance**

Measurements taken on process streams will be used to completely characterize the heat and material balances around the melter. As indicated in the previous section, samples of the input slurry, glass product, scrubber water, scrubber particulates, and offgases will be taken at regular intervals. Analyses of these samples combined with the temperatures and flowrates indicated above will permit closure of the overall and component material balances.

In addition, Westinghouse will establish the fate of the various trace metals in the system and their retention efficiencies in the glass. Of particular interest will be retention of sodium chloride, the volatility of which will determine the required volume of the scrubber recycle stream, and the various heavy metals contaminants, which will determine the volume of the scrubber bleed stream.

Measurement of the material and energy balances will provide information to characterize process streams, define the integrated system options, and provide design specifications for the various unit operations

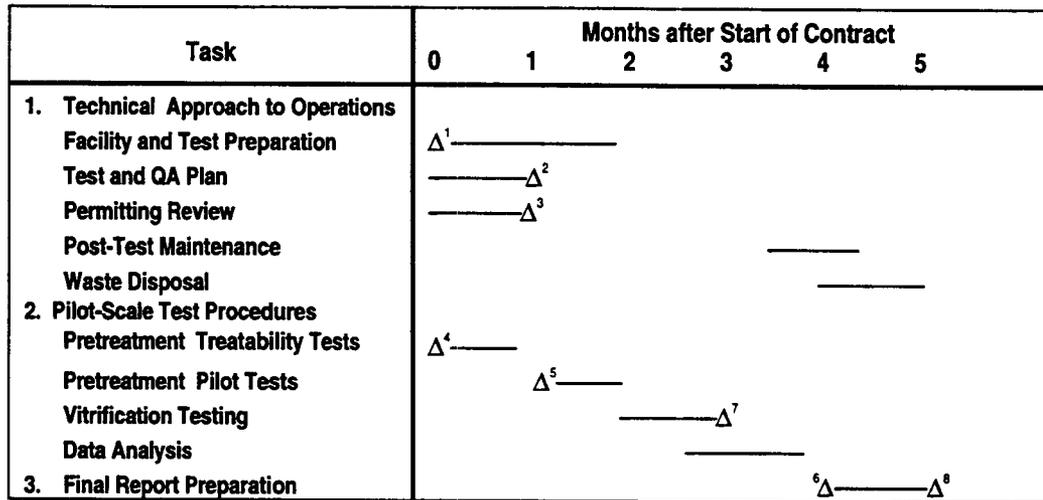
#### **7.4.3.2 Production of a Useable Glass Product**

The pilot program will produce glass with the target chemistry for product formation and low contaminant metal leachability. Westinghouse will provide BNL with 50 kg of product cast glass and 20 kg of quenched glass aggregate.

Notice that the pilot program will *not* have the objective of actually producing glass product with physical form and characteristics equivalent to the final product for sale. To accomplish final product fabrication, the molten output of the plasma process will need to be interfaced with glass production equipment, which could be rock wool spinning wheels, a granulator, a prilling process, or roll casting, depending on the particular product of interest. This interface is not planned for our pilot tests. Glass production operation testing may, however, begin on batch quantities of granular product produced from the plasma pilot unit.

## 7.5 PILOT TEST SCHEDULE AND DELIVERABLES

The schedule proposed for the Phase II Pilot Program is shown below as Figure 7.6 including milestones and deliverables. The Phase II Pilot Testing will need a five-month interval, from the time of contract award to the time of final report submittal. The deliverables for Phase II are Pilot Test samples and a Final Report.



- |                      |   |  |
|----------------------|---|--|
| Phase II Milestones: | 1. Contract Award                               | Phase II Deliverables:                       |
|                      | 2. Test and QA Program Plan Developed           | 7. Deliver samples of process streams to BNL |
|                      | 3. PADEP Approval to Run Test                   | 8. Phase II: Pilot-Scale Testing Report      |
|                      | 4. 5 gallon Sediment Available                  |  |
|                      | 5. Sediment Received                            |  |
|                      | 6. Receive Analysis of Process Streams from BNL |  |

Figure 7.6 — Phase II: Pilot-Scale Testing Schedule

## 8. References

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2. V. B. Guthrie, *Petroleum Products Handbook, 1st Ed.*, McGraw-Hill Book Co. New York NY, 1960, pp. 8-25, 8-32.
3. V. Riboud, Y. Roux, L.-D. Lucas, and H. Gaye, "Improvement of Continuous Casting Powders," *Fachber. Huetttenprax. Metallweiterverarb.*, 19(10), 859 (1981).
4. Mahan, "Slag Control," in *Cupola Handbook, 5th Ed.*, American Foundrymen's Society, Des Plaines IL, 1994, p.259.
5. *Chemical Marketing Reporter*, 248(24), December 11, 1995.
6. C. Weast, Ed., *Handbook of Chemistry and Physics, 49th Ed.*, The Chemical Rubber Co., Cleveland OH, 1968, p. F-145.

## **Appendix A. Corning Engineering Laboratory Services Sediment Elemental Analysis**

Appendix A contains the report received by Westinghouse from Corning Engineering Services Laboratory on the elemental analysis of the total dried sediment sample. This includes quantitative analysis of major metal oxides and carbon, plus semiquantitative analysis of minor metals.

Corning Incorporated  
CELS—Laboratory Services  
Technology Sales & Licensing  
HP ME 03 078 G6  
Corning, New York 14831  
800-235-2357  
607-974-6601  
fax 607-974-6522

Page 1 of 4

November 6, 1995

Ms. Nancy Ulerich  
Westinghouse STC  
1310 Beulah Road  
Pittsburgh, PA 15235

CELS Client No.: 17220-002 **CORNING**  
Date Received : 27-OCT-95  
Date Reported : 04-NOV-95  
Reviewed &  
Approved by : Lisa Hepburn  
Lisa Hepburn  
Analysis  
Coordinator

Copy to: CELS File

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SAMPLE IDENTIFICATION:

Sample 1: NYBASE 1-2  
Sample 2: NYGRAB 4-2

ANALYSIS REPORTED:

Exhibit

- A Quantitative Chemical Analysis
- B Semi-Quantitative Spectrographic Analysis

COMMENTS:

Client Purchase Order No. 34-13485-PR

Direct questions regarding this report to Linda Adams, CELS office.

NOTE: This report shall not be reproduced except in full, without the written approval of CELS - Corning Laboratory Services.

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LABORATORY ANALYSIS REPORT

CELS Client No.: 17220-002

Exhibit A: Quantitative Chemical AnalysisSample Description:

Sample 1: NYBASE 1-2

Sample 2: NYGRAB 4-2

Lab I.D. No.: 24714-95

<u>Determination</u>	<u>Results (Wt.%)</u>		<u>Test Method</u>
	<u>Sample 1</u>	<u>Sample 2</u>	
K <sub>2</sub> O	2.02	1.03	FES
Na <sub>2</sub> O	1.72	0.92	FES
Al <sub>2</sub> O <sub>3</sub>	10.8	4.17	PLS
CaO	1.92	0.71	PLS
Fe <sub>2</sub> O <sub>3</sub>	6.52	2.87	PLS
MgO	2.10	0.65	PLS
SiO <sub>2</sub>	53.4	85.4	PLS
C	8.9	0.52	LECO
LOD	41.8	26.2	LOD
LOI	50.7	28.1	LOI
Cl	0.74	0.47	TITR

LEGEND:

FES: Flame Emission Spectroscopy  
 PLS: Plasma/Emission Spectroscopy  
 LECO: LECO Instrumentation  
 LOD: Loss on Drying at 110°  
 LOI: Loss on Ignition at 650°  
 TITR: Titrimetry

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LABORATORY ANALYSIS REPORT

CELS Client No.: 17220-002

Exhibit B: Semi-Quantitative Spectrographic Analysis

## Sample Description:

Sample 1: NYBASE 1-2

Sample 2: NYGRAB 4-2

Lab I.D. No.: 24714-95

Range %	(ELEMENT)	
	<u>Sample 1</u>	<u>Sample 2</u>
> 30	Si	Si
10 - 30	-	-
3.0 - 10	Al+, Fe	Al-
1.0 - 3.0	Ca, K, Mg, Na	Fe
0.3 - 1.0	Ti	Ca, K, Mg, Na, Ti-
0.1 - 0.3	Cu, Zn	-
0.03 - 0.1	Ba, Mn-, Pb-	-
0.01 - 0.03	Cr+, Ni+, V, Zr	Mn, Zr
0.003 - 0.01	Sn, Sr	Ba, Ni-, Sr, V
0.001 - 0.003	Ag-, B, Co, Ga	B, Co, Cr+, Cu, Ga
<0.001	Mo	Mo, Pb

Comment: Typical detection limits (Wt%) for the ELEMENTS EXAMINED are listed below. They are ONLY general guidelines. Detection limits are composition affected. For oxide conversion factors and a list of other elements that can be detected; see the attached chart.

0.3% - K, P  
 0.1% - As, Cd, Li  
 0.03% - Nb, Zn  
 0.01% - Ba, Na, Sb, Zr  
 0.003% - Al, Co, In, Ni, Si, Ti  
 0.001% - Ag, B, Be, Bi, Ca, Cu, Cr, Fe, Ga, Ge, Mg, Mn, Mo, Pb, Sn, Sr, V

NOTE: (+) after element = upper range and (-) after element = lower range.

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LABORATORY ANALYSIS REPORT

CELS Client No.: 17220-002

## Exhibit B: Semi-Quantitative Spectrographic Analysis (Continued)

FACTORS FOR CONVERSION OF ELEMENTS TO OXIDE**							
Ag2O	1.07	FeO	1.29	Na2O	1.35	Ta2O5	1.22
Al2O3	1.89	Fe2O3	1.43	Nb2O3	1.43	Tb4O7	1.18
As2O3	1.32	Ga2O3	1.34	Nd2O3	1.17	TeO2	1.25
As2O5	1.53	Gd2O3	1.15	NiO	1.27	TiO2	1.67
B2O3	3.22	GeO2	1.44	P2O5	2.29	Tl2O	1.04
BaO	1.12			PbO	1.08	Tl2O3	1.12
BeO	2.78	Ho2O3	1.15	PbO2	1.15	Tm2O3	1.14
Bi2O3	1.11	HfO2	1.18	Pr2O3	1.17		
		In2O3	1.21			VO	1.31
CaO	1.40			RuO2	1.32	VO2	1.63
CdO	1.14	K2O	1.20	RuO4	1.63	V2O5	1.79
CeO2	1.23	La2O3	1.17				
CoO	1.27	Li2O	2.15	Sb2O3	1.20	WO2	1.17
Cr2O3	1.46	Lu2O3	1.14	Sb2O5	1.33	WO3	1.26
CuO	1.25			Sc2O3	1.53		
Cu2O	1.13	MgO	1.66	SiO2	2.14	Y2O3	1.27
		MnO	1.29	Sm2O3	1.16	Yb2O3	1.14
Dy2O3	1.15	MnO2	1.58	SnO	1.13	ZnO	1.24
Er2O3	1.14	MoO3	1.50	SnO2	1.27	ZrO2	1.35
Eu2O3	1.16			SrO	1.18		

\*\* Semi-Quantitative Spectrographic Analysis results are quoted as weight percent of the element (not as the oxide). To convert weight percent element to weight percent oxide, just multiply the percent element by the appropriate factor listed in the above table.

Below is a list of the ELEMENTS that are determined by spectrographic analysis. Analyses are divided into three categories: GENERAL QUANT, NOBEL METALS, AND RARE EARTHS ANALYSES. Nobel Metals and /or Rare Earths may be requested as a group or only by the elements of interest.

General Quant Analysis - Ag, Al, As, B, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cu, Fe, Ga, Ge, In, K, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Sb, Si, Sn, Sr, Ti, V, Zn, Zr, (If requested) - Ta, Te, Tl, W

NOBEL METALS ANALYSIS		RARE EARTHS ANALYSIS			
ELEMENTS	DETECTION %	ELEMENT	DETECTION %	ELEMENT	DETECTION %
Au	0.003	Ce	0.1	Nd	0.3
Ga	0.001	Dy	0.1	Pr	0.1
Hf	0.03	Er	0.03	Sc	0.01
In	0.001	Eu	0.01	Sm	0.1
Ir	0.01	Gd	0.03	Tb	0.03
Pd	0.001	Ho	0.03	Tm	0.01
Pt	0.01	La	0.1	Y	0.003
Re	0.03	Lu	0.01	Yb	0.003
Rh	0.003				
Ru	0.03				

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## **Appendix B. X-Ray Diffraction Analysis of the Harbor Sediment**

Appendix B presents the detailed results of X-ray diffraction analysis done on the Harbor sediment sample by Westinghouse Science and Technology Center, to ascertain the mineral composition of the sediment solids. This appendix is an abridgment of the total XRD report, which also contains numerous scanning electron micrographs of the sediment.



From: Science and Technology Center  
WIN: 236-1290  
Date: November 29, 1995  
Subject: Characterization of Dredge Sediment Samples

To: N.H. Ulerich, 501-3Y64

cc: M.A. Burke, 501-3Y34E

Dear Nancy,

Please find attached the characterization results, including both SEM and XRD, for the five (5) dredge sediment samples you submitted for analysis. A summary of the SEM results is presented in Table 1 while the semi-quantitative XRD results are given in Table 2. The large amount of experimental data generated during this investigation is included for completeness as a series of Appendices. The break-down of this experimental data is as follows:

- Appendix A - SEM Micrographs**
- Appendix B - SEM EDS Spectra and Data**
- Appendix C - X-Ray Dot Maps for Identified Elements**
- Appendix D - X-Ray Diffraction Data**

If you should have any questions regarding this analysis, or if you would like any additional information, please contact me at x1290. Thank you.

Sincerely,

Paula D. Freyer  
Advanced Materials Technology  
Metallurgy  
Materials Characterization

**TABLE 1. SCANNING ELECTRON MICROSCOPY (SEM) MORPHOLOGY AND ENERGY DISPERSIVE SPECTROSCOPY (EDS) ANALYSIS OF DREDGE SEDIMENT SAMPLES**

(all semi-quantitative values given in wt.%)

Sample I.D.	Description	General Features Observed	SEM EDS Elemental Composition
1	NYBASE 1-1	Relatively chemically homogenous material consisting of particles ranging in size from approximately <1 µm to >300 µm. Smooth, flat features observed at higher magnification with a very low density of brightly imaging features also present. (refer to Micrographs, pages 1-6 and EDS Spectra/Data, pages 1-18)	<b>General Area</b> =O (~50), Si (~21), C (~10), Al (~6), Fe (~5), K (~2), S (~2), Na (~1), Ca (~1), Mg (~1), Trace of Cl and Ti. <b>Smooth, flat features</b> =Rich in O, Si, Al, and K. <b>Brightly imaging regions</b> =Rich in Fe, S, and O.
2	NYGRAB 1-1	Relatively well defined and chemically homogeneous circular particles with a consistent diameter of ~ 80 to 120 µm with a low density of larger particles present. Low density of smooth, flat features and brightly imaging features observed at higher magnification. (refer to Micrographs, pages 7-12 and EDS Spectra/Data, pages 19-38)	<b>General Area</b> =O (~51), Si (~22), C (~9), Al (~5), Fe (~5), K (~2), S (~1), Na (~1), Mg (~1), Trace of Cl, Ca, and P. <b>Smooth, flat features</b> =Rich in O and Si. <b>Brightly imaging regions</b> =Rich in Fe, S, and O.
3	NYGRAB 2-1	Relatively well defined and chemically homogeneous circular particles with both small (~80 µm) and large (~1 mm) diameter particles present. Faceted particles observed at ~ 500X with a low density of smooth, flat features and brightly imaging features observed at higher magnification. Ocean organism debris, in a variety of geometries, observed ≥ 2000X (refer to Micrographs page 17 and page 19). (refer to Micrographs, pages 13-19 and EDS Spectra/Data, pages 39-58)	<b>General Area</b> =O (~50), Si (~18), C (~14), Al (~5), Fe (~5), K (~2), S (~1), Na (~1), Mg (~1), Ca (~1), Trace of Cl, and P. <b>Smooth, flat features</b> =Rich in O and Si. <b>Brightly imaging regions</b> =Rich in Fe, S, and O.
4	NYGRAB 3-1	Relatively chemically homogenous material consisting of particles ranging in size from approximately <1 µm to >300 µm (very similar to sample 1, NYBASE 1-1). Smooth, flat features observed at higher magnification with a very low density of brightly imaging features also being present. Organism debris again observed. (refer to Micrographs, pages 20-26 and EDS Spectra/Data, pages 59-81)	<b>General Area</b> =O (~53), Si (~18), C (~9), Al (~6), Fe (~5), Ca (~3), K (~2), S (~1), Na (~1), Mg (~1), Trace of Cl, and P. <b>Smooth, flat features</b> =Rich in O and Si. <b>Brightly imaging regions</b> =Rich in Fe, S, and O.
5	NYGRAB 4-1	Relatively chemically homogenous material consisting of very fine particles ranging in size from approximately <1 µm to >15 µm. In backscatter mode, some of the larger features are observed to be flat and 'flake-like'. Additional smooth features observed at higher magnification with a very low density of brightly imaging features also being present. (refer to Micrographs, pages 27-31 and EDS Spectra/Data, pages 82-97)	<b>General Area</b> =O (~54), Si (~36), Fe (~3), Al (~2), K (~1), Trace of Cl, Na, Mg, S, Ca, and Ti. <b>Smooth, flat features</b> =Rich in O and Si. <b>Brightly imaging regions</b> =Rich in Fe, Si, and O.

**TABLE 2. X-RAY DIFFRACTION (XRD) ANALYSIS OF DREDGE SEDIMENT SAMPLES**  
(all semi-quantitative values gives in wt.%)

Sample No.	Supplied Sample I.D.	Color	XRD File No.	SiO <sub>2</sub> Quartz Silicon Oxide JCPDS 33-1161	H <sub>18.9</sub> Al <sub>18.9</sub> Si <sub>173.1</sub> O <sub>384</sub> Hydrogen Aluminum Silicate JCPDS 42-18	Al <sub>2</sub> SiO <sub>5</sub> <i>Kyanite</i> Aluminum Silicate JCPDS 11-46	Fe <sub>3</sub> (SiFe) <sub>2</sub> O <sub>5</sub> (OH) <sub>4</sub> <i>Cronstedtite</i> Iron Silicate Hydroxide JCPDS 17-470	K-Al-Silicate Hydroxide Phase (a) (b)	Unknown(s) (a) (c)	Amorphous Content (d)
1	NYBASE 1-1	Medium Gray	18795	75	5	6	4	11	0	12
2	NYGRAB 1-1	Medium Gray	18995	66	6	7	6	15	0	3
3	NYGRAB 2-1	Medium Gray	19095	68	6	7	4	15	0	13
4	NYGRAB 3-1	Medium Gray	19195	70	6(e)	7	6	11	0	10
5	NYGRAB 4-1	Light Gray	18895	98	0	0	0	0	2	1

B-4

**Notes:**

- General:** Carbon (JCPDS 26-1079) may also be present in all of the samples (C has only one dominant peak which directly overlaps the dominant peak for SiO<sub>2</sub>).
- (a) Identification of these minor secondary phases generally based on the presence of the 100% intensity peak only.
- (b) This phase was difficult to positively identify but it matches best with the following three compounds. No additional phases could be identified as possible matches.
- Potassium Magnesium Aluminum Silicate Hydroxide (Muscovite-1M, Magnesian, JCPDS 21-993) - KMgAlSi<sub>4</sub>O<sub>10</sub>(OH)<sub>2</sub>
  - Potassium Aluminum Silicate Hydroxide (Muscovite-2M2, Calcian, JCPDS 25-649) - (K,Ca,Na)(Al,Mg,Fe)<sub>2</sub>(Si,Al)<sub>4</sub>O<sub>10</sub>(OH)<sub>2</sub>
  - Potassium Magnesium Aluminum Silicate Hydroxide (JCPDS 40-20) - K(Mg,Al)<sub>2.04</sub>(Si<sub>3.34</sub>Al<sub>10.66</sub>)O<sub>10</sub>(OH)<sub>2</sub>
- (c) Largest unknown peak at d = 5.4843 Å. Numerous searches were run on this small peak with no positive matches identified.
- (d) Values estimated using ratio of amorphous peak height (at highest location of broad peak) to 100% intensity peak height.
- (e) Very questionable if present.

## **Appendix C. Brookhaven National Laboratory Sediment Contaminant and Particle Size Analyses**

Appendix C presents the results of organic and metal contaminant analysis of the as-shipped Harbor sediment, as carried out by Brookhaven National Laboratory. Also shown are the particle size distribution of the sediment, and TCLP leach testing results.

Newtown Creek Sediments - Raw - Collected 10/11/95 ALL VALUES VERY WET. B. Tol.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Analyte	Units	Replicate #1	Replicate #2	Replicate #3	Replicate #4	Replicate #5	Replicate #6	n	Mean	SD	SEMEAN	CV (%)		
Particle size	>4.75 mm	0	0	0	0.18	0.04	0	0	6	0.04	0.07	0.03		179.30
Medium gravel	% weight	0.12	0.12	0	0.87	0.18	0.58	0.74	6	0.18	0.29	0.13		76.08
Fine gravel	% weight	0.78	0.78	1.61	0.6	0.92	0.51	0.57	6	0.82	0.37	0.17		45.04
V. coarse sand	% weight	2	2.4	2.4	1.8	2.2	1.86	2.42	6	2.15	0.21	0.09		8.88
Coarse sand	% weight	4.9	5	4.9	4.7	5.9	5.9	4.9	6	5.08	0.39	0.17		7.73
Medium sand	% weight	9.3	9.6	9.5	8.9	10.5	9.6	9.6	6	9.57	0.48	0.22		5.04
Fine sand	% weight	3.1	3.1	2.9	2.9	3.1	1.7	3.1	6	2.80	0.50	0.22		17.88
V. fine sand	% weight	37.1	38.2	36.9	38	35.8	27.6	27.6	6	35.57	3.66	1.64		10.30
Clay	% weight	41.7	43.8	40.8	43.1	44.3	58	58	6	41.96	5.08	2.27		11.31
Silt														
pH	pH units	7.96	7.96	7.74	7.85	7.68	8.22	8.22	6	7.90	0.18	0.08		2.23
Solids	%	34.1	32.7	33.2	32.6	33.3	32.4	32.4	6	33.05	0.57	0.25		1.72
Sulfides	mg/kg	6200	6200	5900	6500	8500	9700	9700	6	6333.33	1348.66	603.14		17.22
Carbon	%	7.25	7.4	7.7	7.48	7.08	7.07	7.07	6	7.35	0.23	0.10		3.20
PCBs:														
2-Mono	ug/kg	72	50	56	55	64	47	47	6	57.23	8.44	3.77		14.72
4,4'-Di	ug/kg	79	59	62	63	73	52	52	6	64.01	8.92	3.99		13.78
2,4,4'-Tri	ug/kg	193	157	187	153	186	133	133	6	161.17	21.91	8.80		13.03
2,2',5,5'-Tetra	ug/kg	308	237	235	220	406	210	210	6	289.83	88.74	30.74		25.52
3,3',4,4'-Tetra	ug/kg	16	12	13	13	19	10	10	6	13.83	2.91	1.30		21.04
2,3,4,5-Penta	ug/kg	8	5	6	5	7	5	5	6	6.00	1.15	0.52		19.25
2,3,4,4',5-Penta	ug/kg	77	54	68	57	86	58	58	6	68.17	11.63	5.20		17.44
3,3',4,4',5-Penta	ug/kg	0.6	0.4	0.4	0.4	0.6	0.2	0.2	6	0.43	0.14	0.08		31.72
2,3,3',4,4',5'-Hexa	ug/kg	19.7	14	21	15	18	15	15	6	17.12	2.62	1.17		15.31
3,3',4,4',5,5'-Hexa	ug/kg	<	<	<	<	<	<	<	0	<	ERR	ERR		
2,2',3,4,4',5,5'-Hepta	ug/kg	90	63	76	72	79	62	62	6	73.67	9.60	4.28		13.04
2,2',3,3',4,4',5,5'-Octa	ug/kg	20	18	17	16	18	16	16	6	17.17	1.46	0.65		6.52
2,2',3,3',4,4',5,5',6-Nona	ug/kg	15	11	11	11	12	12	12	6	12.09	1.41	0.63		11.79
Deca	ug/kg	10	6	7	7	8	6	6	6	7.33	1.37	0.61		18.74
PCB Totals:														
-Mono	ug/kg	135	96	104	106	122	89	89	6	108.67	15.53	6.95		14.29
-Di	ug/kg	475	347	391	359	403	301	301	6	379.33	53.92	24.11		14.21
-Tri	ug/kg	863	658	732	649	881	584	584	6	727.63	110.70	49.51		15.21
-Tetra	ug/kg	1860	1570	1400	1330	2130	1240	1240	6	1598.33	313.87	140.37		19.78
-Penta	ug/kg	1550	1040	1200	1000	1550	1080	1080	6	1286.67	229.83	102.78		18.58
-Hexa	ug/kg	974	688	948	688	865	712	712	6	803.83	124.54	55.70		15.40
-Hepta	ug/kg	363	249	306	285	318	246	246	6	284.50	40.60	16.16		13.79
-Octa	ug/kg	112	87	97	90	100	90	90	6	95.00	8.43	3.77		8.78
-Nona	ug/kg	25	18	19	19	21	19	19	6	20.17	2.34	1.05		11.80

Lotus 1-2-3 11/27/95 re/lein Preliminary - not DRISP V'd or Q'ed

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Analyte	Units	Replicate #1	Replicate #2	Replicate #3	Replicate #4	Replicate #5	Replicate #6	n	Mean	SD	SEMEAN	CV (%)		
Pesticides (Cl):														
a-BHC	ug/kg													
alpha-Chlordane	ug/kg													
Aldrin	ug/kg	65.6	64.6	79.3	65.7	53.3	101.3	6	75.00	15.77	7.05	21.03		
beta-BHC	ug/kg													
delta-BHC	ug/kg													
4,4'-DDD	ug/kg	161.5	130.6	178.1	149.1	113.3	240	6	162.10	40.55	18.14	25.02		
4,4'-DDE	ug/kg	158.1	128.1	185.6	117.5	92.6	223.3	6	150.87	43.98	19.67	29.21		
4,4'-DDT	ug/kg													
Dieldrin	ug/kg	78.1	57.3	63.7	65.9	48.1	113.6	6	74.45	21.19	9.47	28.46		
Endrin	ug/kg													
Endrin aldehyde	ug/kg													
Endosulfan I	ug/kg													
Endosulfan II	ug/kg													
Endosulfan sulfate	ug/kg													
gamma-BHC (Lindane)	ug/kg													
gamma-Chlordane	ug/kg													
Heptachlor	ug/kg													
Heptachlor epoxide	ug/kg													
Methoxychlor	ug/kg													
Toxaphene	ug/kg													
Semivolatiles:														
Phenol	ug/kg	1176	503	373	365	581	512	6	585.00	275.29	123.11	47.06		
3,4-Methylphenol	ug/kg	1275	1218	1705	1305	1599	1238	6	1399.57	190.02	84.98	13.67		
Naphthalene	ug/kg	2639	2814	2569	3126	2738	2486	6	2728.67	207.23	92.68	7.59		
4-Chloroaniline	ug/kg	1053	1084	648	784	1124	1026	6	1002.86	112.13	50.15	11.18		
2-Methylnaphthalene	ug/kg	2380	2312	1694	2388	2417	2435	6	2301.00	187.35	83.78	8.13		
Acenaphthylene	ug/kg	1427	1255	1100	1213	1420	1318	6	1288.50	115.17	51.51	8.94		
Acenaphthene	ug/kg	961	1050	878	1089	1149	1106	6	1042.83	89.54	40.04	8.59		
Dibenzofuran	ug/kg	1357	1250	984	1225	1143	1163	6	1172.50	111.80	50.04	9.25		
Fluorene	ug/kg	1529	1458	1200	1342	1537	1269	6	1369.77	128.19	57.33	9.23		
Phenanthrene	ug/kg	7229	6911	5453	6283	6927	6733	6	6508.00	583.81	261.09	8.88		
Anthracene	ug/kg	4862	3772	3005	3315	3785	3494	6	3702.77	582.14	260.34	15.72		
DI-n-butyl phthalate	ug/kg	1372	927	1811	1233	1178	790	5	1228.50	358.63	179.32	29.24		
Fluoranthene	ug/kg	11263	10848	8080	9511	11758	10504	6	10328.37	1226.76	548.62	11.88		
Pyrene	ug/kg	7382	7403	5888	6551	7689	7717	6	7101.87	684.08	288.89	9.35		
Butylnaphthalene	ug/kg	1463	1345	1379	2385	1001	1266	6	1479.17	492.57	193.45	29.36		
DI-2-ethylnaphthalene	ug/kg	48983	62435	40301	46073	44606	49377	6	48630.88	6872.30	3073.39	14.13		
Benzofuran	ug/kg	5185	4717	3741	4118	4454	4710	6	4484.77	457.54	204.62	10.20		
Chrysene	ug/kg	5080	4885	3475	4179	4829	4938	6	4584.33	564.73	252.50	12.37		
DI-n-octylphthalate	ug/kg	853				6182		2	8521.50	2669.50	2669.50	75.78		
Benzofluoranthene	ug/kg	3309	2943	2247	2552	3144	3330	6	2922.17	401.06	179.36	13.72		
Benzofluoranthene	ug/kg	1127	947	928	1035	1377	1230	6	1171.33	158.77	71.01	14.34		
Benzofluoranthene	ug/kg	2651	2533	2139	2218	2794	2770	6	2501.63	282.24	126.22	11.08		
Indeno(1,2,3-cd)pyrene	ug/kg	1444	1137	928	763	1185	987	6	1023.67	216.45	98.80	20.12		
Dibenz(a,h)anthracene	ug/kg	677	343		305	341	319	5	307.00	140.71	70.36	35.44		
Benzofluoranthene	ug/kg	1743	1481	1225	694	1221	1182	6	1221.83	316.93	141.74	25.27		
Benzofluoranthene	ug/kg	2430	2126	1672	1900	2327	2298	6	2121.50	284.45	118.26	12.44		
Perylene	ug/kg	1152	869	829	803	1023	985	6	848.66	119.98	53.80	12.64		
(Complete B270A list run but only those above were present at or above the DL)														

Preliminary -

P. 2

Lab error



A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Analyte	Units	Replicate #1	Replicate #2	Replicate #3	Replicate #4	Replicate #5	Replicate #6	Mean	SD	SEMEAN	CV (%)			
111	Dioxins and Furans													
112	2378-TCDD	43.1	37.4	38.8	43.6	40.5	43.8	6	2.83	1.31	7.17			
113	12378-PeCDD	42.9	44.4	42.8	50.9	104	119	6	31.65	14.15	47.00			
114	123478-HxCDD	51.1	54.5	47.3	48.4	88.6	44.6	6	15.08	6.73	26.98			
115	12378-HxCDD	131	139	120	148	180	134	6	18.87	8.44	13.32			
116	123789-HxCDD	137	157	120	148	188	108	6	20.12	9.00	14.47			
117	1234878-HpCDD	2040	2300	2070	2170	2190	1780	6	163.04	72.91	7.79			
118	OCDD	17080	21150	16320	18070	15830	16230	6	1792.85	801.78	10.27			
119	2378-TCDF	348	352	320	364	310	348	6	18.80	8.41	5.33			
120	12378-PeCDF	280	283	263	284	369	378	6	44.58	19.94	14.34			
121	23478-HxCDF	135	151	133	161	181	152	6	16.19	7.24	10.84			
122	123478-HxCDF	1380	1250	1200	1360	1320	1290	6	65.49	29.29	5.02			
123	123878-HxCDF	450	463	435	495	484	457	6	20.20	8.03	4.35			
124	234678-HxCDF	191	193	163	187	207	165	6	15.65	7.00	8.49			
125	123789-HxCDF	6.7	4.3	12.9	6.6	56.4	63.9	6	24.99	11.18	99.44			
126	1234678-HpCDF	6080	4390	4730	5400	4430	4780	6	597.03	267.00	12.02			
127	1234789-HpCDF	104	117	88.8	124	124	95.3	6	11.67	5.22	10.56			
128	OCDF	4130	4080	4150	4840	4200	5110	6	402.80	180.14	9.12			
129	Totals: Dioxins													
130	-TCDD	289	501	203	285	90.6	128	6	133.84	59.77	54.30			
131	-PeCDD	314	640	375	451	320	169	6	144.41	64.58	38.19			
132	-HxCDD	1340	1560	1280	1420	1370	1250	6	111.08	49.67	8.11			
133	-HpCDD	4240	4970	4340	4820	4510	4020	6	301.11	134.66	6.77			
134														
135	Totals: Furans													
136	-TCDF	2300	2730	2450	2780	1970	1880	6	321.89	143.95	13.57			
137	-PeCDF	2390	2510	2270	2730	3320	3900	6	577.54	258.28	20.24			
138	-HxCDF	5420	4880	4800	5700	5130	5040	6	300.78	134.51	5.81			
139	-HpCDF	7210	5550	5780	6880	5380	5820	6	649.58	280.23	10.68			
140														
141														
142														
143	Metals													
144	Al	18.5	19	18.2	17.6	19.8	17.8	6	0.72	0.32	3.82			
145	As	32.5	33.5	33.1	32.3	38.1	30.4	6	2.89	1.21	8.05			
146	Be	0.55	0.58	0.53	0.55	0.56	0.56	6	0.02	0.01	2.70			
147	Cd	38.7	39.4	36.2	35.8	38.6	35.6	6	1.44	0.64	3.89			
148	Cr	374	399	371	366	396	354	6	16.02	7.16	4.25			
149	Cu	1150	1220	1170	1150	1230	1110	6	41.80	18.69	3.57			
150	Ni	288	367	282	280	301	267	6	32.79	14.66	11.03			
151	Pb	581	636	602	688	653	564	6	37.38	16.72	6.08			
152	Sb	9.82	13.1	10	6.72	10.6	9.5	6	1.38	0.62	13.39			
153	Se	2.7	2.9	5.02	2.8	2.8	3.19	6	0.81	0.36	25.13			
154	Tl	2.7	2.9	2.6	2.8	2.8	2.8	6	0.09	0.04	3.41			
155	Zn	1710	1760	1680	1870	1730	1600	6	81.80	38.58	4.74			
156	Hg (total)	1.22	1.28	1.27	1.35	1.38	1.22	6	0.06	0.03	4.68			
157														
158														
159														
160	TCPLP													
161	-Chromium	0.03	0.03	0.02	0.03	0.03	0.03	6	0.00	0.00	13.15			
162	(Complete TCLP analyte list run plus PAHs, but only those shown above were present at or above DL)													

Preliminary

P.3

## **Appendix D. Brookhaven Analyses of Vitrified Sediment Product**

Brookhaven National Laboratory carried out a suite of analyses on samples of the vitrified sediment product, including total organic carbon, sulfide, heavy metals, and contaminant organic species (pesticides, dioxins, furans, PCB's, and PAH's). Leaching properties of the glass were also evaluated using the Environmental Protection Agency's TCLP test for RCRA metals, volatile organics, PAH's, PCB's, dioxins, and furans. The complete spreadsheet report from BNL is included in the following appendix.

A	B	C	D	F-1	F-2	G	H	I	J	K
Analyte	Method	Units		WEST-1	WEST-2	n	Mean	SD	SEMEAN	CV (%)
Analytical Results for Westinghouse End Product										
Gross Physico-Chemical Properties										
Analyte	Method	Units		WEST-1	WEST-2	n	Mean	SD	SEMEAN	CV (%)
Particle size	ASTM D422 (Mod)	% wt (dry)	Vitified			0	ERR	ERR	ERR	ERR
Medium gravel > 4.75 mm	ASTM D422 (Mod)	% wt (dry)	End Product			0	ERR	ERR	ERR	ERR
Fine grave 2-4.75	ASTM D422 (Mod)	% wt (dry)				0	ERR	ERR	ERR	ERR
V. coarse sand 0.85-2	ASTM D422 (Mod)	% wt (dry)	Grain Sizes			0	ERR	ERR	ERR	ERR
Coarse sand 0.425-0.85	ASTM D422 (Mod)	% wt (dry)	Not Run			0	ERR	ERR	ERR	ERR
Medium sand 0.24-0.425	ASTM D422 (Mod)	% wt (dry)				0	ERR	ERR	ERR	ERR
Fine sand 0.106-0.24	ASTM D422 (Mod)	% wt (dry)				0	ERR	ERR	ERR	ERR
V. fine sand 0.075-0.106	ASTM D422 (Mod)	% wt (dry)				0	ERR	ERR	ERR	ERR
Clay	ASTM D422 (Mod)	% wt (dry)				0	ERR	ERR	ERR	ERR
Slk	ASTM D422 (Mod)	% wt (dry)				0	ERR	ERR	ERR	ERR
pH	EPA 9046A	pH Units		7.98	7.81	2	7.895	0.085	0.085	1.08
Solids (total)	EPA 160.3	% wt (dry)		99.7	99.70	2	99.7	0	0	0.00
Sulfides (total)	EPA 9030M	mg/kg (dry)	<	0.5	0.50	2	0.5	0	0	0.00
Organic carbon (total)	ASTM D4129-82M	% wt (dry)	<	0.05	0.05	2	0.05	0	0	0.00

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A	B	C	D	E	F	G	H	I	J	K
Analyte	Method	Units		WEST-1	WEST-2	in	Mean	SD	SEMEAN	CV (%)
Polychlorinated Biphenyls										
PCBs:	EPA MM680/HRGC/MS	ug/kg (dry)								
2-Mono	Congenor #1	ug/kg (dry)	AI <	0.002	0.005	2	0.004	0.002	0.001	42.86
445-Di	#151	ug/kg (dry)		0.030	0.020	2	0.025	0.005	0.005	20.00
244-Tri	#28	ug/kg (dry)		0.170	0.050	2	0.10	0.060	0.080	54.55
2265-Tetra	#52	ug/kg (dry)		0.060	0.020	2	0.035	0.015	0.016	42.86
3344-Tetra	#77	ug/kg (dry)	AI <	0.010	0.002	2	0.006	0.004	0.004	66.67
23445-Penta	#116	ug/kg (dry)	AI <	0.030	0.010	2	0.020	0.010	0.010	50.00
23344-Penta	#105	ug/kg (dry)	AI <	0.010	0.010	2	0.010	0.000	0.000	0.00
33445-Penta	#126	ug/kg (dry)	AI <	0.005	0.020	2	0.013	0.008	0.008	60.00
233445-Hexa	#156	ug/kg (dry)	AI <	0.003	0.020	2	0.012	0.008	0.009	73.91
334455-Hexa	#169	ug/kg (dry)	AI <	0.006	0.020	2	0.013	0.007	0.007	53.85
2234455-Hexa	#180	ug/kg (dry)		0.020	0.010	2	0.015	0.005	0.005	33.33
22334455-Octa	#194	ug/kg (dry)	AI <	0.005	0.030	2	0.018	0.013	0.013	71.43
223344556-Nona	#206	ug/kg (dry)	AI <	0.010	0.040	2	0.025	0.015	0.015	60.00
Deca	#209	ug/kg (dry)	AI <	0.010	0.010	2	0.010	0.000	0.000	0.00
PCB Totals:										
Mono	EPA MM680/HRGC/MS	ug/kg (dry)	AI <	0.002	0.005	2	0.004	0.002	0.001	42.86
Di	EPA MM680/HRGC/MS	ug/kg (dry)		0.100	0.050	2	0.075	0.025	0.025	33.33
Tri	EPA MM680/HRGC/MS	ug/kg (dry)		0.720	0.230	2	0.475	0.245	0.245	51.58
Tetra	EPA MM680/HRGC/MS	ug/kg (dry)		0.660	0.170	2	0.416	0.245	0.245	59.04
Penta	EPA MM680/HRGC/MS	ug/kg (dry)		0.220	0.040	2	0.130	0.090	0.090	69.23
Hexa	EPA MM680/HRGC/MS	ug/kg (dry)		0.180	0.060	2	0.10	0.050	0.050	45.45
Hepta	EPA MM680/HRGC/MS	ug/kg (dry)		0.050	0.010	2	0.030	0.020	0.020	66.67
Octa	EPA MM680/HRGC/MS	ug/kg (dry)	AI <	0.010	0.030	2	0.020	0.010	0.010	50.00
Nona	EPA MM680/HRGC/MS	ug/kg (dry)		0.010	0.040	2	0.025	0.015	0.015	60.00

A	B	C	D	F	F	F	G	H	I	J	K
Analyte	Method	Units		WEST-1	WEST-2	n	Mean	SD	SEMEAN	CV (%)	
7	Chlorinated Pesticides and Herbicides										
97	Pesticides (C):										
98	e-BHC	ug/kg (dry)	All <	1.66	1.66	2	1.66	0.00	0.00	0.00	
99	e-Chlordane	ug/kg (dry)	All <	1.66	1.66	2	1.66	0.00	0.00	0.00	
100	Aldrin	ug/kg (dry)	All <	1.66	1.66	2	1.66	0.00	0.00	0.00	
101	beta-BHC	ug/kg (dry)	All <	1.66	1.66	2	1.66	0.00	0.00	0.00	
102	delta-BHC	ug/kg (dry)	All <	1.66	1.66	2	1.66	0.00	0.00	0.00	
103	4,4'-DDD	ug/kg (dry)	All <	3.32	3.32	2	3.32	0.00	0.00	0.00	
104	4,4'-DDE	ug/kg (dry)	All <	3.32	3.32	2	3.32	0.00	0.00	0.00	
105	4,4'-DDT	ug/kg (dry)	All <	3.32	3.32	2	3.32	0.00	0.00	0.00	
106	Dieldrin	ug/kg (dry)	All <	3.32	3.32	2	3.32	0.00	0.00	0.00	
107	Endrin	ug/kg (dry)	All <	3.32	3.32	2	3.32	0.00	0.00	0.00	
108	Endrin aldehyde	ug/kg (dry)	All <	1.66	1.66	2	1.66	0.00	0.00	0.00	
109	Endosulfan I	ug/kg (dry)	All <	3.32	3.32	2	3.32	0.00	0.00	0.00	
110	Endosulfan II	ug/kg (dry)	All <	3.32	3.32	2	3.32	0.00	0.00	0.00	
111	Endosulfan sulfate	ug/kg (dry)	All <	3.32	3.32	2	3.32	0.00	0.00	0.00	
112	g-BHC (Lindane)	ug/kg (dry)	All <	1.66	1.66	2	1.66	0.00	0.00	0.00	
113	Heptachlor	ug/kg (dry)	All <	1.66	1.66	2	1.66	0.00	0.00	0.00	
114	Heptachlor epoxide	ug/kg (dry)	All <	1.66	1.66	2	1.66	0.00	0.00	0.00	
115	Methoxychlor	ug/kg (dry)	All <	16.6	16.6	2	16.60	0.00	0.00	0.00	
116	Toxaphene	ug/kg (dry)	All <	166	166.36	2	166.19	0.19	0.19	0.11	
117											
118											
119											
120	Chlorinated Herbicides										
121	2,4-D	mg/kg (dry)	All <	0.2	0.2	2	0.20	0.00	0.00	0.00	
122	2,4,5-TP (Silvex)	mg/kg (dry)	All <	0.05	0.05	2	0.05	0.00	0.00	0.00	
123	2,4,5-T	mg/kg (dry)	All <	0.05	0.05	2	0.05	0.00	0.00	0.00	
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A	B	C	D	E	F	G	H	I	J	K
Analyte	Method	Units		WEST-1	WEST-2	n	Mean	SD	SEMEAN	CV (%)
Semivolatile Compounds (inc)										
Phenol	EPA 8270A	ug/kg (dry)	All <	66.3	74.6	2	70.45	4.15	4.15	5.89
bis(2-Chloroethyl)ether	EPA 8270A	ug/kg (dry)	All <	78.4	88.2	2	83.30	4.80	4.90	5.88
2-Chlorophenol	EPA 8270A	ug/kg (dry)	All <	82.2	92.4	2	87.30	5.10	5.10	5.84
1,3-Dichlorobenzene	EPA 8270A	ug/kg (dry)	All <	66.1	74.3	2	70.20	4.10	4.10	5.84
1,4-Dichlorobenzene	EPA 8270A	ug/kg (dry)	All <	64.0	71.9	2	67.95	3.95	3.95	5.81
1,2-Dichlorobenzene	EPA 8270A	ug/kg (dry)	All <	70.7	79.5	2	75.10	4.40	4.40	5.86
Benzyl alcohol	EPA 8270A	ug/kg (dry)	All <	158.5	176.2	2	166.35	9.85	9.85	5.85
2,2'-oxybis(1-Chloropropane)	EPA 8270A	ug/kg (dry)	All <	73.0	82.0	2	77.50	4.50	4.50	5.81
2-Methylphenol	EPA 8270A	ug/kg (dry)	All <	98.2	108.1	2	102.15	5.85	5.95	5.82
3/4-Methylphenol	EPA 8270A	ug/kg (dry)	All <	90.7	101.9	2	96.30	5.60	5.60	5.82
N-Nitroso-d-n-propylamine	EPA 8270A	ug/kg (dry)	All <	107.1	120.5	2	113.80	6.70	6.70	5.89
Hexachloroethane	EPA 8270A	ug/kg (dry)	All <	114.2	128.5	2	121.35	7.15	7.15	5.89
Nitrobenzene	EPA 8270A	ug/kg (dry)	All <	62.2	71.7	2	66.95	4.75	4.75	7.09
Isophorone	EPA 8270A	ug/kg (dry)	All <	38.4	41.9	2	39.15	2.75	2.75	7.02
2-Nitrophenol	EPA 8270A	ug/kg (dry)	All <	144.8	166.9	2	155.85	11.05	11.05	7.08
2,4-Dimethylphenol	EPA 8270A	ug/kg (dry)	All <	73.8	85.1	2	79.45	5.65	5.65	7.11
bis(2-Chloroethoxy)methane	EPA 8270A	ug/kg (dry)	All <	65.2	76.2	2	70.20	5.00	5.00	7.12
Benzic acid	EPA 8270A	ug/kg (dry)	All <	342.4	394.6	2	368.50	26.10	26.10	7.08
2,4-Dichlorophenol	EPA 8270A	ug/kg (dry)	All <	96.6	111.3	2	103.95	7.35	7.35	7.07
1,2,4-Trichlorobenzene	EPA 8270A	ug/kg (dry)	All <	67.3	77.5	2	72.40	5.10	5.10	7.04
Naphthalene	EPA 8270A	ug/kg (dry)	All <	29.6	34.1	2	31.85	2.25	2.25	7.06
4-Chloroaniline	EPA 8270A	ug/kg (dry)	All <	87.8	100.9	2	94.25	6.65	6.65	7.08
Hexachlorobutadiene	EPA 8270A	ug/kg (dry)	All <	74.9	86.4	2	80.65	5.75	5.75	7.13
4-Chloro-3-methylphenol	EPA 8270A	ug/kg (dry)	All <	111.2	128.1	2	119.65	8.46	8.46	7.06
2-Methylnaphthalene	EPA 8270A	ug/kg (dry)	All <	43.8	50.5	2	47.15	3.35	3.35	7.10
Hexachlorocyclopentadiene	EPA 8270A	ug/kg (dry)	All <	117.3	135.3	2	126.30	9.00	9.00	7.13
2,4,6-Trichlorophenol	EPA 8270A	ug/kg (dry)	All <	168.5	194.3	2	181.40	12.90	12.80	7.11
2,4,5-Trichlorophenol	EPA 8270A	ug/kg (dry)	All <	182.3	210.3	2	196.30	14.00	14.00	7.13
2-Chloronaphthalene	EPA 8270A	ug/kg (dry)	All <	57.2	66.0	2	61.60	4.40	4.40	7.14
2-Nitroaniline	EPA 8270A	ug/kg (dry)	All <	254.8	293.9	2	274.35	19.55	19.55	7.13
Dimethylphthalate	EPA 8270A	ug/kg (dry)	All <	58.2	64.8	2	60.50	4.30	4.30	7.11
2,6-Dinitrotoluene	EPA 8270A	ug/kg (dry)	All <	278.3	318.7	2	297.50	21.20	21.20	7.13
2,4-Dinitrotoluene	EPA 8270A	ug/kg (dry)	All <	186.7	215.3	2	201.00	14.30	14.30	7.11
Acenaphthylene	EPA 8270A	ug/kg (dry)	All <	40.0	46.2	2	43.10	3.10	3.10	7.19
3-Nitroaniline	EPA 8270A	ug/kg (dry)	All <	328.9	379.4	2	354.15	25.25	25.25	7.13
Acenaphthene	EPA 8270A	ug/kg (dry)	All <	60.2	69.4	2	64.80	4.60	4.60	7.10
2,4-Dinitrophenol	EPA 8270A	ug/kg (dry)	All <	698.5	805.7	2	752.10	53.60	53.60	7.13
4-Nitrophenol	EPA 8270A	ug/kg (dry)	All <	206.5	238.2	2	222.35	15.95	15.95	7.13
Dibenzofuran	EPA 8270A	ug/kg (dry)	All <	45.8	52.6	2	49.10	3.50	3.50	7.13
Diethylphthalate	EPA 8270A	ug/kg (dry)	All <	50.8	58.6	2	54.70	3.90	3.90	7.13
4-Chlorophenyl-phenylether	EPA 8270A	ug/kg (dry)	All <	94.8	109.3	2	102.05	7.25	7.25	7.10
Fluorene	EPA 8270A	ug/kg (dry)	All <	60.4	69.7	2	65.05	4.65	4.65	7.15
4-Nitroaniline	EPA 8270A	ug/kg (dry)	All <	217.4	250.7	2	234.05	16.65	16.65	7.11
4,6-Dinitro-2-methylphenol	EPA 8270A	ug/kg (dry)	All <	293.7	381.3	2	337.50	43.80	43.80	12.98
N-Nitrosodiphenylamine	EPA 8270A	ug/kg (dry)	All <	98.6	128.0	2	113.30	14.70	14.70	12.97
4-Bromophenyl-phenylether	EPA 8270A	ug/kg (dry)	All <	194.9	253.0	2	223.95	29.05	29.05	12.97

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A	B	C	D	E	F	G	H	I	J	K
Analyte	Method	Units	AI <	WEST-1	WEST-2	n	Mean	SD	SEMEAN	CV (%)
Hexachlorobenzene	EPA 8270A	ug/kg (dry)	AI <	140.8	182.5	2	181.55	20.86	20.86	12.97
Pentachlorophenol	EPA 8270A	ug/kg (dry)	AI <	285.9	371.1	2	328.50	42.80	42.80	12.97
Phenanthrene	EPA 8270A	ug/kg (dry)	AI <	37.5	48.6	2	43.05	5.55	5.55	12.89
Anthracene	EPA 8270A	ug/kg (dry)	AI <	39.3	51.1	2	45.20	5.90	5.90	13.05
Di-n-butylphthalate	EPA 8270A	ug/kg (dry)	AI <	25.8		1	25.80	0.00	ERR	0.00
Fluoranthene	EPA 8270A	ug/kg (dry)	AI <	19.8	25.6	2	22.70	2.90	2.90	12.78
Pyrene	EPA 8270A	ug/kg (dry)	AI <	21.9	24.2	2	23.05	1.15	1.15	4.98
Butylbenzylphthalate	EPA 8270A	ug/kg (dry)	AI <	187.1	208.5	2	188.30	21.20	21.20	11.28
3,3'-Dichlorobenzidine	EPA 8270A	ug/kg (dry)	AI <	65.8	72.8	2	69.30	3.50	3.50	5.05
Bis-2-ethylhexylphthalate	EPA 8270A	ug/kg (dry)	AI <	44.5	44.0	2	44.25	0.25	0.25	0.58
Benzo(a)anthracene	EPA 8270A	ug/kg (dry)	AI <	19.3	21.4	2	20.35	1.05	1.05	5.16
Chrysene	EPA 8270A	ug/kg (dry)	AI <	22.0	24.4	2	23.20	1.20	1.20	5.17
Di-n-octylphthalate	EPA 8270A	ug/kg (dry)	AI <	13.9	13.9	2	13.90	0.00	0.00	0.00
Benzo(b)fluoranthene	EPA 8270A	ug/kg (dry)	AI <	20.7	20.8	2	20.75	0.05	0.05	0.24
Benzo(k)fluoranthene	EPA 8270A	ug/kg (dry)	AI <	20.8	20.8	2	20.80	0.00	0.00	0.00
Benzo(e)pyrene	EPA 8270A	ug/kg (dry)	AI <	21.4	21.4	2	21.40	0.00	0.00	0.00
Indeno(1,2,3-cd)pyrene	EPA 8270A	ug/kg (dry)	AI <	21.8	21.8	2	21.80	0.00	0.00	0.00
Dibenz(a,h)anthracene	EPA 8270A	ug/kg (dry)	AI <	28.0	28.1	2	28.05	0.05	0.05	0.18
Benzo(ghi)perylene	EPA 8270A	ug/kg (dry)	AI <	24.3	24.4	2	24.35	0.05	0.05	0.21
Benzo(e)pyrene	EPA 8270A	ug/kg (dry)	AI <	22.0	22.0	2	22.00	0.00	0.00	0.00
Perylene	EPA 8270A	ug/kg (dry)	AI <	23.2	23.2	2	23.20	0.00	0.00	0.00

A	B	C	D	F	F	G	H	I	J	K
Analyte	Method	Units		WEST-1	WEST-2	n	Mean	SD	SEMEAN	CV (%)
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241										
242										
243	Dioxins and Furans									
244	EPA 8290	ng/kg (dry)	All <	0.20	0.30	2	0.25	0.05	0.05	20.00
245	EPA 8290	ng/kg (dry)	All <	0.40	0.50	2	0.45	0.05	0.05	11.11
246	EPA 8290	ng/kg (dry)	All <	0.30	0.40	2	0.35	0.05	0.05	14.29
247	EPA 8290	ng/kg (dry)	All <	0.30	0.40	2	0.35	0.05	0.05	14.29
248	EPA 8290	ng/kg (dry)	All <	0.55	0.40	2	0.48	0.08	0.07	15.79
249	EPA 8290	ng/kg (dry)	All <	3.60	0.68	2	2.14	1.46	1.46	68.22
250										
251	EPA 8290	ng/kg (dry)	All <	0.20	0.30	2	0.25	0.05	0.05	20.00
252	EPA 8290	ng/kg (dry)	All <	0.30	0.40	2	0.35	0.05	0.05	14.29
253	EPA 8290	ng/kg (dry)	All <	0.30	0.40	2	0.35	0.05	0.05	14.29
254	EPA 8290	ng/kg (dry)	All <	0.30	0.40	2	0.35	0.05	0.05	14.29
255	EPA 8290	ng/kg (dry)	All <	0.20	0.30	2	0.25	0.05	0.05	20.00
256	EPA 8290	ng/kg (dry)	All <	0.41	0.39	2	0.40	0.01	0.01	2.50
257	EPA 8290	ng/kg (dry)	All <	0.30	0.30	2	0.30	0.00	0.00	0.00
258	EPA 8290	ng/kg (dry)	All <	0.31	0.30	2	0.31	0.00	0.01	1.64
259	EPA 8290	ng/kg (dry)	All <	0.30	0.40	2	0.35	0.05	0.05	14.29
260	EPA 8290	ng/kg (dry)	All <	0.98	0.40	2	0.69	0.29	0.28	42.03
261										
262	Totals: Dioxins									
263	-TCDD	ng/kg (dry)	All <	0.20	0.30	2	0.25	0.05	0.05	20.00
264	-PeCDD	ng/kg (dry)	All <	0.40	0.50	2	0.45	0.05	0.05	11.11
265	-HxCDD	ng/kg (dry)	All <	0.30	0.40	2	0.35	0.05	0.05	14.29
266	-HpCDD	ng/kg (dry)	All <	0.94	0.40	2	0.67	0.27	0.27	40.30
267										
268	Totals: Furans									
269	-TCDF	ng/kg (dry)	All <	0.20	0.30	2	0.25	0.05	0.05	20.00
270	-PeCDF	ng/kg (dry)	All <	0.30	0.40	2	0.35	0.05	0.05	14.29
271	-HxCDF	ng/kg (dry)	All <	0.41	0.39	2	0.40	0.01	0.01	2.50
272	-HpCDF	ng/kg (dry)	All <	0.75	0.30	2	0.53	0.23	0.23	42.86
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A	B	C	D	E	F	G	H	I	J	K
Analyte	Method	Units		WEST-1	WEST-2	n	Mean	SD	SEM	CV (%)
Metals										
Ag	EPA 6010A	mg/kg (dry)		2,320	2,610	2	2.47	0.16	0.14	5.88
As	EPA 6010A	mg/kg (dry)		4,600	5,650	2	5.18	0.38	0.39	7.28
Be	EPA 6010A	mg/kg (dry)	All <	0.181	0.177	2	0.18	0.00	0.00	1.12
Ca	EPA 6010A	mg/kg (dry)		4,150	4,840	2	4.40	0.24	0.24	5.67
Cr	EPA 6010A	mg/kg (dry)		70,900	77,200	2	74.05	3.15	3.15	4.25
Cu	EPA 6010A	mg/kg (dry)		158,000	175,000	2	166.50	8.50	8.50	5.11
Ni	EPA 6010A	mg/kg (dry)		47,800	62,400	2	50.10	2.30	2.30	4.59
Pb	EPA 6010A	mg/kg (dry)		88,100	98,900	2	93.50	5.40	5.40	5.78
Sb	EPA 6010A	mg/kg (dry)		1,230	1,460	2	1.35	0.12	0.11	8.55
Se	EPA 6010A	mg/kg (dry)	All <	0.904	0.883	2	0.89	0.01	0.01	1.18
Tl	EPA 6010A	mg/kg (dry)	All <	0.804	0.883	2	0.89	0.01	0.01	1.18
Zn	EPA 6010A	mg/kg (dry)		260,000	407,000	2	333.50	73.50	73.50	22.04
Hg (total)	EPA 7471	mg/kg (dry)	All <	0.072	0.075	2	0.07	0.00	0.00	2.04

A	B	C	D	E	F	G	H	I	J	K
Analyte	Method	Units		WEST-1	WEST-2	n	Mean	SD	SEMEAN	CV (%)
Metals (TCLP)										
-Arsenic	EPA 1311/3010/6010A	mg/L (extract)	All <	0.1	0.1	2	0.10000	0.00000	0.00000	0.00
-Barium	EPA 1311/3010/6010A	mg/L (extract)	All <	0.5	0.5	2	0.50000	0.00000	0.00000	0.00
-Cadmium	EPA 1311/3010/6010A	mg/L (extract)	All <	0.01	0.01	2	0.01000	0.00000	0.00000	0.00
-Chromium	EPA 1311/3010/6010A	mg/L (extract)	All <	0.01	0.01	2	0.01000	0.00000	0.00000	0.00
-Lead	EPA 1311/3010/6010A	mg/L (extract)	All <	0.10	0.12	2	0.14000	0.02000	0.02000	14.29
-Mercury	EPA 1311/7470	mg/L (extract)	All <	0.001	0.001	2	0.00100	0.00000	0.00000	0.00
-Selenium	EPA 1311/3010/6010A	mg/L (extract)	All <	0.1	0.1	2	0.10000	0.00000	0.00000	0.00
-Silver	EPA 1311/3010/6010A	mg/L (extract)	All <	0.01	0.01	2	0.01000	0.00000	0.00000	0.00
Organo-Cl Pesticides (TCLP)										
-Chlordane	EPA 1311/8080	mg/L (extract)	All <	0.005	0.005	2	0.00500	0.00000	0.00000	0.00
-Endrin	EPA 1311/8080	mg/L (extract)	All <	0.0005	0.0005	2	0.00050	0.00000	0.00000	0.00
-Heptachlor	EPA 1311/8080	mg/L (extract)	All <	0.0005	0.0005	2	0.00050	0.00000	0.00000	0.00
-Heptachlor epoxide	EPA 1311/8080	mg/L (extract)	All <	0.0005	0.0005	2	0.00050	0.00000	0.00000	0.00
-Lindane (g-BHC)	EPA 1311/8080	mg/L (extract)	All <	0.0005	0.0005	2	0.00050	0.00000	0.00000	0.00
-Methoxychlor	EPA 1311/8080	mg/L (extract)	All <	0.001	0.001	2	0.00100	0.00000	0.00000	0.00
-Toxaphene	EPA 1311/8080	mg/L (extract)	All <	0.01	0.01	2	0.01000	0.00000	0.00000	0.00
Cl Herbicides (TCLP)										
-2,4-D	EPA 1311/8150A (Mod)	mg/L (extract)	All <	0.1	0.1	2	0.10000	0.00000	0.00000	0.00
-2,4,5-TP (Silvex)	EPA 1311/8150A (Mod)	mg/L (extract)	All <	0.01	0.01	2	0.01000	0.00000	0.00000	0.00
Volatile Organics (TCLP)										
-Benzene	EPA 1311/8240A	mg/L (extract)	All <	0.2	0.2	2	0.20000	0.00000	0.00000	0.00
-Carbon tetrachloride	EPA 1311/8240A	mg/L (extract)	All <	0.2	0.2	2	0.20000	0.00000	0.00000	0.00
-Chlorobenzene	EPA 1311/8240A	mg/L (extract)	All <	0.2	0.2	2	0.20000	0.00000	0.00000	0.00
-Chloroform	EPA 1311/8240A	mg/L (extract)	All <	0.2	0.2	2	0.20000	0.00000	0.00000	0.00
-1,4-Dichlorobenzene	EPA 1311/8240A	mg/L (extract)	All <	0.2	0.2	2	0.20000	0.00000	0.00000	0.00
-1,2-Dichloroethane	EPA 1311/8240A	mg/L (extract)	All <	0.2	0.2	2	0.20000	0.00000	0.00000	0.00
-1,1-Dichloroethene	EPA 1311/8240A	mg/L (extract)	All <	0.2	0.2	2	0.20000	0.00000	0.00000	0.00
Methyl ethyl ketone	EPA 1311/8240A	mg/L (extract)	All <	5	5	2	5.00000	0.00000	0.00000	0.00
Tetrachloroethene	EPA 1311/8240A	mg/L (extract)	All <	0.2	0.2	2	0.20000	0.00000	0.00000	0.00
Trichloroethene	EPA 1311/8240A	mg/L (extract)	All <	0.2	0.2	2	0.20000	0.00000	0.00000	0.00
Vinyl chloride	EPA 1311/8240A	mg/L (extract)	All <	0.1	0.1	2	0.10000	0.00000	0.00000	0.00
Semi-Volatiles (TCLP)										
-Hexachloroethane	EPA 1311/8270A	mg/L (extract)	These analyses			0	ERR	ERR	ERR	ERR
-Nitrobenzene	EPA 1311/8270A	mg/L (extract)	analyses were			0	ERR	ERR	ERR	ERR
-Hexachlorobutadiene	EPA 1311/8270A	mg/L (extract)	not run			0	ERR	ERR	ERR	ERR
-2,4-Dinitrotoluene	EPA 1311/8270A	mg/L (extract)	not run			0	ERR	ERR	ERR	ERR
-Hexachlorobenzene	EPA 1311/8270A	mg/L (extract)				0	ERR	ERR	ERR	ERR
-2,4,6-Trichlorophenol	EPA 1311/8270A	mg/L (extract)				0	ERR	ERR	ERR	ERR
-2,4,5-Trichlorophenol	EPA 1311/8270A	mg/L (extract)				0	ERR	ERR	ERR	ERR
-Pentachlorophenol	EPA 1311/8270A	mg/L (extract)				0	ERR	ERR	ERR	ERR
-Pyridine	EPA 1311/8270A	mg/L (extract)				0	ERR	ERR	ERR	ERR
-o-Cresol	EPA 1311/8270A	mg/L (extract)				0	ERR	ERR	ERR	ERR

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A	B	C	D	E	F	G	H	I	J	K
Analyte	Method	Units		WEST-1	WEST-2	n	Mean	SD	SEMEAN	CV (%)
				ERR	ERR		ERR	ERR	ERR	ERR
385	-m,p-Cresols	mg/L (extract)				0				
386	-Total Cresols	mg/L (extract)				0				
387										
388	PAHs (TCLP)									
389	Naphthalene	mg/L (extract) All <		0.1		2	0.10000	0.00000	0.00000	0.00
390	2-Methylnaphthalene	mg/L (extract) All <		0.1		2	0.10000	0.00000	0.00000	0.00
391	Acenaphthylene	mg/L (extract) All <		0.1		2	0.10000	0.00000	0.00000	0.00
392	Acenaphthene	mg/L (extract) All <		0.1		2	0.10000	0.00000	0.00000	0.00
393	Dibenzofuran	mg/L (extract) All <		0.1		2	0.10000	0.00000	0.00000	0.00
394	Fluorene	mg/L (extract) All <		0.1		2	0.10000	0.00000	0.00000	0.00
395	Phenanthrene	mg/L (extract) All <		0.1		2	0.10000	0.00000	0.00000	0.00
396	Anthracene	mg/L (extract) All <		0.1		2	0.10000	0.00000	0.00000	0.00
397	Fluoranthene	mg/L (extract) All <		0.1		2	0.10000	0.00000	0.00000	0.00
398	Pyrene	mg/L (extract) All <		0.1		2	0.10000	0.00000	0.00000	0.00
399	Benzo(a)anthracene	mg/L (extract) All <		0.1		2	0.10000	0.00000	0.00000	0.00
400	Chrysene	mg/L (extract) All <		0.1		2	0.10000	0.00000	0.00000	0.00
401	Benzo(b)fluoranthene	mg/L (extract) All <		0.1		2	0.10000	0.00000	0.00000	0.00
402	Benzo(k)fluoranthene	mg/L (extract) All <		0.1		2	0.10000	0.00000	0.00000	0.00
403	Benzo(e)pyrene	mg/L (extract) All <		0.1		2	0.10000	0.00000	0.00000	0.00
404	Indeno(1,2,3-cd)pyrene	mg/L (extract) All <		0.1		2	0.10000	0.00000	0.00000	0.00
405	Dibenz(a,h)anthracene	mg/L (extract) All <		0.1		2	0.10000	0.00000	0.00000	0.00
406	Benzo(ghi)perylene	mg/L (extract) All <		0.1		2	0.10000	0.00000	0.00000	0.00
407										
408	Dioxins/Furans (TCLP)									
408	2378-TCDD	ng/L (extract) All <		0.002	0.0046	2	0.00330	0.00130	0.00130	39.39
410	12378-PeCDD	ng/L (extract) All <		0.0097	0.0092	2	0.00945	0.00025	0.00025	2.65
411	123478-HxCDD	ng/L (extract) All <		0.0093	0.0087	2	0.00800	0.00030	0.00030	3.33
412	123678-HxCDD	ng/L (extract) All <		0.0078	0.0073	2	0.00755	0.00025	0.00025	3.31
413	123789-HxCDD	ng/L (extract) All <		0.008	0.0074	2	0.00770	0.00030	0.00030	3.90
414	1234678-HpCDD	ng/L (extract) All <		0.0017	0.0116	2	0.00685	0.00495	0.00495	74.44
415	OCDD	ng/L (extract) All <		0.0123	0.0273	2	0.01980	0.00750	0.00750	37.88
416										
417	2378-TCDF	ng/L (extract) All <		0.0056	0.0032	2	0.00440	0.00120	0.00120	27.27
418	12378-PeCDF	ng/L (extract) All <		0.0088	0.0051	2	0.00685	0.00175	0.00175	25.55
419	23478-PeCDF	ng/L (extract) All <		0.0084	0.005	2	0.00670	0.00170	0.00170	25.37
420	123478-HxCDF	ng/L (extract) All <		0.001	0.0043	2	0.00265	0.00165	0.00165	62.26
421	123678-HxCDF	ng/L (extract) All <		0.00045	0.0034	2	0.00193	0.00148	0.00148	78.92
422	234878-HxCDF	ng/L (extract) All <		0.0042	0.0039	2	0.00405	0.00015	0.00015	3.70
423	123789-HxCDF	ng/L (extract) All <		0.00037	0.0048	2	0.00259	0.00222	0.00222	85.89
424	1234678-HpCDF	ng/L (extract) All <		0.0019	0.0042	2	0.00305	0.00115	0.00115	37.70
425	1234789-HpCDF	ng/L (extract) All <		0.0098	0.0083	2	0.00805	0.00175	0.00175	21.74
426										
428	OCDF	ng/L (extract) All <		0.0037	0.0213	2	0.01260	0.00880	0.00880	70.40
427										
428	Totals: Dioxins									
428	-TCDD	ng/L (extract) All <		0.0314	0.0046	2	0.01800	0.01340	0.01340	74.44
430	-PeCDD	ng/L (extract) All <		0.001	0.0092	2	0.00510	0.00410	0.00410	80.39
431	-HxCDD	ng/L (extract) All <		0.00085	0.0078	2	0.00433	0.00348	0.00348	80.35
432	-HpCDD	ng/L (extract) All <		0.0017	0.0116	2	0.00665	0.00485	0.00485	74.44

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A	B	C	D	F	F	F	G	H	I	J	K
Analyte	Method	Units		WEST-1	WEST-2	n	Mean	SD	SEMEAN	CV (%)	
Totals: Furans											
-TCDF	EPA 8290	ng/L (extract)	All <	0.0056	0.0032	2	0.00440	0.00120	0.00120	27.27	
-PeCDF	EPA 8290	ng/L (extract)	All <	0.0026	0.005	2	0.00380	0.00120	0.00120	31.58	
-HxCDF	EPA 8290	ng/L (extract)	All <	0.005	0.0039	2	0.00445	0.00055	0.00055	12.36	
-HpCDF	EPA 8290	ng/L (extract)	All <	0.0019	0.005	2	0.00345	0.00155	0.00155	44.93	
PCBs (TCCLP)											
PCBs:	EPA MM680/HRGC/MS	ug/L (extract)									
2-Mono	Congenor #1	ug/L (extract)	All <	0.0002	0.0001	2	0.00015	0.00005	0.00005	33.33	
44'-Di	#15	ug/L (extract)	All <	0.0003	0.0002	2	0.00025	0.00005	0.00005	20.00	
244'-Tri	#28	ug/L (extract)	All <	0.0002	0.0002	2	0.00020	0.00000	0.00000	0.00	
22'55'-Tetra	#77	ug/L (extract)	All <	0.0003	0.00032	2	0.00031	0.00001	0.00001	3.23	
33'44'-Tetra	#118	ug/L (extract)	All <	0.0003	0.0003	2	0.00030	0.00000	0.00000	0.00	
2344'5'-Penta	#105	ug/L (extract)	All <	0.0004	0.0003	2	0.00035	0.00005	0.00005	14.29	
233'44'-Penta	#128	ug/L (extract)	All <	0.0004	0.0005	2	0.00045	0.00005	0.00005	11.11	
33'44'5'-Penta	#156	ug/L (extract)	All <	0.0005	0.0004	2	0.00045	0.00005	0.00005	11.11	
233'44'5'-Hexa	#169	ug/L (extract)	All <	0.0004	0.0003	2	0.00035	0.00005	0.00005	14.29	
33'44'55'-Hexa	#180	ug/L (extract)	All <	0.0005	0.0004	2	0.00045	0.00005	0.00005	11.11	
22'344'55'-Hepta	#206	ug/L (extract)	All <	0.0007	0.0006	2	0.00065	0.00005	0.00005	7.69	
22'33'44'55'8'-Nona	#206	ug/L (extract)	All <	0.0009	0.0008	2	0.00085	0.00005	0.00005	5.88	
Deca	#209	ug/L (extract)	All <	0.0007	0.0006	2	0.00065	0.00005	0.00005	7.69	
PCB Totals:											
-Mono	EPA MM680/HRGC/MS	ug/L (extract)	All <	0.0002	0.0001	2	0.00015	0.00005	0.00005	33.33	
-Di	EPA MM680/HRGC/MS	ug/L (extract)	All <	0.0003	0.0002	2	0.00025	0.00005	0.00005	20.00	
-Tri	EPA MM680/HRGC/MS	ug/L (extract)	All <	0.0002	0.0002	2	0.00020	0.00000	0.00000	0.00	
-Tetra	EPA MM680/HRGC/MS	ug/L (extract)	All <	0.0003	0.0007	2	0.00050	0.00020	0.00020	40.00	
-Penta	EPA MM680/HRGC/MS	ug/L (extract)	All <	0.0004	0.0045	2	0.00245	0.00205	0.00205	83.67	
-Hexa	EPA MM680/HRGC/MS	ug/L (extract)	All <	0.0005	0.0017	2	0.00110	0.00080	0.00080	54.55	
-Hepta	EPA MM680/HRGC/MS	ug/L (extract)	All <	0.0005	0.0004	2	0.00045	0.00005	0.00005	11.11	
-Octa	EPA MM680/HRGC/MS	ug/L (extract)	All <	0.0007	0.0006	2	0.00085	0.00005	0.00005	7.69	
-Nona	EPA MM680/HRGC/MS	ug/L (extract)	All <	0.0009	0.0008	2	0.00085	0.00005	0.00005	6.88	

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## **Appendix E. - Toxicity Characteristic Leaching Procedure (TCLP) Testing of Glass Product**

The following report from Antech Ltd., a Pittsburgh analytical laboratory, presents the results of TCLP testing on the product glass generated during Phase I. It is seen that the only two metals which were detectable in the leach solution were calcium and magnesium, with none of the toxic metals present leachable from the glass matrix.

LABORATORY REPORT

J. E. Marzullo  
 Westinghouse Electric Corp  
 Science & Technology Center  
 1310 Beulah Road  
 Pittsburgh, PA 15235-5098

Sample Received: 11/16/95  
 Report Date: 12/01/95  
 P. O. #: 34-14148-PR

SAMPLE ID	LAB ID	ANALYSIS	RESULTS
			<i>Group I</i>
NY WASH 1	N-5518	Aluminum	< 8 ppm
		Barium	< 8 ppm
		Beryllium	< 8 ppm
		Calcium	230 ppm
		Cadmium	< 8 ppm
		Cobalt	< 8 ppm
		Chromium	< 8 ppm
		Copper	< 8 ppm
		Iron	< 8 ppm
		Gallium	< 8 ppm
		Magnesium	440 ppm
		Manganese	< 8 ppm
		Molybdenum	< 8 ppm
		Nickel	< 8 ppm
		Phosphorus	< 8 ppm
		Lead	< 8 ppm
		Silicon	< 8 ppm
		Tin	< 8 ppm
		Strontium	< 8 ppm
		Titanium	< 8 ppm
		Vanadium	< 8 ppm
		Zinc	< 8 ppm
		Zirconium	< 8 ppm

CB:yd