Department of
Environmental Protection

Jeb Bush
Governor

Marjory Stoneman Douglas Building
3900 Commonwealth Boulevard
Tallahassee, Florida 32399-3000

David B. Struhs
Secretary

February 1
~~January 30~~, 2001

CERTIFIED MAIL RETURN RECEIPT REQUESTED

Mr. William C. Thomas, III
Vice President of Industrial Development & Operations
Conrad Yelvington Distributors, Inc.
Post Office Box 1686
Daytona Beach, Florida 32115

Re: Amended Application for an Air Construction Permit
Powerscreen Sand and Gravel Classifier: Draft Permit No.: 7770473-001-AC

Dear Mr. Thomas:

We received the original application for an air construction permit for a Powerscreen Chieftain 510 on April 19, 2000. The initial application indicated that the screener was to be employed as a relocatable facility at any on the applicant's aggregate storage and processing yards for screening and classifying sand and rock aggregates, at various storage yards owned or operated by Conrad Yelvington Distributors, Inc.(CYDI), throughout the state. This application was processed to a draft Air Construction Permit that was issued on August 11, 2000. In the final days of processing the application we discovered, during a telephone call, that the CYDI intended to use this screener for processing spent abrasive blasting media (ABM). This intended use was not indicated in the application. The spent ABM has the potential of containing toxic heavy metals and toxic chemical residues from paints. Rather than delay or deny the draft permit at that time, we included a paragraph prohibiting the processing of ABM or other hazardous material.

CYDI has never published the public notice that was included in the "Intent to Issue" package for 7770473-001-AC. Rather, CYDI sought to amend the application, and urge the Department to modify the draft Air Construction Permit. Assurances were to be provided that the spent abrasive material was not hazardous, that the proposed processing of ABM would not violate state or federal air pollution standards, that the ABM would not constitute a health hazard, to provide testing criteria for acceptable material, and a management plan for dust and unacceptable spent ABM material.

We agreed to allow you 60 days to amend the application (without additional fees).

Your letter transmitting Stephanie Brooks' undated letter and laboratory reports followed on October 2, 2000. We accepted these documents as an "amendment" to the application. Ms. Brooks made some emission calculations based on TCLP test results and AP 42 emission factors. These calculations were unacceptable because TCLP is not an appropriate laboratory test for determining potential air emissions. I deemed this amendment to the application insufficient and wrote a "Completeness Review and Request for Additional Information", which was mailed on October 16, 2000. I also provided technical reference material that I obtained from the Department's Division of Waste and from an EPA internet search site.

7099 3400 0000 1449 4185

U.S. Postal Service

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iam C. Thomas, III
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Dept. of Environmental Protection
Division of Air Resources Mgt.
Bureau of Air Regulation, NSR
2600 Blair Stone Rd., MS 5505
Tallahassee, FL 32399-2400

The certified mail return receipt card shows that you received the notice of completeness review and request for additional information on October 23, 2000.

More than 90 days have past since you received our completeness letter. The application has been in house 280 days, including our agreed extensions.

The Powerscreen Chieftain 510 is not permitted to operate at this time. The documents issued on August 11, 2000, do not authorize assembly, testing or operation of the facility. They only reflect the Department's intent to issue an Air Construction Permit, following (and conditioned upon) the publication of a public notice and resolution of any issues arising therefrom. The procedure for obtaining an Air Operation Permit requires the existence of a valid Air Construction Permit, a separate application and fee for the Air Operating Permit, as well as completion of compliance testing.

Rule 62-4.055(1) Florida Administrative Code provides:

> (1) Within thirty days after receipt of an application for a permit and the correct processing fee the Department shall review the application and shall request submittal of additional information the Department is authorized by law to request. The applicant shall have ninety days after the Department mails a timely request for additional information to submit that information to the Department. If an applicant requires more than ninety days in which to respond to a request for additional information, the applicant may notify the Department in writing of the circumstances, at which time the application shall be held in active status for one additional period of up to ninety days. Additional extensions shall be granted for good cause shown by the applicant. A showing that the applicant is making a diligent effort to obtain the requested additional information shall constitute good cause. Failure of an applicant to provide the timely requested information by the applicable deadline shall result in denial of the application.

Since we have had no response to our letter of October 16, 2000, requesting additional information, nor have we had any request for an extension to the 90 day response time, the Department will allow you thirty days from the receipt of this letter to provide all the information requested in the October 16 letter, or to indicate good cause why this time should be extended. Otherwise, the requested permit will be denied.

If you have any questions, please call me at (850) 921-9522.

Sincerely,

W. Leffler

William Leffler, P.E.
Permitting Engineer

Cc:
Stephanie S. Brooks, P.E., Brooks and Associates, Inc.
Clair Fancy, BAR
Bruce Mitchell, BAR
Jerry Campbell, Hillsborough County Environmental Protection Commission
Richard B. Tedder, Division of Waste Management

Brooks & Associates, Inc.
Engineering and Environmental Consulting

February 28, 2001

RECEIVED
MAR 06 2001
BUREAU OF AIR REGULATION

Mr. William Leffler, PE
Permitting Engineer
Division of Air Resources Management
Department of Environmental Protection
3900 Commonwealth BLVD
Tallahassee FL 32399-3000

RE: Response to RAI 7770473-001-AC

Dear Mr. Leffler:

Brooks & Associates, CYDI and Alex Padva, Ph.D. have been involved in developing the answers to your request. The items will be taken out of order but will provide information for all.

Items 8 and 9 CYDI does not accept any material that has not passed hazardous waste screening tests. Therefore there is no need for extraordinary methods of dealing with spills. The off-spec or unmerchantable portions of the spent ABM are hauled to a landfill for disposal. The handling of the material may change depending on the Reuse memo that is being generated by the Solid and Hazardous Waste Sections.

Item 10 The power screen will potentially be used in Hillsborough County at the current location, Duval County at a location to be determined and Orange County at a location to be determined.

Item 5 Additional permitting if required by the reuse memo will be handled on an as needed basis. CYDI and Brooks & Associates are well aware of the rule that getting an air permit does not grant immunity from other permitting requirements. A. Padva, Ph.D. is involved in resolving solid waste issues associated with the spent ABM.

Item 6 As the power screen is designed to be a portable unit, the requirement of a negative pressure dust collection system with air pollution control system along with an enclosed structure seem to be more applicable to permanent and therefore a continuous source of air pollution rather than a temporary one. The same comment extends to a continuous mist suppression system. The material's moisture content of 0.4% which is similar to the moisture content of crushed stone. A concrete floor is less onerous but still seems extraordinary for a slag material that isn't considered hazardous. Please see Virginia Material's Reuse document that allows for storage of material on the ground with a berm around it and a tarp to cover it for short-term storage.

Item 4 CYDI does not accept spent ABM that fails the TCLP determination for hazardous wastes. Each source of material is tested prior to being transported to the site. If the material fails, it isn't accepted and the generator of the material has to dispose of it instead of it being processed and then reused as kiln feed. Your rather broad request for " reasonable assurance that the permittee will not .... nor create any unsafe condition or health hazard by processing spent ABM on any of its sites" can only be answered by CYDI does not intend to create an unsafe condition or health hazards for the general population or its workers by processing any kind of material. In support of this statement please find a copy of the MSDS for similar material from Virginia Materials and copy of that company's beneficial reuse program document.

Item 3 Emission estimates for the piles. See Emissions inventory questionnaire from State of Missouri for Storage Piles.

Tampa area Emission Factors based on this sheet are:

Wind erosion 0.53 lb PM10 per acre of storage pile per day
Activity 0.41 lb PM 10 per ton

Using the chemical composition of Spent Coal Slag Media from Technical Memorandum TM-2178-ENV RECYCLING AND REUSE OPTIONS FOR SPENT ABRASIVE BLASTING MEDIA AND SIMILAR WASTES published in April 1996, we find that the weight percent of metals varies and that the TCLP results are very similar to the results of TCLP performed on our samples. Therefore, we can extrapolate that the weight percent of metals will be similar to the report's results.

Metal Emissions (example)

	Wind Erosion lb PM10 – day/acre	Activity lb PM10/ton
Pb	0.0027	0.0021

Processing 1000 tons per day from a pile that occupies about 3/10 of an acre and 255 days/yr operation.

Pb	0.0001 tpy	0.27 tpy

Items 1 and 2 The answers are contained in the enclosures. We have provided sieve analyses on our material, additional testing on our material and on similar from alternate sources. We have identified two additional technical documents which we use to base our belief that as long as the material does not fail TCLP or SPLP, it can safely be processed by CYDI without requiring onerous additional testing requirements or facilities to be built for processing and storage.

Should you have any questions, please call me at (954) 796-1987.

Thank you for your assistance,

Stephanie S. Brooks, PE

Stephanie S. Brooks, PE

Enclosures: Historical Weather Data for Tampa FL

Typical Chemical Analysis for Black Sand/Boiler Slag

MSDS for "Black Blast Abrasives"

Sieve Analyses

SPLP and TCLP data on Gross and Fine Samples

Additional Test Results for Black Sand

Screen or Mesh Size information

Beneficial Reuse and Disposal of Spent Abrasives Program

Emissions Inventory Questionnaire

Recycling and Reuse options for Spent Abrasive Blasting Media and Similar Wastes

Investigation of Separation, Treatment, and Recycling Options for Hazardous Paint Blast Media Waste

Cc: Mr. William Thomas, CYDI
Mr. Frank Milton, CYDI
Mr. Alex Padva, Ph.D.

Brooks & Associates, Inc.
Engineering and Environmental Consulting

3/6/01

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APR 12 2001
BUREAU OF AIR REGULATION

Bill,

Please use this sealed letter to adopt my 2/28/01 submittal.

Thanks
Stephanie

5068 NW 85th Rd. Coral Springs, FL 33067
Phone: (954) 796-1987 Fax: (954) 796-1984

**US Army Corps
of Engineers**
Construction Engineering
Research Laboratories

**USACERL Technical Report 96/51
Febrauary 1996**

Investigation of Separation, Treatment, and Recycling Options for Hazardous Paint Blast Media Waste

by
Jeffrey H. Boy, Timothy D. Race, and Keturah A. Reinbold

U.S. Army depot depaint operations generate over 4 million kg per year of contaminated paint blast media wastes. A variety of abrasive blast media are used. Spent blast media wastes are often determined to be hazardous when tested for characteristic metals using Toxicity Characteristic Leaching Procedure (TCLP) Method 1311. Disposal of contaminated blast media is regulated by the Environmental Protection Agency as well as state and local authorities. Because environmentally sound disposal of hazardous waste is very expensive, the Army could significantly benefit from cost-effective treatment processes that would render paint blast media wastes nonhazardous, or reduce waste bulk by isolating and disposing separately of hazardous components. The objective of this work was to investigate technologies that might significantly mitigate this Army hazardous waste disposal problem.

Most of the technologies investigated either failed to meet acceptable TCLP levels for hazardous metals content, or failed to meet Army disposal requirements. However, based on a review of several commercially available services, it is recommended that Army depot depaint operations consider processing hazardous blast media waste through properly regulated contractors that offer safe, effective, and economical stabilization, fixation, and recycling technologies. Due consideration should include an appropriate legal review of liability and regulatory issues.

SF 298

Foreword

This research was performed for the U.S. Army Environmental Center under Project 4A262720D048, "Industrial Operations Pollution Control Technology"; Work Unit NN-UT4, "Hazardous Waste Separation from Paint Blast Media." The technical monitor was Ronald P. Jackson, ENAEC-TS-D.

The work was performed by the Materials Science and Technology Division (FL-M) of the Facilities Technology Laboratory (FL), and the Natural Resources Assessment and Management Division (LL-N) of the Land Management Laboratory (LL), U.S. Army Construction Engineering Research Laboratories (USACERL). Dr. Alan W. Moore is Acting Chief and Donald F. Fournier is Acting Operations Chief, CECER-FL. William D. Goran is Chief and Dr. William D. Severinghaus is Acting Operations Chief, CECER-LL.

Patricia A. Kemme of the Analytical Chemistry Laboratory (CECER-UL-I) is acknowledged for her efforts on this project. Part of the work was performed under contract by Mr. John Bukowski and Dr. Xiaofeng Zhu of the Center for Cement Composite Materials at the University of Illinois at Urbana-Champaign.

COL James T. Scott is Commander and Acting Director of USACERL, and Dr. Michael J. O'Connor is Technical Director.

Contents

List of Tables and Figures

Tables

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1 Introduction

Background

Abrasive blasting has become the preferred method of paint removal at Army maintenance facilities (PEI 1990). Army facilities generate over 4 million kg per year of contaminated paint blast media wastes from paint removal operations. Depending on the paint system and substrate, a variety of abrasive blast media may be used for paint removal. Most blasting operations have a recirculation system that removes spent blast media particles too small for efficient paint removal. The resulting blast media wastes are often determined to be hazardous when tested for characteristic metals using the Environmental Protection Agency (EPA) Toxicity Characteristic Leaching Procedure (TCLP) Method 1311. The typical contaminants found in spent media are barium, cadmium, chromium, and lead. Disposal of contaminated blast media is regulated by the Federal government through, for example, the *Resource Conservation and Recovery Act of 1976* (RCRA, PL 94-580, as amended) as well as by state and local authorities. Because environmentally sound disposal of hazardous waste is very expensive, the Army could significantly benefit from cost-effective treatment processes that would render paint blast media waste nonhazardous, or reduce waste bulk by isolating and disposing separately of hazardous components. The U.S. Army Construction Engineering Research Laboratories (USACERL) was tasked to investigate technologies that might significantly mitigate this hazardous waste disposal problem.

Objective

The objective of this work was to evaluate and identify cost-effective processes for separating, breaking down, immobilizing, or recycling hazardous compounds in paint blast media wastes generated by Army depot depaint operations.

Approach

The Air Force Engineering and Service Laboratories previously evaluated disposal and recovery methods for plastic media blasting (PMB) waste in a multiphase research program. The results of these studies (Tapscott, Blahut, and Kellogg 1988; Jermyn and Wichner 1991) were reviewed by the researchers to avoid duplication of effort and to eliminate previously evaluated and rejected technologies.

Personnel from the U.S. Army Construction Engineering Research Laboratories (USACERL) conducted site visits to Army maintenance facilities where abrasive paint blast operations were performed. These included Red River Army Depot, TX; Sacramento Army Depot, CA; Corpus Christi Army Depot, TX; Tooele Army Depot, UT; Anniston Army Depot, AL; and Letterkenny Army Depot, PA. USACERL personnel observed these operations and retrieved samples of blast media waste for laboratory analysis and testing.

Waste processing techniques investigated in the laboratory by USACERL included cement stabilization and acid digestion. USACERL personnel also evaluated the chemical stabilization and fixation processes used by Red River Army Depot, and performed independent laboratory tests to verify the suitability of the process. Additional studies were performed by contractors to investigate microbiological digestion and low-temperature ashing (incineration). USACERL personnel also visited Army and Air Force maintenance facilities using lease recycle programs, and evaluated those programs.

Mode of Technology Transfer

The technologies recommended in this report may be suitable for use by a variety of Department of Defense installations including all Army, Navy, Air Force, Marine, Corps and National Guard installations involved in the repair and renovation of equipment. Technology transfer will be through the U.S. Army Environmental Center (USAEC) and the Army Center for Technical Excellence (CTX) for Mechanical Depaint (Industrial Operations Command), Anniston Army Depot, AL. The findings of this research were presented and published in the technical proceedings of the following symposia: the 17th Army Environmental Research and Development Conference (Boy et al., June 1993), the American Ceramic Society annual meeting (Bukowski et al., April 1994), and the 87th Annual Air and Waste Management Conference (Boy et al., June 1994). Results were also published in the peer-reviewed journal *Hazardous Waste & Hazardous Materials* (Boy et al. 1995).

Units of Measure

This report principally uses standard international (SI) units of measure. Where any U.S. standard unit appears, a conversion factor is provided on first use.

2 Abrasive Blasting Processes, Media, and Waste

Selection of Abrasive

Selection of the size and type of abrasive that most effectively and economically produces the desired surface finish depends on several variables including:

- the nature of the substrate being cleaned, including surface hardness
- the degree of corrosion that may have developed before blast cleaning
- the nature of any previous paint or coating system
- the type of surface finish desired.

Steel shot is a common abrasive blast media used on heavy steel structures. Steel shot consists of spherical particles of steel created by granulating a molten stream of metal with water, air, or other methods. Cast steel grit consist of angular particles produced by crushing steel shot.

Nonmetallic abrasive blast media are listed in Table 1*. Sand has been replaced by a number of alternatives because of the respiratory hazards associated with free silica. Inorganic substitutes in use are garnet, alumina (aluminum oxide), silicon carbide, and glass beads. Agricultural media include ground walnut shells or apricot pits, and wheat starch or corn starch products.

A number of plastic blast media available for paint removal are summarized in Table 2. The harder and larger particles generally provide faster paint removal but are also more likely to damage to the underlying substrate. Therefore, on sensitive equipment, softer materials (with slower removal rates) are often used.

The types and distribution of media used at two Army maintenance facilities are shown in Table 3. The wide variety of abrasive blast media used at various Army maintenance facilities makes it difficult to develop one optimum waste separation technique for universal Army use.

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* Tables and figures in this report may be found at the end of the chapter in which they are first referenced.

Substrate Considerations

Grey (1993) reviewed the advantages and disadvantages for the use of plastic blast media. Although paint removal from hard steel substrates, used in support equipment, proved to be very successful by plastic media blasting (PMB), it did not produce the surface roughness that normally occurred with grit blasting. A more aggressive blast media such as steel shot or mineral abrasives will produce the appropriate roughness.

Clad-type aluminum alloys are often used in structures exposed to severe environments such as those found in many military aircraft components. This clad aluminum consists of a corrosion-prone structural aluminum core with an outer cladding layer of a more corrosion-resistant aluminum alloy. Because this outer layer is soft, it is prone to damage during paint removal. The use of Type V acrylic plastic media has been found to inflict less damage to this outer layer than Type II urea formaldehyde plastic media (Grey 1993; Pauli 1993).

Paint removal from composites during maintenance has generally been difficult. Grey (1993) reported that Type V acrylic media or specialized commercial media (Type VI) may be used with operating conditions that remove minimal amounts of the polymer matrix. Alternately, the use of wheat starch for paint removal on air frames, has been accepted by several major aerospace manufacturers. The use of agricultural and starch abrasive media continues to grow (Pauli 1993). A variety of agricultural based abrasive blast media have been approved for use by the military (Military Specification [Mil] G-634C), Table 4.

Waste Characterization

Waste treatment technologies for PMB waste have been previously evaluated by the U.S. Air Force Engineering and Services Center and Oak Ridge National Laboratory (Tapscott, Blahut, and Kellogg 1988; Jermyn and Wichner 1991). Paint blast media waste is generated by in-line classification equipment that rejects all material passing through a 60 mesh screen. This corresponds to particles smaller than 250 μm. Size measurements performed by sieving indicated a highly variable particle size distribution, generally between 38 and 250 μm. However, photomicrographs revealed many particles of a much smaller size, ranging between 1.0 and 0.1 μm. In addition, they reported that photomicrographs showed numerous extremely small particles, which they attributed to the stripped paint, that were adhered to the large degraded PMB particles. They further concluded that dry separation treatments which seek to reduce waste volume by removing the paint particle from the degraded PMB waste would likely be ineffective due to the adhesive forces between the small paint particles and the larger blast media particles.

Toxic Characteristic Leaching Procedure

The Toxicity Characteristic Leaching Procedure (TCLP) is the means mandated by the EPA for determining the toxicity of a hazardous material (Federal Register, 13 June 1986). Method 1311, the procedure used in this research, is outlined below:

1. A 100 gram sample of the waste is crushed to pass through a 9.5 mm standard sieve
2. A 5 gm portion of the sample is used to determine the extraction solution

    - A 5 gm sample is weighed into a 250 ml beaker
    - 99.5 ml of deionized water is added to the 5 gm sample, stirred vigorously for 5 minutes, and the pH of the solution is determined
    - If the pH is <5.0, then Extraction Solution A is used—an acetic acid-sodium acetate buffer solution (pH = 4.93 +/- 0.05)
    - If the pH is >5.0, then Extraction Solution B is used—an acetic acid solution (pH = 3.88 +/- 0.05). (Note: this is the only point at which the pH is determined in the TCLP.)

3. A 100 gram sample is transferred to a plastic bottle and 2 liters of the appropriate extraction solution is added.
4. The sample is rotated for 18 +/- 2 hours.
5. The sample is filtered and the extraction fluid retained for chemical analysis.

Chemical Analysis

As part of this study, USACERL personnel retrieved samples of paint blast media waste from operations at several Army depots. The results of the laboratory testing and analysis are presented in Appendix A, Tables A1–A10.

The principal RCRA metal contaminants in paint blast media waste were found to be barium (Ba), cadium (Cd), chromium (Cr), and lead (Pb). The blast media waste samples failed the TCLP extraction test for Cd, Cr, and Pb. No sample failed TCLP for Ba. The principal difficulties of this work were: (1) the wide variety of blast media types utilized at the various facilities (see Table 3) and (2) the wide variability of contaminant concentration for a given waste from any individual facility. This variability arose from the diversity of waste, sources, and paint systems being removed at the time of waste sampling.

Table 1. Physical data on nonmetallic abrasives.

Media	Hardness (Mohs)	Shape	Sp. Gr.	Bulk Density (g/ml)	Color	Fee Silica	Degree of Dusting	Reuse
Naturally Occurring Abrasives								
Silica								
Silica	5	Round	2 to 3	100	White	90 +	High	Poor
Mineral	5 to 7	Round	3 to 4	125	Variable	< 5	Medium	Good
Flint	6.7 to 7	Angular	2 to 3	80	Lt. Gray	90 +	Medium	Good
Garnet	7.5	Angular	4	145	Pink	nil	Medium	Good
Zircon	47.5	Cubic	4.5	185	White	nil	Low	Good
Novaculite	4	Angular	2.5	100	White	90 +	Low	Good
By-Product Abrasives								
Slags								
Boiler	7	Angular	2.8	85	Black	nil	High	Poor
Copper	8	Angular	3.3	110	Black	nil	Low	Good
Nickel	8	Angular	2.7	85	Black	nil	High	Poor
Walnut Shells	3	Cubic	1.3	45	Black	nil	Low	Poor
Peach Shells	3	Cubic	1.3	45	Black	nil	Low	Poor
Corn Cobs	3	Angular	1.3	45	Black	nil	Low	Good
Manufactured Abrasives								
Silicon Carbide	9	Angular	3.2	105	Black	nil	Low	Good
Aluminum Oxide	8	Blocky	4.0	120	Black	nil	Low	Good
Glass Beads	5.5	Spherical	2.5	100	Black	nil	Low	Good

Source: From SSPC's *Steel Structures Painting Manual, Volume Two, Systems and Specifications*, 6th Edition ©1991. Used with permission of the Steel Structures Painting Council (SSPC), 40 24th Street, 6th Floor, Pittsburgh, Pennsylvania 15222-4643, USA.

Table 2. Comparative properties of plastic media used in paint stripping.

Type	Composition	Thermal Properties	Hardness (Barcol)	Paint Stripping Rate	Effect On Substrate	Applications
I	Polyester	Thermoset	34 to 42	Slow	Low	Thin sections metal Alloys
II	Urea Formaldehyde	Thermoset	54 to 62	Acceptable	Medium	Non-critical thin section metal alloy
III	Melamine-Formaldehyde	Thermoset	64 to 74	Fast	Severe	Steel and other ferrous alloys
IV	Phenol-Formaldehyde	Thermoset	54 to 62	Fast	Very Server	Steel and other ferrous alloys
V	Acrylic	Thermo-plastic	46 to 54	Acceptable	Low	Thin section metal alloys & composites
VI	Poly-allyl-diglycol-carbonate	Thermo-plastic	20 to 30	Acceptable	Very Low	Thin section metal alloys & composites

Source: Grey 1993.

Table 3. Summary of abrasive paint operations at selected Army depots.

Media	Anniston		Letterkenny	
	10^3 Kg	%	10^3 Kg	%
Walnut Shells	240	15	1306	80
Coal Slags	827	51		
Magnesium/Iron Silicates	400	24		
Plastic Media			82	5
Glass	80	5	26	1
Aluminum Oxide	40	2.5		
Steel Shot	40	2.5	226	14
Sand			5	>1
Totals	1627	100	1645	100

Source: PEI 1990.

Table 4. Grain, abrasive, soft, for carbon removal.

Type	Media	Approved Use
I	Apricot Pits	Aircraft jet engine or general purpose use
II	Pecan Shells	General purpose use only
III	Black Walnut Shells	Aircraft jet engine or general purpose use
IV	Corn Cobs	General purpose use only
IV	Rice Hulls	General purpose use only
VI	English walnut shells, apricot pit shells, or a mixture of the two	Aircraft jet engines only
VII	Peach Pits	Aircraft jet engines or general purpose use

Source: Military Specification (MIL) G-5634C.

3 Physical Separation Processes for PMB

The Air Force Engineering and Service Laboratories (Tapscott, Blahut, and Kellogg 1988) evaluated cost-effective and environmentally sound disposal and recovery methods for PMB waste residues. The physical, chemical, and thermal treatment processes evaluated are summarized in Table 5. The knowledge gained in this and subsequent work was used to avoid duplication of effort by USACERL and to eliminate previously evaluated and rejected technologies.

Dry Separation Processes

Waste samples were separated into various particle size fractions using a series of progressively finer sieves. Tapscott, Blahut, and Kellogg (1988) concluded that because the hazardous and nonhazardous particulate are very close in size, screening cannot efficiently separate the waste into regulated and nonregulated components.

Electrostatic separation was also evaluated in the Air Force study. Electrostatic separation involved injecting the PMB waste into a high-voltage direct-current electrical field. After exposure to the electric field, material falls to either side of a gate: material more attracted to the electric field falls to one side of the gate and material less attracted falls to the other side of the gate. Tapscott, Blahut, and Kellogg (1988) reported that the process sometimes resulted in fractions that differed greatly in metal concentrations, but the results were erratic and separation was insufficient.

Liquid Media Separation

Tapscott, Blahut, and Kellogg (1988) evaluated liquid density separation as a means to separate PMB waste into metals-rich and metals-depleted fractions. A ferric chloride solution showed little separation while potassium iodine solution showed modest success in generating a float-rich fraction. Carbon tetrachloride (CCl_4) worked very well, giving sink materials containing most of the metal contaminants. However, owing to the cost and toxicity of this material, handling and disposal would be difficult and expensive. A separation was also attempted with the less toxic chlorofluorocarbon (CFC) 113 ($CF_2ClCFCl_2$). The analysis showed little separation.

Additional work was performed on the liquid density separation of the hazardous component from PMB waste as summarized in Table 7 (Jermyn and Wichner 1991). Visual evidence indicated good physical separation of Type V PMB and paint solids using a potassium carbonate (K_2CO_3) solution with a density of 1.30 g/ml. Agitation (ultrasonic vibration and pumped circulation stirring) and centrifugation were found to aid physical separation. Addition of a surfactant (Turgitol) had only a marginal effect. Potassium carbonate solution had a deleterious chemical effect as lead and chromium leached into the liquid. Lead and barium were found to be more leachable by means of TCLP as the paint solids deteriorated. Calcium bromide solution (1.3 g/ml) also yielded good physical separation of Type V PMB and paint solids. Yellow coloration of the liquid occurred, indicating the presence of chromium in solution. However, calcium bromide solution (1.60 g/ml) yielded good physical separation of Type V PMB and paint solids. No liquid coloration occurred. Sucrose solutions (density 1.25) yielded poor separation. The researchers found that liquid density separation generally resulted in significant leaching of the metal contaminants into the liquid solution so the liquid itself was rendered a characteristic hazardous material.

Conclusions on the feasibility of liquid media separation (Jermyn and Wichner, 1991) included the following:

- The possibility of leaching pigment metals (particularly chromium) into solution, detracts from the liquid media separation concept
- Some water-based liquids render the pigment metals more susceptible to TCLP extraction; in some cases marginally hazardous PMB waste becomes more hazardous
- It would be difficult to develop a liquid media separation process for a broad range of paint and PMB densities that would provide effective separation and not leach metals
- Since there appeared to be no suitable organic liquid for such a process, the concept of liquid media density separation of PMB paint solids should not be further pursued.

Table 5. Results of Air Force survey of waste treatment options.

Treatment Method	Positive	Negative	Recommendations
Incineration	High degree of volume reduction	Regulatory difficulty, costly, hazardous off gases	Not recommended
Chemical treatment		Produces hazardous liquid wastes	
Charring	Good waste reduction	Produces flammable off gas, regulatory difficulty	
Encapsulation in plastic	Passed EP toxicity test	High cost	
Encapsulation in cement	Passed EP toxicity test	Adds to waste volume, good formulation not found	
Density Separation*	Good waste reduction	Only hazardous liquids (CCl_4 worked)	Recommended Best Approach
Electrostatic precipitation		Erratic results	
Aerodynamic classification		Poor waste concentration	

Source: Tapscott, Blahut, and Kellogg 1988.

Table 6. Metal ion analysis on density separated fractions.

		Total Metals			EP Toxicity Test		
	Fraction % of Total	Pb (ppm)	Cd (ppm)	Cr (ppm)	Pb (mg/L)	Cd (mg/L)	Cr (mg/L)
Ferric Chloride							
Float		400	200	380			
Sink		350	608	434			
Potassium Iodide Soln.							
Input		590	67	625	<0.2	1.08	18.0
Float	82%	590	67	625	<0.2	0.38	0.5
Sink	18%	230	25	150			
Carbon Tetrachloride							
Input		1400	60	1200	0.14	0.006	0.12
Float	94%	140	40	140	0.014	0.004	0.014
Sink	6%	17200	400	17100	1.72	0.040	1.71
CFC - 113							
Input		790	152	1700	<0.2	1.70	28.1
Float	28%	1390	248	2430	<0.2	1.97	64
Middle	16%	885	131	1480	<0.2	1.00	23
Sink	57%	660	191	1190	<0.2	10.4	20.5

Source: Tapscott, Blahut, and Kellogg 1988.

Table 7. Liquid density separation test.

PMB Waste	Liquid Solution	Liquid Density (g/ml)	Details	Results
Type V	Sucrose	1.25	Centrifuge (~500 G)[a]	No separation (with or without wetting agent
Type V	Potassium Carbonate	<1.25	Centrifuge (~550 G)	No separation (with or without wetting agent)
Type V	Potassium carbonate	1.30	Centrifuge (~550 G)	Good separation (with or without wetting agent) Liquid colored yellow[b]
Type V	Potassium carbonate	1.30	1 Gravity settling, ultrasonic vibration and pumped circulation trials	Good separation (no wetting agent) Liquid colored yellow[b]
Type V	Calcium Bromide	1.30	1 Gravity settling, ultrasonic vibration and pumped circulation trials	Good separation (no wetting agent) Liquid colored yellow[b]
Type II	Calcium Bromide	1.30	1 Gravity Settling	Good separation Clear Liquid

Source: Jermyn and Wichner 1991.

[a] Indicates acceleration in terms of gravity units

[b] Indicates extraction of chromium.

4 Low-Temperature Ashing

Objective of the Technology

Low-temperature ashing (LTA) involves subjecting the blast media waste to mild oxidation conditions at moderately elevated temperatures. Preliminary work was performed by Oak Ridge National Laboratory (ORNL) on LTA for the treatment of hazardous plastic blast media waste for the Air Force Engineering and Service Center (Jermyn and Wichner 1991). Weight loss measurements of a sample of Type V acrylic blast media heated to 500 °C in air resulted in a 95 percent reduction of the sample mass. The potential advantages of LTA includes a high degree of waste volume reduction. The ashing procedure reduces the waste volume down to the nonoxidizable portion of the waste (i.e., the pigment and the contaminants) and removes by vaporization the nonhazardous plastic portion that comprises at least 90 percent of the waste. The LTA treatment process is relatively robust. It does not depend on the microscopic properties of the waste (such as particle size) or pigment nature. Compared to high temperature incineration, LTA would be more likely to contain the hazardous components more completely within the ash than in the off-gas. The ash product of LTA would require further treatment before disposal. However the LTA ash to be disposed would be reduced to 5 percent of its original mass.

LTA Applicability and Process

LTA would be an appropriate candidate for treatment of blast media wastes that undergo significant decomposition upon heating in the temperature range of 500-600 °C. LTA would not be suitable for mineral or slag abrasives that have significantly higher melting points, nor for glass beads that melt without significant decomposition or volume reduction. In addition to Type V (acrylic) and Type III (urea formaldehyde) plastic media, LTA was investigated as possible treatment process for ground walnut shell blast media.

The experimental work, performed by ORNL, focused on determining certain thermal properties of virgin paint blast media used at Army maintenance facilities. The experiment involved three principal tests: (1) thermogravimetric (TG) analysis, i.e., weight loss as function of temperature at a controlled heating rate, (2) measurement of the vaporized gas volume, and (3) characterization of significant volatile organic compounds (VOCs) generated during LTA. The objective was to test the suitability of LTA process against Army requirements. The procedures used by ORNL in conducting these tests are detailed in Appendix B.

Results

Thermal Decomposition

The acrylic paint blast media was essentially converted into a gaseous state, with no residue, during TG analysis. During sample heating, slight mass loss was observed beginning at about 133 °C. Mass loss became rapid at about 250 °C, and began to level off at around 350 °C. Solid acrylic material, which is a light white powder at room temperature, was essentially converted into gasses at temperatures above 420 °C (Figure 1). During TG analysis a weight decrease of 99.75 percent was recorded.

Thermal analysis of urea formaldehyde blast media yielded a more complex mass loss curve, and a residue was left even after heating the media to 1200 °C. The weight change was 87.7 percent (as shown in Figure 2). Observable mass loss began to occur at 65 °C and continued until about 780 °C, with major inflection points at 258 °C, 360 °C, 520 °C, and 678 °C.

The ground walnut shell blast media, which also contained some fruit pits, was also subjected to TG analysis. Sample mass loss began at about 55 °C and ended at about 670 °C. Less than 1 percent of the original mass was left over as residue; the total weight change was 99.02 percent (Figure 3).

Volume of Gases Produced

During LTA experiments to determine the gaseous volume generated by paint blast media samples, significant amounts of smoke were produced. A light-colored smoke was observed during ashing of the acrylic material. Generated smoke from ground walnut shell and urea formaldehyde was denser and darker in color. The ground walnut shell media produced a significant amount of dark liquid condensate. Calculated gaseous combustion exhaust volumes, from integrated mass flow rate data (Table 8) were used to estimate the undiluted significant VOC concentrations in the smoke (Tables 9, 10, and 11). Gaseous volumes data also were plotted versus time (Appendix B). Note that the major portion of combustion effluent is generated during the first minute or two of a timed LTA experiment. With the urea formaldehyde media, off-gassing continued at a slower rate for approximately 20 minutes. Since the ashing process is exothermic, the experimental setpoint temperature of 575 °C was slightly exceeded during combustion experiments. Actual transient temperatures approaching 620 °C were observed briefly during ashing before dropping back to the setpoint temperature.

Characterization of Significant Volatile Organic Compounds (VOCs) Produced

Clearly, products generated by the combustion of paint blast media represents a very complex mixture. The reconstructed total ion chromatograms from a chamber blank and for the vapor phase samples generated from the combustion of paint blast materials of the ground walnut shell, acrylic, and urea formaldehyde media are presented in Appendix B. Because of the complex nature and overly abundant constituents present in each of the vapor phase samples, the effort was focused on the identification of major components. Those components represent a chromatographic area equal or greater than 1.0 percent of the total chromatographic area.

Electron impact (EI) mass spectral data obtained from thermal desorption (TD) and gas chromatography/mass spectroscopy (GC/MS) analyses were used to carry out identification. Identification of most components was based on the best match of the mass spectral pattern with those provided in the *Eight Peak Index Mass Spectra*, 3d ed. (Royal Society of Chemistry 1983). For components without a match (or with a poor match), chemical structures were postulated to best correlate with the observed fragmentation patterns. Tables 9–11 list compounds that have been tentatively identified in the sample traps. Their estimated quantities (μg/L), as determined based on the response factor of d_6-benzene, were also listed. Chemical nomenclature in the tables refer to general chemical structures, which may include structural isomers with the same chemical formula.

The ground walnut shell media generated predominantly oxygen-containing compounds upon combustion. The abundance of components with furan, phenol, and catechol moieties may be derived from lignin polymer. Because this sample trap was used with a mass range of 35–500 atomic mass units (amu), the water peak was not detected.

The acrylic blast material produced abundant quantities (approximately 5 μg/L) of methyl methacrylate (methyl ester of methacrylic acid) from the combustion process. Other compounds containing methacrylic acid moiety were also detected. Significant amounts of water accumulated on the sample trap most likely came from the combustion products or from the ambient air being used to purge the combustion chamber during sampling. Although the sorbent materials in triple absorbent traps (TST) are hydrophobic, excess amounts of water are retained on the traps despite purging with 1 liter of helium prior to TD step.

The urea formaldehyde blast material is made of polymerized urea formaldehyde (98 percent) with alpha cellulose filler. The hazardous decomposition products or byproducts for this material as listed in the Material Safety Data Sheets (MSDS) are smoke, carbon monoxide, carbon dioxide, formaldehyde, and hydrogen cyanide. Significant amounts (0.5 μg/L) of carbon dioxide [mass/atomic number (m/z) = 44] have been detected in the air peak along with m/z 28 ions, which is a molecular ion for either carbon monoxide or nitrogen. The selective ion mode was used to obtain mass chromatograms of m/z 27 and 26 (the two most abundant ions for hydrogen cyanide) to search for the presence of hydrogen cyanide. Experimental details are presented in Appendix B. A similar procedure was employed to search for the presence of formaldehyde; none of the early eluting components exhibited the expected characteristic ions generated from formaldehyde. It was determined through consultations that Carbosieve S-II sorbent in the TST is not expected to retain formaldehyde. In addition, Carbosieve S-III is not an ideal sorbent for hydrogen cyanide. Other major components found in the trap include alkyl nitriles, alkylamides of various chain lengths, and compounds with alcohol and furan moieties.

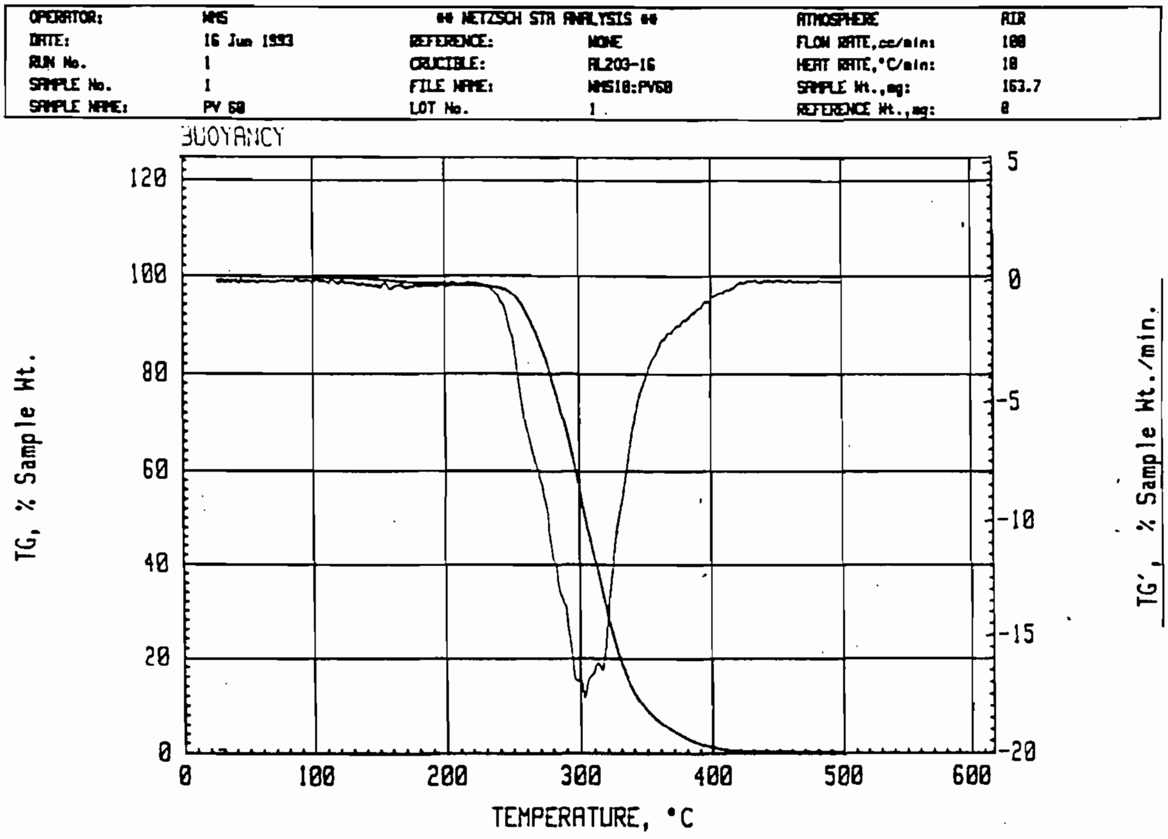
Summary of LTA Results

Temperatures required for media waste volume reduction differ depending on the waste type being processed. Treatment of acrylic media would probably involve effective, almost total reduction of the polymer at temperatures under 400 °C. Processing the ground walnut shell media and especially the urea formaldehyde media would most likely require a cost-benefit analysis to determine the degree of volume reduction desired as compared to the energy expenditure necessary to accomplish it. Temperature inflection points may indicate good management control points in the waste volume reduction process. Mass loss rates, detailed above, may have implications for waste processing time and power consumption during different steps in the LTA process. Weight loss measurements on virgin media indicated that the weight of urea formaldehyde media decreased by 87 percent at 800 °C, and ground walnut shell media decreased in weight by more than 99 percent at 700 °C.

Discussion

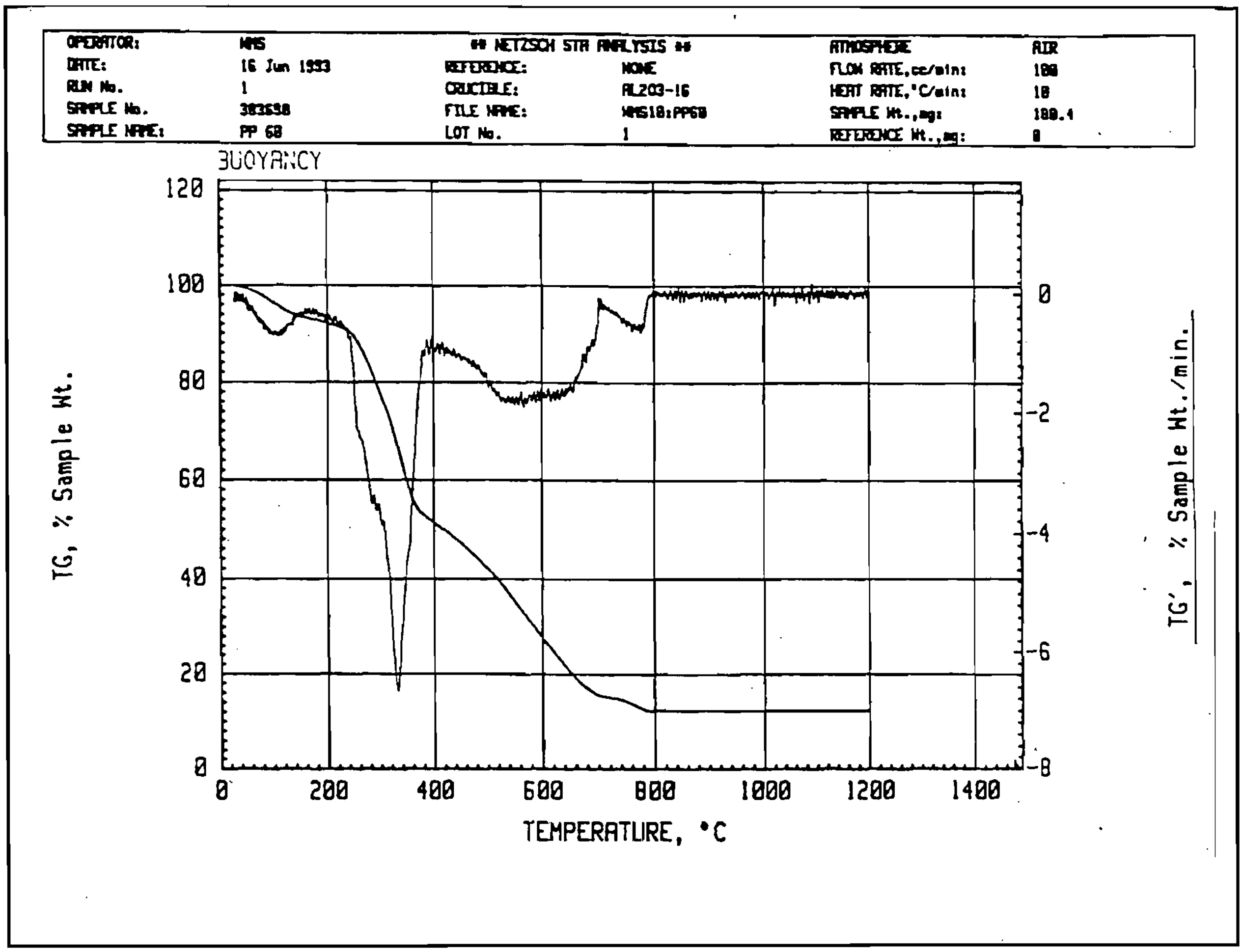
LTA is basically low-temperature incineration. Although the experimental design used triple sorbent traps to capture volatile organics, the sorbent was not effective in trapping formaldehyde and hydrogen cyanide. These components may be produced during LTA and perhaps were present in the combustion effluent of urea formaldehyde media even though the triple sorbent traps used did not effectively capture those compounds. Both formaldehyde and hydrogen cyanide are classified as hazardous air pollutants under the Clean Air Act. The thermal decomposition of the agricultural media generated phenol, and the polymerized urea formaldehyde generated toluene—also classified as hazardous air pollutants. Any volatilized heavy metal contaminants would be classified as hazardous air pollutants.. The difficulty of obtaining regulatory approval for any incineration process makes it unlikely that this process could successfully be implemented at Army facilities.

In addition to the air pollution concerns, most of the heavy metal contaminants would be expected to remain in the ash residue, and would require further treatment disposal. Use of LTA at Army maintenance facilities is not recommended at this time.



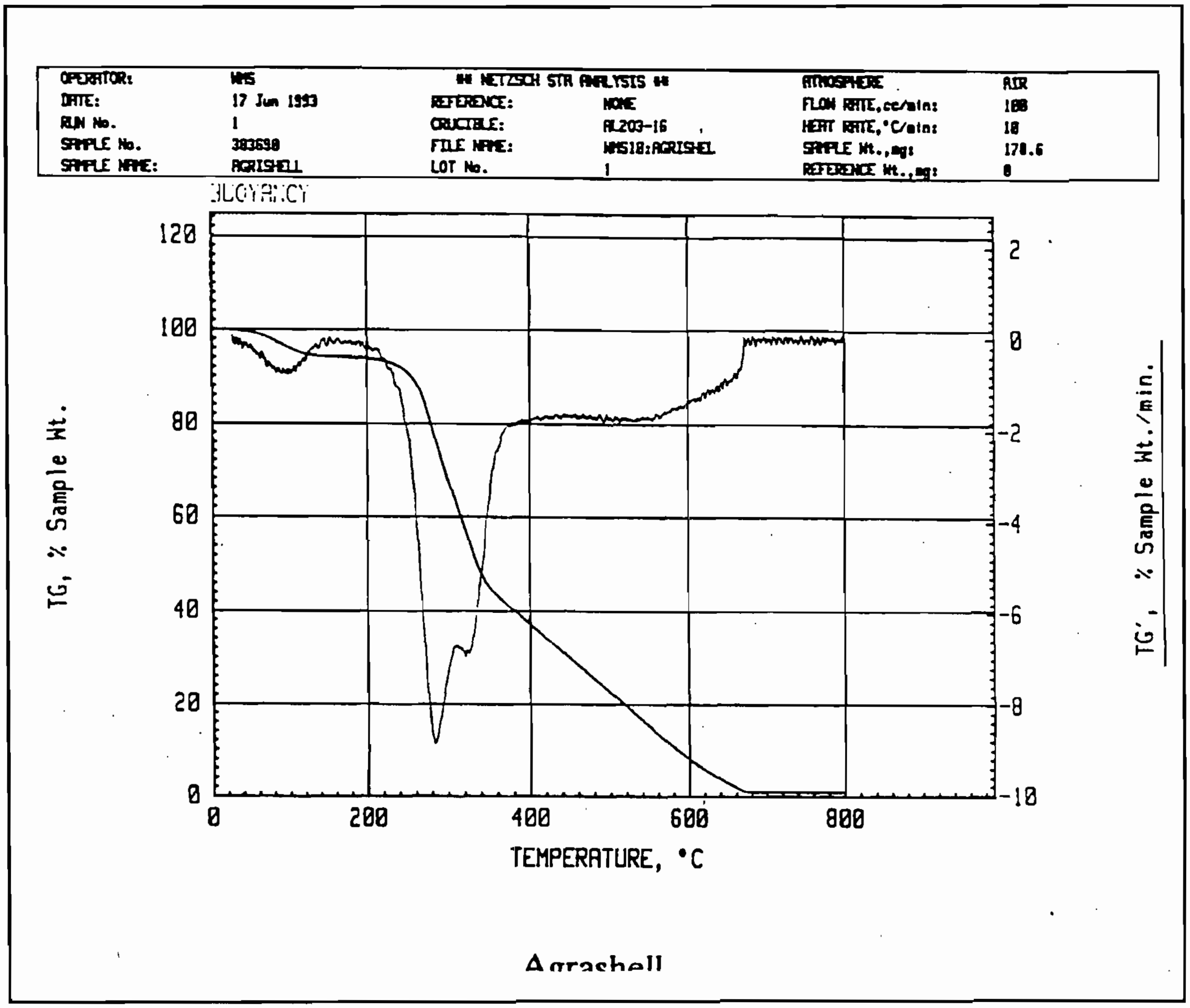
OPERATOR:	NMS	** NETZSCH STA ANALYSIS **		ATMOSPHERE	AIR
DATE:	16 Jun 1993	REFERENCE:	NONE	FLOW RATE,cc/min:	100
RUN No.	1	CRUCIBLE:	AL203-16	HEAT RATE,°C/min:	10
SAMPLE No.	1	FILE NAME:	NMS10:PV60	SAMPLE Wt.,mg:	163.7
SAMPLE NAME:	PV 60	LOT No.	1 .	REFERENCE Wt.,mg:	0

Figure 1. Mass loss for acrylic blast media during LTA for media sample PV60.



OPERATOR:	WMS	** NETZSCH STA ANALYSIS **		ATMOSPHERE	AIR
DATE:	16 Jun 1993	REFERENCE:	NONE	FLOW RATE,cc/min:	100
RUN No.	1	CRUCIBLE:	AL2O3-16	HEAT RATE,°C/min:	10
SAMPLE No.	303650	FILE NAME:	WMS10:PP60	SAMPLE Wt.,mg:	100.4
SAMPLE NAME:	PP 60	LOT No.	1	REFERENCE Wt.,mg:	0

Figure 2. Mass loss for urea formaldehyde blast media during LTA for media sample PP60.



OPERATOR:	WMS	** NETZSCH STA ANALYSIS **		ATMOSPHERE	AIR
DATE:	17 Jun 1993	REFERENCE:	NONE	FLOW RATE,cc/min:	100
RUN No.	1	CRUCIBLE:	AL203-16	HEAT RATE,°C/min:	10
SAMPLE No.	303690	FILE NAME:	WMS18:AGRISHEL	SAMPLE Wt.,mg:	170.6
SAMPLE NAME:	AGRISHELL	LOT No.	1	REFERENCE Wt.,mg:	0

Agrashell

Figure 3. Mass loss for ground walnut shell blast media during LTA.

Table 8. Gaseous exhaust generated during low-temperature ashing.

Paint Blast Media Sample	Ground Walnut Shells	Urea formaldehyde	Acrylic
Net Volume	0.873 L	1.899 L	1.212 L
Total Exhaust Volume	10.873 L	11.899 L	11.212 L
Net Mass	0.999 g	0.878 g	1.012 g

*Net gaseous volumes were obtained by subtracting the air affluent volume from the total gaseous volume generated during LTA experiment. Sample residues remaining after ashing were subtracted from the total sample mass to obtain the net mass.

Table 9. Volatile organic compounds collected from low-temperature ashing of ground walnut shell paint blast media.

Compound Tentatively Identified	Retention Time (min.)	Exhaust Conc. (mg/m^3)	Chamber Conc. (mg/m^3)
2-propanol	6.42-8.87	418.5	3.25
methyl acetate	9.28	95.3	0.74
propanoic acid	11.45	57.9	0.45
methyl ester of pyruvic acid	11.93	101.7	0.79
furancarboxaldehyde	12.62	158.4	1.23
butanone	13.57	88.8	0.69
acetyl-oxy-porpanone	13.68	119.8	0.93
methyl-furanone	14.08	63.1	0.49
3,4-dihydro-3H-pyran	15.03	88.8	0.69
methyl-furanone (isomer of 14.08 min peak)	15.32	200.9	1.56
phenol	16.20	90.1	0.70
dihydroxy-cyclobutene-dione	16.88	96.6	0.75
methyl-cyclopetane-dione	17.50	77.3	0.60
methyl-phenol	18.10	61.8	0.48
methoxy-phenol	18.58	202.2	0.57
mixture of oxygenated compounds	19.07	119.8	0.93
dimethoxy benzene	20.42	114.6	0.89
benzene-diol	20.70	76.0	0.59
C_2-methoxy-phenol	21.85	124.9	0.97
isomer of C_2-methoy-phenol	22.08	73.4	0.57
C_2-phenol	22.47	108.2	0.84
dimethoxy-phenol	23.03	193.1	1.5
hydroxy-methoxy-benzaldehyde	23.98	47.6	0.37
trimethoxy-benzene	24.42	100.4	0.78
methoxy-propenyl-phenol	24.52	68.24	0.53
C_2-biphenyl	25.50	52.8	0.41
C_1-fluorene	26.17	63.1	0.49
mixture of oxygenerated compounds and isomers	26.48-26.75	226.6	1.76
dimethoxy-hydroxy-benzaldehyde	27.93	117.2	0.91
dimethoxy-propenyl-phenol	28.37	85.0	0.66
phenyl-acetopohenone	29.23	48.9	0.38
dimethoxy-propenyl-benzene	29.48	54.1	0.42
trihydroxy-methylphenyl-butanone	29.85	67.0	0.52
hexadecanoic acid	35.05	115.9	0.90
hydroxy-dimethoxy-phenyl-propenal	35.52	96.6	0.75

Table 10. Volatile organic compounds collected from low-temperature ashing of acrylic paint blast media.

Compound Tentatively Identified	Retention Time (min.)	Exhaust Conc. (mg/m^3)	Chamber Conc. (mg/m^3)
carbon dioxide	2.53	191.1	1.53
water	3.50-5.58	144.8	1.16
methyl ester of methasrcyllic acid	9.32-10.44	576.9	4.62
methyl ester of pentenoic acid	12.15	31.2	0.25
hexamethyl-cyclotrisiloxane	12.42	36.2	0.29
C_9-alkanol	13.38	121.1	0.397
isomer of 12.15 min peak	13.70	25.0	0.20
alkanol	14.33	201.0	1.61
methyl ester of alkanoic acid	15.35	72.4	0.58
methyl ester of methyl-cyclohexyl carboxylic acid	16.35	38.7	0.31
C_4-dioxane	17.77	30.0	0.24
methoxy-pentenyl acetate	18.38	68.7	0.55
C_4-cyclopentane-dione	20.53	28.7	0.23
propyl ester of cyclopentenyl acetic acid	21.35	18.7	0.15
propyl ester of methacrylic acid	22.18	38.7	0.31
alkyl-ester of methacrylic acid	22.47	35.0	0.28
C_6-cyclopentene	22.60	33.7	0.27
methyl ester of phenoxy-acetic acid	23.12	37.5	0.30
isomer of above	23.42	32.5	0.26
phthalate	72.57	196.0	1.57

Table 11. Volatile organic compounds collected from low-temperature ashing urea formaldehyde paint blast media.

Compound Tentatively Identified	Retention Time (min.)	Exhaust Conc. (mg/m^3)	Chamber Conc. (mg/m^3)
carbon dioxide	2.10	58.8	0.50
water	2.77-4.98	62.4	0.53
mixture of propanol and others	7.83	34.1	0.29
dimethyl-amino-actonitrile	10.18	27.1	0.23
toluene	10.75	7.1	0.06
N-methyl-formamide	11.87	41.2	0.35
furancaboxaldehyde	12.63	5.9	0.05
1H-imidazole-2-methanol	13.45	30.6	0.26
furanone	14.90	21.2	0.18
oxygenated compounds (possible alkanol)	21.2	27.1	0.23
napthalene	23.67	40.0	0.34
alkanoic acid	26.60	10.6	0.09
n-tetradecanenitrile	31.93	12.9	0.11
methyl ester of alkanoic acid	32.28	9.4	0.08
n-hexadecanenitrile	38.37	24.7	0.21
methyl ester of alkanoic acid	38.77	20.0	0.17
n-alkylamide	41.92	42.4	0.36
n-alkylamide	55.18	36.5	0.31

5 Chemical Separation

Objective of the Technology

Treatment of contaminated abrasive blasting wastes by chemical separation (acid extraction and digestion) was investigated. Conceptually a multistage process was envisioned involving acid extraction of metal contaminants and subsequent alkaline precipitation of metal salts. The decontaminated media would be landfilled while the precipitated metals would require disposal as a hazardous waste. The purpose of this work was to develop an acid digestion process that would be suitable for all types of blast media waste.

Acid Extraction and Digestion Processes

A series of laboratory experiments was performed at USACERL to determine the feasibility of the process. Samples of contaminated blast media waste were collected from Army maintenance facilities and subjected to various digestion processes using citric acid, ethylenediaminetetraacetic acid (EDTA), nitric acid, sulfuric acid, or hydrochloric acid. Leachable metal concentrations of the principal contaminants—Pb, Cd, and Cr—were measured using TCLP before and after acid digestion.

The experimental series was dynamic in that the experimental results from one series of extraction experiments gave insights that led to the design of subsequent experiments. The initial series of extractions used 5 percent, 10 percent, and 20 percent concentrated sulfuric acid for 24 hours. In an attempt to raise the pH value of the waste solution following the extraction, a series of 7 to 12 rinses with water followed an extraction using 5 percent sulfuric acid for 24 hours. A more aggressive rinse using a $NaOH/H_2O$ solution was also evaluated. Other acids, such as citric acid, EDTA, and nitric acid, were evaluated for use as the extraction solution. EDTA in combination with HCl was also tested. These acids were subsequently rejected, and a new series of extraction using 5 percent hydrochloric acid for 24 hours, and 5 percent nitric acid for 24 hours were performed. Subsequent work settled on the use of nitric acid as the extraction solution. The effect of nitric acid concentration was further evaluated.

To monitor the performance of the analytical procedures used, quality-control matrix spikes are called for in the TCLP protocol. The matrix spikes were added at a concentration equivalent to the corresponding regulatory level. The results of these quality-control tests are shown in Appendix C.

Results of Chemical Separation Experiments

The initial series of extractions used 5 percent, 10 percent, and 20 percent concentrated sulfuric acid for 24 hours on coal slag, mixed plastic, and glass bead blast media (Table 12). TCLP results showed a decrease in the leachable cadmium and an increase in the leachable Pb and Cr. Pb and Cr are amphoteric, with increasing solubility at high and low pH. At the low pH of the concentrated sulfuric acid extraction solution, Pb and Cr solubilities are very high.

In an attempt to raise the pH of the waste solution following extraction, an extraction solution using 5 percent H_2SO_4 for 24 hours was followed by a single rinse, either with distilled water or NaOH solution. The water rinses raised the final pH to 4.0 while the NaOH rinse raised the final pH to between 7.3 and 7.7. TCLP results showed that the leachable Cd and Cr decreased, and the Pb increased, compared to the received waste (Table 13). The increase in the TCLP results was higher for samples rinsed with NaOH solution compared to the distilled water.

A 5 percent sulfuric acid extraction for 24 hours, followed by a series of multiple rinses using a NaOH/H_2O solution, was subsequently evaluated. A water rinse followed by centrifuge and decanting of the rinse solution was repeated between 7 and 13 times, yielding final pH of between 4.3 and 5.0. The TCLP results showed that the leachable Cd and Cr decreased and that the leachable Pb increased (Table 14).

Alternative acids were then considered for use as extraction solutions. A 0.002M* citric acid extraction for 24 hours, followed by three water rinses, was performed on coal slag and glass bead blast media wastes. The rinse solutions were retained and the metal concentration determined (Table 15). The metal content decreased in successive rinse solutions. The TCLP results for the washed and rinsed blast media wastes showed the Cd and Cr to have deceased but there was no change in the TCLP results for Pb.

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* M: molar concentration.

Other acids, such as EDTA, hydrochloride, and nitric acid, were evaluated for use as extraction solutions. The use of EDTA in combination with hydrochloric acid was also evaluated (Tables 16 and 17). The HCl extraction produced TCLP results showing the leachable Cr to increase from the mixed plastic and glass waste, and for the leachable Pb to increase from the coal slag blast media waste.

An acid extraction using 100 ml 0.1M EDTA plus 2 ml HCl for 24 hours caused the Cd and Cr TCLP results to decrease, and the Pb TCLP results to increase. When either 0.1 M EDTA or 5 percent nitric acid were used by themselves as the extraction fluid for 24 hours, the TCLP results for Cd, Cr, and Pb decreased (Tables 16 and 17). However, due to the higher cost of EDTA compared to nitric acid, subsequent work focused on nitric acid as the extraction fluid.

The effect of nitric acid concentration was evaluated. Extractions using 1 percent, 3 percent, and 5 percent solutions on coal slag, mixed glass, and plastic blast media wastes were conducted. The extractions resulted in a decrease in the leachable Cd, Cr, and Pb as determined by using TCLP. No appreciable difference was detected between the 3 percent and 5 percent nitric acid extraction solutions (Table 18).

The effect of acid concentration on the TCLP results for Pb was specifically evaluated using nitric acid extraction solutions in concentrations of 0.5 percent, 1 percent, and 2 percent. The filtrates were retained and the metal contents determined (Table 19). The TCLP results for Pb decreased for all three concentration levels. The Pb content of the retained filtrate was 262 ppm in the 2 percent extraction solution, and 0.97 ppm in the 0.5 percent extraction solution.

To verify the effectiveness of nitric acid extraction on various waste streams, glass beads and plastic blast media wastes were also tested (Tables 20–21). The TCLP results for Cd, Cr, decreased while the TCLP Pb results for the plastic media showed a slight increase. Again, the more concentrated extraction fluids resulted in higher metal contents in the retained filtrates.

Various acid digestion processes using citric acid, EDTA, nitric acid, sulfuric acid, or hydrochloric acid were evaluated. A 16-hour extraction using 2.0 percent nitric acid followed by multiple rinses with deionized (DI) water was determined to be the best extraction process.

Discussion

Acid treatments were found to decrease leachable heavy metal concentrations as measured by TCLP. However, post-treatment total metals concentrations were still quite high. Table 22 shows metal concentrations of the extraction fluid following a nitric acid extraction and following a different extraction using a $LiBO_2$ (lithium metaborate) flux at 1000 °C for 5 minutes. The nitric acid extractions were found to remove only 0.1 percent of the total chromium and 0.2 percent of total barium, compared to the $LiBO_2$ flux. Thus although the leachable component of metal decreased by acid extraction, the largest portion of hazardous metal contaminants was not removed by acid digestion. The acid digestion processes removed only a fraction of the total heavy metal contaminants. Use of these processes is not recommended.

Table 12. TCLP results for sulfuric acid extraction.

Sample	Lab ID	Extraction	Conc.	Time (days)	Cd (ppm)	Cr (ppm)	Pb (ppm)
Coal Slag ANAD	800863	As Received			BDL	0.4	BDL
	800863	H_2SO_4	5%	1	BDL	BDL	12
	800863	H_2SO_4	10%	1	BDL	0.1	15
	800863	H_2SO_4	15%	1	BDL	0.1	20
	800863	H_2SO_4	5%	2	0.1	BDL	7
	800863	H_2SO_4	10%	2	BDL	0.1	7
	800863	H_2SO_4	15%	2	BDL	BDL	8
Mixed Plastic Media SAAD	800864	As Received			5.2	N/A	BDL
	800864	H_2SO_4	5%	1	1.8	51.8	15
	800864	H_2SO_4	10%	1	0.9	35.3	13
	800864	H_2SO_4	15%	1	1.7	58.8	2
	800864	H_2SO_4	5%	2	0.1	0.3	11
	800864	H_2SO_4	10%	2	0.2	0.3	11
	800864	H_2SO_4	15%	2	0.2	0.5	11
Glass Beads - CCAD	800958	As Received			31.6	2.3	0.7
	800958	H_2SO_4	5	1	BDL	BDL	BDL
	800958	H_2SO_4	10%	1	BDL	BDL	BDL
	800958	H_2SO_4	15%	1	BDL	BDL	BDL
	800958	H_2SO_4	5%	2	0.1	BDL	0.7
	800958	H_2SO_4	10%	2	BDL	BDL	BDL
	800958	H_2SO_4	15%	2	BDL	BDL	BDL
Quality Control							
Glass Beads	800958			1	0.02	0.01	0.1
	+ 10 ppm Cd, Cr, Pb			1	9.4	11.5	7.6
	% Recovery				94	115	75
	800958			2	0.04	0	0.24
	+ 10 ppm Cd, Cr, Pb				0.91	0.11	8.42
	% Recovery			2	109	101	82

Table 13. TCLP results for sulfuric acid extraction followed by NaOH rinse.

Sample	ID	Test	Extraction	Conc	Time (hours)	Rinse	pH Final	Cd (ppm)	Cr (ppm)	Pb (ppm)
As Received	800863	Total Metals	(Lab A)					386	259	40.7
As Received	800863	TCLP	(Lab B)					0.628	0.947	4.96
Coal Slag	800863	TCLP	H_2SO_4	5%	24	NaOH	7.7	BDL	BDL	11.0
	800863	TCLP	H_2SO_4	5%	24	NaOH	7.3	BDL	BDL	10.3
As Received	800958	Total Metals	(Lab A)					472	91.4	13.6
As Received	800958	TCLP	(Lab B)					31.6	2.3	0.7
Glass Beads	800958	TCLP	H_2SO_4	5%	24	Water	4.0	BDL	BDL	0.2
	800958	TCLP	H_2SO_4	5%	24	Water	4.0	BDL	BDL	0.3
Blank								BDL	BDL	BDL
Quality Control										
	800863	TCLP	(Lab B)			NaOH	7.7	0.02	0.1	11.04
	800863 +10 ppm Cd, Cr, Pb	TCLP	(Lab B)			NaOH	7.7	10.32	9.8	17.95
% Recovery								103%	97%	69.1%

Table 14. TCLP results for sulfuric acid extraction followed by multiple water rinses.

Sample	ID	Test	Extraction	Conc %	Time hours	Rinse	No of Rinses	pH Final	Cd ppm	Cr ppm	Pb ppm
As Received	800863	Total Metals	(Lab A)						386	259	40.7
As Received	800863	TCLP	(Lab A)						0.628	0.947	4.96
Coal Slag	800863	TCLP	H_2SO_4	5%	24	Water	13	5.0	0.03	0	4.3
	800863	TCLP	H_2SO_4	5%	24	Water	13	4.8	0.05	0	5.3
	800863	TCLP	H_2SO_4	5%	24	Water	7	4.4	0.05	0	6.1
	800863	TCLP	H_2SO_4	5%	24	Water	7	4.3	0.04	0	7.2
Blank									0.04	0	0.8
Quality Control											
	800863	TCLP	H_2SO_4	5%	24	Water	13	5.0	0.03	0	4.3
	800863 + 10 ppm Cd Cr Pb	TCLP	H_2SO_4	5%	24	Water	13	5.0	11.12	9.7	14.3
% Recovery									111%	97%	100%

Table 15. Citric acid extraction results.

Sample	ID	Test	Extraction	Conc	Time hours	Rinse	No of Rinses	pH Final	Cd ppm	Cr ppm	Pb ppm
As Received	800863	Total Metals	(Lab A)						386	259	40.7
As Received	800863	TCLP	(Lab A)						0.628	0.947	4.96
Coal Slag	800863	TCLP	Citric Acid	0.02M	24	Water	3		0.1	0.2	4.8
1st Rinse									0.7	4.5	34.9
2nd Rinse									0.2	0.9	8.2
3rd Rinse									0.1	0.3	2.3
As Received	800958	Total Metals							472	91.4	13.6
As Received	800958	TCLP							31.6	2.3	0.7
Glass Beads	800958	TCLP	Citric Acid	0.02M	24	Water	3		0.1	0.1	0.4
1st Rinse									24.2	3.6	1.3
2nd Rinse									3.1	0.4	0.4
3rd Rinse									0.3	0.1	0.3
Quality Control											
	800863	TCLP							0.1	0.2	4.8
	800863 + 10 ppm Cd Cr Pb	TCLP							7.7	9.9	15.3
% Recovery									76%	97%	105%

Table 16. Results for EDTA, nitric acid, and hydrochloric acid extraction from waste sample 800863.

Sample	ID	Test	Extraction Fluid	Conc	Time hours	Rinse	No of Rinses	pH Final	Cd ppm	Cr ppm	Pb ppm
As Received	800863	Total Metals	(Lab A)						386	259	40.7
As Received	800863	TCLP	(Lab B)						0.37	BDL	BDL
Coal Slag	800863	TCLP	EDTA	0.1M	24	Water	5		0.29	0.3	1
Filtrate									5.92	17.78	139
3rd Rinse									0.16	0.07	0.7
5th Rinse									0.12	0.01	0.2
As Received	800863	TCLP							0.37	BDL	BDL
Coal Slag	800863	TCLP	Nitric	5%	24	Water	5		0.05	0.01	0.1
Filtrate									7.28	87.64	355.2
3rd Rinse									0.12	0.06	0.5
5th Rinse									0.1	0.016	0.16
As Received	800863	TCLP							0.37	BDL	BDL
Coal Slag	800863	TCLP	EDTA + HCl	0.1M 2%	24	Water	5		0.46	0.04	6.3
Filtrate									5.32	75.74	205.02
3rd Rinse									0.16	0.08	0.7
5th Rinse									0.11	0.02	0.5
As Received	800863	TCLP							0.37	BDL	BDL
Coal Slag	800863	TCLP	HCl Acid	5%	24	Water	5		0.19	0.02	1.9
Filtrate									3.56	41.16	152.48
3rd Rinse									0.1	1.02	4.9
5th Rinse									0.07	0.01	0.3

Table 17. Results for EDTA, nitric acid, and hydrochloric acid extraction of waste sample 800963.

Sample	ID	Test	Extraction Fluid	Conc %	Time hours	Rinse	No of Rinses	pH Final	Cd ppm	Cr ppm	Pb ppm
As Received	800963	Total Metal	(Lab A)						16.7	256	888
As Received	800963	TCLP	(Lab A)						0.783	0.65	4.41
Plastic/Glass	800963	TCLP	Water		24	Water	5		25.25	2.36	1.2
Filtrate									25.69	107.84	0.48
3rd Rinse									2.17	8.83	0.1
5th Rinse									0.9	2.16	0.1
As Received	800963	TCLP							0.783	0.65	4.41
Plastic/Glass	800963	TCLP	EDTA	0.1M	24	Water	5		0.64	1.89	0.4
Filtrate									268.21	127.12	17.31
3rd Rinse									8.08	4.2	0.7
5th Rinse									0.96	1.2	0.7
As Received	800963	TCLP							0.783	0.65	4.41
Plastic/Glass	800963	TCLP	Nitric Acid	5%	24	Water	5		1.05	0.1	0.1
Filtrate									252.17	251.35	251.35
3rd Rinse									3.68	1.29	1.29
5th Rinse									0.85	0	0.04
As Received	800963	TCLP							0.783	0.65	4.41
Plastic/Glass	800963	TCLP	HCl Acid	5%	24	Water	5		2.1	0.13	0.13
Filtrate									199.76	167.85	167.85
3rd Rinse									8.28	1.28	1.28
5th Rinse									3.25	0.04	0.04

Table 18. Nitric acid extractions from waste sample 800863.

Sample	ID	Test	Extraction Fluid	Conc %	Time hours	Rinse	No of Rinses	pH Final	Cd ppm	Cr ppm	Pb ppm
As Received	800863	Total Metal							386	259	40.7
As Received	800863	TCLP							0.628	0.947	4.96
Coal Slag	800863	TCLP	Nitric Acid	1%	24				0	0.20	0.30
	800863	TCLP	Nitric Acid	3%	24				0	0	0.03
	800863	TCLP	Nitric Acid	5%	24				0.01	0	0.03
	800863	TCLP	HCl Acid	5%	24				0	0	0.72
As Received	800963	Total Metals							16.7	256	888
As Received	800963	TCLP							0.783	0.65	4.41
Plastic/Glass	800963	TCLP	Nitric Acid	1%	24				0.01	0.50	0.06
	800963	TCLP	Nitric Acid	3%	24				0.01	0.21	0.10
	800963	TCLP	Nitric Acid	5%	24				0.02	0.14	0.16
	800963	TCLP	HCl Acid	5%	24				0.09	0.11	0.10

Table 19. Nitric acid extraction results for lead.

Sample	ID	Test	Extraction Fluid	Conc %	Time hours	Rinse	No of Rinses	pH Final	Pb ppm	Pb ppm	Average Pb ppm
As Received	800863	Total Metal	(Lab B)						727.8		727.8
As Received	800863	TCLP	(Lab B)						3.29	3.29	3.29
Coal Slag	800863	TCLP	DI Water		16	Water	3		3.38	3.38	3.29
Filtrate									0	0	0
Rinse 1									0	-0.02	-0.01
Rinse 2									0	0	0.01
Rinse 3										-0.01	-0.01
As Received	800863	TCLP							3.29	3.29	3.29
Coal Slag	800863	TCLP	Nitric Acid	0.5%	16	Water	3		1.70	1.57	1.64
Filtrate									0.96	0.98	0.97
Rinse 1									0.33	0.35	0.34
Rinse 2									0.22	0.25	0.24
Rinse 3									0.22	0.24	0.23
As Received	800863	TCLP							3.29	3.29	3.29
Coal Slag	800863	TCLP	Nitric Acid	1.0%	16	Water	3		1.44	1.42	1.43
Filtrate									86.40	N/A	86.40
Rinse 1									8.73	8.82	8.78
Rinse 2									3.81	3.88	3.85
Rinse 3									2.35	2.33	2.34
As Received	800863	TCLP							3.29	3.29	3.29
Coal Slag	800863	TCLP	Nitric Acid	2.0%	16	Water	3		1.52	1.38	1.45
Filtrate									262.50	N/A	262.50
Rinse 1									16.93	17.07	17.00
Rinse 2									8.98	9.11	9.05
Rinse 3									4.38	4.43	4.41

Table 20. Nitric acid extraction results for glass media waste sample 800961.

Sample	ID	Test	Extraction Fluid	Conc %	Time hours	Rinse	No of Rinses	pH Final	Cd ppm	Cr ppm	Pb ppm
As Received	800961	Total Metal	(Lab A)						20.7	20.7	142.1
As Received	800961	TCLP	(Lab B)						0.72	BDL	5.05
Glass Beads	800961	TCLP	DI		16	Water	3		0.05	0.96	0.26
Filtrate									0.11	0.32	0.01
Rinse 1									0.08	0.01	0
Rinse 2									0.08	0	0
Rinse 3									0.05	0	0
As Received	800961	TCLP									
Glass Beads	800961	TCLP	Nitric Acid	0.5%	16	Water	3		0	0.01	0.01
Filtrate									13.58	0.61	77.38
Rinse 1									1.5	0.21	8.12
Rinse 2									0.15	0.14	0.89
Rinse 3									0	0.06	0
As Received	800961	TCLP									
Glass Beads	800961	TCLP	Nitric Acid	2.0%	16	Water	3		0	0	0.01
Filtrate									13.50	0.92	69.34
Rinse 1									1.56	0.23	7.65
Rinse 2									0.18	0.06	0.91
Rinse 3									0	0.05	0
As Received	800961	TCLP									
Glass Beads	800961	TCLP	Nitric Acid	5.0	16	Water	3		0	0.03	0.01
Filtrate									15.74	1.07	71.70
Rinse 1									1.75	0.25	7.82
Rinse 2									0.21	0.09	1.00
Rinse 3									0.02	0.08	0.01

Table 21. Nitric acid extraction results for PMB waste.

Sample	ID	Test	Extraction Fluid	Conc %	Time Hours	Rinse	No of Rinses	pH Final	Cd ppm	Cr ppm	Pb ppm
As Received	800968	Total Metal	(Lab B)						39.4	704	675.2
As Received	800968	TCLP	(Lab B)						1.5	11.0	BDL
Plastic Beads	800968	TCLP	DI		16	Water	3		1.32	4.59	0.44
Filtrate									0.64	65.64	0.05
Rinse 1									0.20	21.17	0.04
Rinse 2									0.13	13.29	0.03
Rinse 3									0.10	9.40	0
As Received	800968	TCLP									
Plastic Beads	800968	TCLP	Nitric Acid	0.5%	16	Water	3		0.01	0.23	1.19
Filtrate									22.56	141.75	13.5
Rinse 1									5.25	35.28	3.32
Rinse 2									1.2	8.22	1.23
Rinse 3									0.34	2.66	0.67
As Received	800968	TCLP									
Plastic Beads	800968	TCLP	Nitric Acid	2.0%	16	Water	3		0.00	0.16	0.18
Filtrate									23.06	425.75	164.00
Rinse 1									5.43	31.00	48.29
Rinse 2									1.31	23.41	12.50
Rinse 3									0.37	7.23	3.95
As Received	800968	TCLP									
Plastic Beads	800968	TCLP	Nitric Acid	5.0	16	Water	3		0.00	0.20	0.70
Filtrate									20.86	482.50	220.00
Rinse 1									4.70	94.00	51.81
Rinse 2									1.09	23.85	3.60
Rinse 3									0.28	8.62	5.15

Table 22. Comparison of nitric acid and $LiBO_2$ flux digestion for metals analysis.

Test No.	Sample	Test	Cd ppm	Pb ppm	Cr ppm	Ba ppm
124	P1	HNO_3	1.79	34.01	22.99	30.22
125	P1	HNO_3	1.65	33.08	22.58	30.51
159	P1	$LiBO_2$			20557	3044
160	P1	$LiBO_2$			17199	2580
133	P2	HNO_3	1.57	30.14	20.88	28.02
134	P2	HNO_3	1.46	28.04	19.95	27.16
161	P2	$LiBO_2$			18470	2780
162	P2	$LiBO_2$			18955	2672
128	P3	HNO_3	0.41	5.53	6.92	4.36
129	P3	HNO_3	0.38	5.86	6.91	4.54
163	P3	$LiBO_2$			9219	478
164	P3	$LiBO_2$			9165	455
135	P4	HNO_3	0.35	5.39	5.47	4.98
136	P4	HNO_3	0.39	5.55	5.76	5.13
157	P4	HNO_3 - $LiBO_2$			6842	518
158	P4	HNO_3 - $LiBO_2$			6865	508
138	Glass 5	HNO_3	4.69	1.38	0.10	0.03
139	Glass 5	HNO_3	4.44	1.20	0.10	0.03
150	Glass 5	$LiBO_2$			4	9
151	Glass 5	$LiBO_2$			13	11
142	Glass 6	HNO_3	0.52	0.39	0.21	0.14
143	Glass 6	HNO_3	0.39	0.26	0.13	0.09
155	Glass 6	$LiBO_2$			45	25
156	Glass 6	$LiBO_2$			35	12
145	Sand 7	HNO_3	0.15	0.75	0.60	1.22
146	Sand 7	HNO_3	0.15	0.79	0.58	1.15
152	Sand 7	$LiBO_2$			810	887
153	Sand 7	$LiBO_2$			819	899
165	Sand 7	HNO_3	14.5	85	70	121
166	Sand 7	HNO_3	15.5	69	60.35	126
167	Sand 7	$LiBO_2$ (after 165#)			689.5	818
168	Sand 7	$LiBO_2$ (after 165#)			726.5	804
114	Sand 8	HNO_3	0.93	0.21	0.19	0.27
115	Sand 8	HNO_3	0.94	0.15	0.19	0.21
30	Sand 8	$LiBO_2$	86		40	704
31	Sand 8	$LiBO_2$	82		38	765

6 Biodegration Through Microbial Digestion

Objective

The term *biodegradation* is often used to describe a variety of quite different microbial processes that occur in natural ecosystems. Biodegradation can be defined as the breakdown of organic compounds in nature by actions of microorganism, such as bacteria, actinomycetes, and fungi. The microorganisms derive energy and may increase in biomass from the process (Riser-Roberts 1992). The breakdown can proceed via either an aerobic or anaerobic digestion process. The difference is that aerobic digestion requires the presence of oxygen, while anaerobic digestion proceeds without oxygen.

The objective was to evaluate the potential of a biodegradation process to either render the contaminated paint blast media waste nonhazardous or to decrease the disposal volume. Bioremediation treatment processes that consist of the biodegradation of organic-based plastic media waste or agricultural-based blast media waste were considered in this study. Bioremediation processes would not be suitable for inorganic blast media such as mineral, slag, or glass abrasives.

Approach

DOT Technologies of Vancouver, BC, has developed a bioremediation process for the successful treatment of solvent-based paint strippers. The process was modified to treat starch-based ground walnut shell blast media wastes generated by the commercial airline industry (Oestreich and Waugh 1993; Oestreich and Waugh 1994). A preliminary evaluation of this process was conducted by USACERL.

The DOT bioremediation process starts with a starch enzyme liquefaction step. To make the starch blast media soluble in water, the starch waste must be dispersed in water and treated with an enzyme. The alpha amylase enzyme is widely used in the starch industry to liquefy starch for the production of syrups and sweeteners. The enzyme particle is specifically designed to cleave the starch polymers, reducing the carbohydrate polymers to simple sugars and low-molecular-weight oligosaccharides.

Following liquefaction, the mixture is filtered through 25- and 15-micron filters. The paint solids that accumulate in the particulate filters, can be directly disposed of as a hazardous waste or further digested. The volume of paint solids collected was typically 5 to 10 percent of the original starch waste volume. The filtered starch solution is then passed through an ion-exchange system to remove metal contaminants, including heavy metals.

The resulting starch solution is transferred to starch waste digestion. A bacteria and nutrient package is added to start the digestion and the starch is degraded over a 5-7 day period. Specific-gravity readings can be used to monitor the solids reduction with time to indicate when the starch has been fully digested. The remaining water is pumped back to disperse the next batch of starch waste, and the process is repeated.

Discussion

The disposal costs for the bioremediation of starch waste were projected by DOT Technologies to compare favorably to current methods of disposal in a hazardous waste landfill. Total cost per pound* were estimated to range from US $0.50/lb for waste volumes greater than 150,000 lb, to $0.75 US/lb for waste volumes of less than 50,000 lb.

The advantage of the bioremediation process developed by DOT Technologies is that the process decreases the disposal volume of the hazardous waste.

Disadvantages include the following:

- The complexity of the bioremediation process impacts its feasibility for use on an industrial scale at an Army facility
- Bioremediation requires specialized knowledge and equipment not currently available at most army depot facilities
- The DOT Technologies process was developed specifically for ground walnut shell media; the process can not be modified for use with other media types
- The selection of the bacteria may be specific to the waste stream, requiring different mixtures of bacteria for different waste streams
- The final extraction of the hazardous species in the treatment process and their disposal is ambiguous and needs further clarification

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* 1 lb. = 0.4536 kg.

- Abrasive blasting with starch media is not a major depaint method at Army depots.

Considering these disadvantages, the use of a bioremediation process for treating paint blast media waste at Army facilities is not recommended.

7 Self-Encapsulation of Plastic Media Waste

The self-encapsulation of thermoplastic blast media waste was investigated previously by Jermyn and Wichner (1991). The concept consists of heating the thermoplastic Type V - acrylic media, such that it softens to a point that it can be molded into a non-leachable waste form. The self-encapsulation of Type V acrylic waste by softening and pressure molding was shown to pass EPA leachability requirements (Table 23). Thermoset media Types I, II, III, and IV do not melt on heating, but directly decompose. To encapsulate these waste types, they were mixed with a thermoplastic material. The thermoplastic would soften, encapsulating the contaminated thermoset blast media wastes. Table 23 shows that encapsulation with a 1:3 blend of Type II media wastes in Type V thermoplastic material failed the TCLP leachability test for Cd and Cr.

Self-encapsulation of plastic media was found to be effective only with Type V thermoplastic blast media waste. The limited data showed that self-encapsulation was not effective on thermoset media blended into thermoplastic media. Because most depot depaint operations use a variety of both thermoplastic and thermoset plastic media, a treatment process applicable only to one type of plastic medium is of limited utility to the Army.

Table 23. TCLP results for self-encapsulated plastic media waste materials.

	Ba ppm	Cd ppm	Cr ppm	Pb ppm	Status
Type V Waste	1.5	0.83	19	0.07	Passed
Self-encapsulated Type V Pellet	1.0	0.26	2.7	0.82	Passed
Type II Waste	1.5	2.0	29	0.08	Failed Cd, Cr
1:3 Blend, Type II: Type V	1.5	1.2	22	0.07	Failed Cd, Cr
Palletized blend	0.91	1.4	4.5	2.3	Failed Cd
TCLP Limit	100	1	5	5	

Source: Jermyn and Wichner 1991.

8 Waste Stabilization in Portland Cement

Background

Cement-based materials were the first ingredients used in chemical fixation and stabilization of hazardous wastes and have been the most widely used (Connors 1990). Cement stabilization was first used in the processing of nuclear wastes in the 1950s. Cement and cement-based materials for the treatment of both hazardous and radioactive wastes have since been widely studied (Topp 1982; Barth 1990; Canadian Portland Cement Association 1992).

Cement stabilization was investigated as a universal treatment for the waste generated by the full range of media types used at Army depot facilities.

Portland cement was patented in 1824 by Joseph Aspidin and is made by heating together limestone and clay at about 1500 °C. It was named after the natural stone that it resembled from the quarries of Portland, England. Portland cement is a mixture of various calcium silicates and calcium aluminate minerals, principally dicalcium silicate and tricalcium silicate with smaller amounts of tricalcium aluminate and calcium aluminoferrite. These are represented in the cement notation as C_2S , C_3S, C_3A, and C_4AF, respectively. A typical weight proportion of Portland cement is 55 percent C_3S, 25 percent C_2S, 10 percent C_3A, and 10 percent C_4AF.

The cement's reaction process begins with the introduction of water. The water reacts with the silicate mixture of the cement to ultimately form a hard, dense matrix. Although the specific reactions are complex (Lea 1970), it may be considered as a series of reactions between the solid cement components and a fluid (Barneyback and Diamond 1981). The fluid initially is the mixture water, and the solid component is the cement. Shortly after mixing, the water is converted into a complex alkali- and sulfate-bearing solution. On setting, some fluid is captured in the pores of the matrix. Further hydration takes place as the cement components continue to react with the pore solution. The hazardous waste can be either mixed with the dry cement or added to the mixture shortly after the water is mixed in.

The use of a cement system containing superplastizers, fly ash, and silica fume was reported to stabilize paint blast waste (Garner, Carrasquillo, and Fowler 1993). However, the specific chemical processes that occurred during the solidification were not discussed.

Approach

A multiphase approach was used. In Phase I, blast media waste samples were collected from Army depot facilities. These samples were tested for leachable metals, and those determined to be hazardous were solidified in commercial Portland cement. Cement stabilization was found to yield the paint blast samples nonhazardous for Cd, but the process was not able to stabilize Cr.

In Phase II, additional blast media waste samples were collected and characterized. To simulate the high pH chemical environment encountered during the hydration reaction in a cement matrix, the response of the paint blast media waste to simulated pore solutions was investigated.

In Phase III, the paint blast media wastes were encapsulated in Portland cement. The pore solution, which is the actual chemical environment that the wastes encounter during cement hydration, was expressed from cast cement and waste samples. The metal content of expressed pore solution was analyzed.

In the expectation that granulated blast furnace slag would chemically reduce the valence of the chromium from the waste during the cement hydration reaction, samples of paint blast media wastes were cast in a mixture of Portland cement and blast furnace slag during Phase IV. The complete laboratory results of the cement stabilization work are presented in Appendix C.

Phase I—Cement Stabilization

Paint blast media waste samples were obtained from Army Depot facilities. The concentration of leachable RCRA metals of the as-received wastes was determined by TCLP (Table 24). Five of the 10 wastes were found to be not hazardous and no additional testing was necessary. Cement stabilization of the five samples that failed TCLP was studied. These samples failed TCLP for Cd and/or Cr.

Water is necessary to initiate the cement hydration reaction. However, to form a workable body with adequate flow characteristics, additional water above the stoichiometric requirement is generally added. This is typically described in terms of the water-to-cement ratio, the stoichiometric value being 0.44. Typical commercial concrete uses a water-to-cement ratio of +/- 0.5. In the Phase I study, 22 percent Portland cement, and 11 percent water by weight were added to the waste. The three waste samples that initially failed TCLP only for Cd were successfully stabilized by this procedure. The remaining two wastes, which initially failed both for Cd and Cr as received, passed TCLP for Cd but failed the TCLP test for Cr after encapsulation. These results indicate that Cd-contaminated waste can be successfully stabilized in Portland cement.

The two wastes that failed the TCLP for Cr in the first stabilization—sand and plastic media from SSAD—were subjected to further evaluation. The wastes were treated by 20 percent Portland cement and 20 percent water additions. These wastes failed the TCLP test for Cr, and subsequently were treated with 33 percent addition of Portland cement and 17 percent water addition. Again the two wastes failed TCLP. These results indicated the difficulty of cement stabilization of Cr-contaminated waste in Portland cement.

Work beyond encapsulation and TCLP testing was necessary to gain insight into the chemical processes occurring during cement solidification. The use of simulated and expressed pore solutions was investigated and is discussed in the sections below.

Phase II—Simulated Pore Solution Analysis

Waste Characterization

Additional paint blast media waste samples generated at an Army maintenance facility were obtained for use in this and subsequent phases of the investigation. The wastes selected were among those more commonly generated at the facility. Samples were taken from a number of blasting stations for each type of media. The total metal (As, Ag, Cd, Hg, Pb, and Se) concentrations were determined by dissolving the sample in a concentrated solution of nitric acid (1 HNO_3 : 1 H_2O) at 80 °C for 12 hours. The Cr and Ba content was determined using a $LiBO_2$ flux at 1000 °C for 5 minutes. The results are presented in Table 25.

The leachable component of the waste as measured by TCLP using the EPA protocol is shown in Table 26. The results of TCLP analyses showed that seven of the eight wastes failed for Cd, and all plastic media wastes failed for Cr. Despite significant Pb and Ba contents in the raw waste, all wastes passed TCLP for those elements.

Approach

The TCLP is designed to simulate the leaching of a waste form in a municipal landfill along with other general refuse. However, the actual chemical environment that a hazardous species may encounter may be substantially different. Bishop (1988) reported that for cement-based systems, the high alkalinity quickly neutralizes all of the acid present in the leachant, so that the leaching occurs under highly alkaline conditions rather than acidic conditions. Therefore, for waste treated with Portland cement, the measured concentration of metals in TCLP leachate may not accurately represent the true stability of the waste specie.

The extraction and analysis of the pore solution from Portland cement has provided insight into the hydration process (Longuet, Burglen, and Zelwer 1973; Barneyback and Diamond 1981). Pore solutions recovered after set are typically found to be concentrated solutions of alkali hydroxides with modest contents of other compounds. The overall pH of the pore solution is extremely alkaline, with a pH >13; this is the chemical environment that any foreign species, introduced from the hazardous waste, would encounter during stabilization. Understanding the behavior of foreign species in this specific chemical environment should give insight into the chemical processes that occur during stabilization. Such an understanding was expected to permit the subsequent optimization of the stabilization matrix to enhance the long-term stabilization of hazardous wastes.

Due to the difficulty of extracting or expressing pore solution from cement samples, and the resulting complex chemistry of the pore solution environment, simulated pore solutions had to be used to model the response of a waste to this environment. An advantage of using simulated pore solutions is that the role of pH on the solubility of metal species in the waste is isolated.

The simulated pore solution used in this study consisted of 1.0M and 0.1M solutions of KOH + NaOH (3:1 mole ratio) corresponding to typical high- and low-alkali Portland cements. Samples of abrasive blast media waste (100g) were placed into 2 liters of model pore solution. After storage in a nitrogen environment for 1 day and 28 days respectively (these are standard mileposts for cement hydration), the samples were filtered and the metal contents determined. Concentrations of As, Ag, Ba, Cd, Cr, Pb, and Se were determined using inductively coupled plasma. The method detection limits (mg/l) are as follows: As = 0.11, Ba = 0.030, Cd = 0.017, Cr = 0.007, Pb = 0.066, Se = 0.18, and Ag = 0.016. A graphite furnace atomic absorption spectrometric method was used to determine Hg content (Keller, Peden, and Rattonetti 1984).

Results

The results of simulated pore solutions for each waste are presented in Table 27. The controlling factor in the response of a waste species to the simulated pore solution is the pH. Due to the high pH of cements, the pH is not directly measured. Instead, the buffering capacity to an acid titration is determined. The predominant anion is assumed to be OH^- such that the approximate pH can be calculated. The type of blast media did not seem to have significant effect on the behavior of the metal species in the waste. The length of residence in the simulated pore solution did not greatly affect the concentration of metals in solution.

All blast media wastes failed the TCLP for Cd, but when samples of the waste were exposed to the simulated pore solutions, the concentration of Cd decreased to below 1 ppm. This is consistent with the work of other investigators as summarized by Connor (1990), who reported that Cd was found to be insoluble at the high pH encountered in the model pore solution. Cd begins to leach significantly only below pH 9.

Cr exhibits amphoteric (both acid and basic) behavior with high solubility at both low and high pH (Pourbaix 1974). The plastic blast media wastes failed TCLP due to significant Cr content. When subjected to the chemical environment of the simulated pore solution, the concentration of Cr increased due to the high pH of the solution, and was dependent on the pH (Figure 4). The chromium ion is expected to be present as Cr^{6+}, which is highly soluble (Pourbaix 1974).

Similar behavior was encountered for Pb-containing wastes. Even though the samples successfully passed TCLP, when subjected to the model pore solutions the concentration of Pb increased with increasing solution pH (Figure 5). This was due to the amphoteric behavior of the Pb. For the highly alkaline conditions of the pore solution, the increased solubility of both Pb and Cr confirmed the controlling role that pH plays in the response of waste species in cement-based matrix. This demonstrates the care which must be taken in interpreting TCLP results for hazardous waste treated in cement.

Next the paint blast media wastes were encapsulated in Portland cement. The actual pore solution was extracted from cast samples of cement and blast media waste to determine directly the chemical response of the hazardous components of the waste to the actual cement hydration environment.

Phase III—Portland Cement Stabilization

Approach

In this phase, the paint blast media wastes analyzed in Phase II were encapsulated in Portland cement. An important goal in stabilization and solidification of any hazardous waste is the final disposal volume generated. In order to minimize the final disposal volume, a loading of 75 percent waste and 25 percent cement (by volume) was utilized. High waste loading also minimizes the raw material costs of the Portland cement used for stabilization.

The exact chemical and mineral makeup of Portland cement depends on the original raw materials utilized. These raw materials tend to vary depending on the local geology of origin, particularly in terms of alkali content. Therefore, in this phase, two commercially available Portland cements were used—one corresponding to the lower limit of alkali content in commercial cements and the other corresponding to the upper limit. Chemical analysis of the high- and low-alkali cements were performed using x-ray fluorescence, and are shown in Table 28.

Paint blast media waste, cement, and water were blended in a planetary mixer, cast with vibration into plastic cylinders approximately 47 x 70 mm, and sealed. Water is necessary to initiate the cement hydration reaction. However, to form a workable body with adequate flow characteristics, additional water above the stoichiometric value is generally added. In this study, water judged to yield suitable workability was added and varied depending on the fineness of the waste media. The water-to-cement ratios are presented in Tables 29 and 30. Samples were allowed to hydrate for 1 day and 28 days (for high- and low-alkali cements, respectively) before pore solutions were expressed.

A schematic of the pore expression apparatus is shown in Figure 6. Compressive loads as high as 500 MegaPascals (MPa) were applied to effectively express pore solutions from the solidified waste specimens. The expressed pore solution was collected and stored under nitrogen atmosphere until analyzed.

Results

The chemical analysis of expressed pore solutions from spent paint blast media wastes incorporated into ordinary Portland cement matrix are given in Tables 29 and 30. The OH-concentration of the pore solution expressed from cement waste forms are lower than those used in the simulated pore solution study—particularly for the plastic media P1 and P2. The high water-to-solid ratio of the waste forms, required due to the extreme fineness of the spent plastic media, diluted the alkali levels of the pore solutions. Still, the solubility of the hazardous elements in the expressed pore solutions followed the general trends seen in Phase II. The expressed pore solution contained very low concentrations of Cd and Ba (as BaSO4) in solution because Cd and Ba are insoluble at high pH.

Both Cr and Pb showed significant solubility within the matrix of the solidified waste form. The initial concentration of Cr in the expressed pore solution was much higher after 1 day hydration in both low- and high-alkali cement systems than was seen in the simulated pore solutions. In the expressed pore solutions, Cr increased in concentration with an increase in OH^- concentration (Figure 7). However, as shown in Figure 8, samples hydrated 28 days had higher $[OH^-]$ and lower Cr concentrations compared to samples hydrated 1 day. For longer times, the $[OH^-]$ concentration increased with hydration time and the Cr concentration decreased. This is opposite to the response expected with $[OH^-]$ control of the chromium concentration. It seems obvious that additional processes must be occurring. Processes to decrease the chromium concentration in the pore solution may include a very extended reduction process of the chromium or some combination of physical adsorption and/or incorporation of the Cr into the cement hydration products. It appears that the kinetics are sufficiently slow that the process may extend beyond the 28-day hydration period studied.

The concentration of Pb was not controlled by the $[OH^-]$ of the expressed pore solution (Figure 9). The Pb concentration of samples P1 and P2 decreased despite an increase in the $[OH^-]$ of the expressed pore solution. Clearly other factors besides the $[OH^-]$ influenced the solubility of Pb within the actual matrix of ordinary Portland cement waste forms. The lower Pb concentration in the expressed pore solution of the high- alkali cement may possibly be due to the higher sulfate content of the high-alkali cement (Table 28). During normal cement hydration sulfate ions are released into the pore solution. The presence of sulfates would be expected to react with the Pb species present and precipitate out a low-solubility Pb sulfide, resulting in a decrease of the Pb concentration in the pore solution.

TCLP calls for any initial liquid phase present in the waste to be added to the liquid extract, and for these to be analyzed together. The results of the TCLP analysis performed on the solid residue retained after expression of the pore solution are given in Table 31. Due to the trapping of pore solution in the many isolated submicron pores, the expression of pore solution typically only extracts 10 to 25 percent of the total pore solution. The results of TCLP performed on similar samples that did not have the pore solution expressed are shown in Table 32. No significant difference was found in the two sets of TCLP results. The Cr concentration was slightly higher in the low-alkali cement waste forms compared to the high-alkali cement wastes. TCLP analysis showed no apparent trend due to hydration time.

The plastic media waste samples P1 and P2 stabilized in Portland cement failed TCLP for Cr. The high pH of the cement completely neutralized the acid present in the TCLP test. Both the initial pH and final [OH^-] of the TCLP test were measured. For samples P1 and P2, the calculated final pH was >12.2, at which Cr is highly soluble. The Cr metal concentration of samples G5, G6, S7, and S8, which were at least one order of magnitude lower than P1 and P2 (Table 25) all passed TCLP when stabilized in Portland cement.

The final [OH^-] of the TCLP extraction fluid was in the identical range as the [OH^-] of the expressed pore solution. The similarity of the [OH]$^-$ is demonstrated clearly in Figure 10, where the chromium concentration of the expressed pore solutions is plotted on the same graph as the Cr concentration obtained from the TCLP analyses. Both the expressed pore solution and TCLP are at the same high [OH^-] such that both show the similar high Cr solubility. It is this final pH of the TCLP extraction test, controlled by the alkalinity of the cement, that determines the leachable chromium.

Summary of Phase III Results

Paint blast media wastes were encapsulated in Portland cement. The expressed pore solutions had calculated pH greater than 12. At this pH, Cd and Ba concentrations were low and Cr and Pb concentrations were high. The response of the Cr and Pb concentrations to pH and hydration time were observed. The high pH of the cement completely neutralized the acid present in the TCLP test. Samples P1 and P2, stabilized in Portland cement, failed TCLP for Cr.

Phase IV—Stabilization in Cement and Blast Furnace Slag Addition

Approach

An approach developed by Pourbaix (1974), which is widely used by electrochemists and corrosion engineers, is to represent the stability fields of ionic species on a two-dimensional plot of the electrochemical potential versus pH. The potential-pH diagram for system chromium in water is shown in Figure 11. The stabilization and solidification of Cr^{6+} is typically a two-step process, with an initial reduction of

Cr^{6+} to Cr^{3+} by the addition of ferrous salts followed by encapsulation in cement or another type of matrix.

The stability fields for Portland cement and Portland cement with blast furnace slag were superimposed by Macphee and Glasser (1993) onto Figure 11. They showed ordinary Portland cements to have a $pH > 13$. The addition of blast furnace slag reduced the pH to between 11 and 13, and also reduced the electrochemical potential from oxidizing to reducing. It was inferred that this may be sufficient to reduce the Cr^{6+} in equilibrium with a Portland cement system to Cr^{3+} in a blast furnace slag/cement system. Therefore, to control the stability of the chromium in a solidification matrix, it is necessary to control the electrochemical potential and pH that determines the ionic species and its solubility.

Blast furnace slag is formed during the manufacturing of iron when limestone reacts with the silica and alumina present in the ore as impurities. Blast furnace slag is a pozzolanic material; although it will not hydrate directly with water, when combined with cement it will participate in the cement hydration reaction. The addition of blast furnace slag to Portland cement is known to slow the hydration kinetics and to increase the final compressive strength of the cement (Taylor 1990).

The addition of blast furnace slag to Portland cement was investigated to test the hypothesis that it would reduce the electrochemical potential sufficiently to also reduce the valence of the chromium from the highly soluble Cr^{6+} to the more stable Cr^{3+}.

This work concentrated on the plastic media waste samples P1, P2, P3, and P4 discussed in Phase III, as these had high concentrations of Cr and failed TCLP for Cr. Samples of paint blast media waste were blended and cast with a mixture of Portland cement and granulated blast furnace slag. The cement used in Phase III was replaced with 25% by volume of the blast furnace slag yielding a composition of 75% waste and 25% cement blended with slag. The composition of the blast furnace slag as determined by x-ray fluorescence analysis is given in Table 33. The experimental procedures were similar to those used in Phase III. Samples were cast and allowed to hydrate for 1 or 28 days, as prescribed in the previous section. The pore solutions were expressed and analyzed, and TCLP analyses were performed (see Tables 34 and 35).

Results

The chromium concentration of the expressed pore solution in relation to the $[OH^-]$ is shown in Figure 12. The different wastes, with different level of contaminants, in the different cement matrices, resulted in different initial [OH^-]. Despite significantly different initial [OH^-], the partial replacement of the cement with blast furnace slag universally resulted in a decrease in the [OH^-] and a corresponding decrease in the Cr concentration. For both the 1 and 28 day hydrations the response was the same; partial replacement of cement by blast furnace slag resulted in a decrease in the [OH^-] and a corresponding decrease in the Cr concentration.

The effect of hydration on the Cr concentration of the expressed pore solutions is shown in Figure 13. The data showed an increase in [OH^-], with an increase in hydration time for all samples with blast furnace slag additions. With the exception of the high-alkali data for samples P1 and P2, the data showed an decrease in the chromium concentration, consistent with the Phase III results. This finding again indicates the occurrence of an unidentified long-term process to yield a decrease in the chromium concentration over time

Samples encapsulated in a mixture of Portland cement and blast furnace slag failed TCLP for Cr (Tables 36 and 37). The addition of blast furnace slag was found to have shifted the final [OH^-] of the TCLP extraction fluid to a slightly lower range of values (Figure 14). However, the impact of blast furnace slag additions is a secondary effect superimposed on the much greater role played by the buffering capacity of the cement matrix on the final [OH^-] of the TCLP extraction fluid. The expressed pore solution results showed a decrease in the Cr concentration with the addition of blast furnace slag. TCLP results showed that although three of the four samples hydrated 1 day and all four samples hydrated 28 days showed a slight decrease in the leachable Cr due to blast furnace slag additions, they all failed TCLP for Cr.

The chemical histories of these samples were quite complex. The waste was mixed with a cement or a cement/slag matrix, allowed to hydrate for 1 or 28 days, and then granulated for TCLP testing. The initial environment of the TCLP extraction was acidic. At some point during the extraction, the buffering capacity was consumed and the pH shifted to highly alkaline conditions. The leachable Cr concentration was then determined. At each step in this process, chemical reactions occurred. Normally in the acid environment of the TCLP test, the blast furnace slag should react with Cr^{6+} and reduce it to the less-soluble Cr^{3+}. It may be possible that this occurred during the initial stages of the TCLP extraction, before the buffering capacity of the acid was consumed. The shift of the TCLP from the initial acidic conditions to highly alkaline conditions had a greater affect on the final [OH^-] and the leachable Cr than the addition of blast furnace slag to the waste form. The leachable chromium concentration measured by the TCLP, with or without blast furnace slag, appeared to be controlled by the final high pH of the extraction solution.

Summary of Phase IV Results

Despite the replacement of the cement with blast slag, the high pH of the cement completely neutralized the acid present in the TCLP test and all samples failed TCLP for Cr. This had a greater affect on the final [OH^-] and leachable Cr than the addition of blast furnace slag to the waste form. However, the blast furnace slag additions did slightly decrease the [OH^-] and resulted in a corresponding decrease in the Cr concentration in the expressed pore solutions of waste forms hydrated for 28 days. Although this decrease may be due to the reduction of Cr valence by the blast furnace slag, the reaction kinetics appear to be too slow to make this process applicable to Army needs.

Table 24. TCLP results for 10 waste samples for Phase I cement encapsulation study.

Depot	Waste	Stabilization (wt%)	As ppm	Hg ppm	Se ppm	Cr ppm	Cd ppm	Pb ppm	Ag ppm	Ba ppm	Results
ANAD	Coal Slag		BDL	BDL	0.089	0.0296	0.497	0.801	BDL	1.5	Pass All
ANAD	Glass Beads		0.049	BDL	0.019	0.405	0.245	0.453	BDL	0.6	Pass All
ANAD	Steel		BDL	BDL	0.146	BDL	0.121	0.082	BDL	1.5	Pass All
CCAD	Star Blast		0.024	BDL	0.026	0.144	0.084	0.171	0.1	0.1	Pass All
CCAD	Plastic		0.026	BDL	BDL	3.353	0.058	0.479	BDL	0.1	Pass All
ANAD	Mg/Fe Silicates		BDL	BDL	BDL	0.0693	10.051	0.308	0.01	1.7	Fail Cd
ANAD	Mg/Fe Silicates	22%Cem + 11% H_2O	BDL	BDL	0.017	0.028	BDL	BDL	BDL	0.2	Pass All
ANAD	Alumina		BDL	BDL	BDL	0.602	2.721	0.611	BDL	0.3	Fail Cd
ANAD	Alumina	22%Cem + 11%H_2O	BDL	BDL	0.023	0.122	BDL	0.019	BDL	0.2	Pass All
SAAD	Sand		BDL	BDL	BDL	12.9	1.5	0.1	BDL	0.7	Fail Cr, Cd
SAAD	Sand	22%Cem + 11%H_2O	BDL	BDL	0.021	6.659	BDL	BDL	BDL	0.2	Fail Cr
SAAD	Sand	22%Cem + 20%H_2O	BDL	BDL	0.029	7.518	BDL	BDL	BDL	0.2	Fail Cr
SAAD	Sand	33%Cem + 17%H_2O	BDL	BDL	0.04	4.999	BDL	BDL	BDL	0.4	Fail Cr
SAAD	Plastic		0.094	BDL	0.088	19.6	2.8	0.1	BDL	0.9	Fail Cr, Cd
SAAD	Plastic	22%Cem + 11% H_2O	BDL	BDL	0.012	13.2	BDL	BDL	BDL	0.2	Fail Cr
SAAD	Plastic	22%Cem + 20% H_2O	0.04	BDL	0.026	13.2	BDL	BDL	BDL	0.3	Fail Cr
SAAD	Plastic	33%Cem + 17% H_2O	0.04	BDL	0.025	10.259	BDL	BDL	0.046	0.3	Fail Cr
SAAD	Glass Beads		0.037	BDL	0.0256	0.379	14.8	3.5	BDL	0.3	Fail Cd
SAAD	Glass Beads	22%Cem. + 11% H_2O	BDL	BDL	BDL	0.206	BDL	BDL	BDL	0.1	Pass All
TCLP Limits			5.0	0.2	1.0	5.0	1.0	5.0	5.0	100.0	

Table 25. Total metal analysis of Army-generated paint blast media waste (ppm).

	Cd	As	Pb	Hg	Ba	Se	Ag	Cr
Plastic 1	172.0	< 11.0	3355.0	<10.0	2812.0	<18.0	<10.0	20557.0
Plastic 2	152.0	<11.0	2909.0	<10.0	2726.0	<18.0	<10.0	18173.0
Plastic 3	39.5	<11.0	570.0	<10.0	467.0	<18.0	<10.0	9192.0
Plastic 4	37.0	<11.0	547.0	<10.0	518.0	<18.0	<10.0	6842.0
Glass 1	457.0	<11.0	129.0	<10.0	10.0	<18.0	<10.0	8.5
Glass 2	45.5	<11.0	332.5	<10.0	18.5	<18.0	<10.0	40.0
Sand 1	15.0	<11.0	77.0	<10.0	893	<18.0	<10.0	815.0
Sand 2	93.5	<11.0	18.0	<10.0	735	<18.0	<10.0	39.0

Table 26. TCLP analysis of Army-generated paint blast media waste (ppm).

Waste	Cd	As	Pb	Hg	Ba	Se	Ag	Cr	Status
Plastic 1	4.90	0.14	<0.066	<0.1	0.65	<0.18	<0.016	43.07	Failed Cd, Cr
Plastic 2	5.15	0.14	<0.066	<0.1	0.74	<0.18	<0.016	44.73	Failed Cd, Cr
Plastic 3	1.35	<0.11	<0.066	<0.1	0.55	<0.18	<0.016	18.01	Failed Cd, Cr
Plastic 4	1.35	<0.11	<0.066	<0.1	0.56	<0.18	<0.016	16.32	Failed Cd, Cr
Glass 1	28.17	<0.11	4.86	<0.1	0.09	<0.18	<0.016	0.16	Failed Cd
Glass 2	1.93	<0.11	0.24	<0.1	0.17	<0.18	<0.016	0.03	Failed Cd
Sand 1	0.62	<0.11	0.18	<0.1	1.03	<0.18	<0.016	0.47	Passed
Sand 2	4.85	<0.11	0.10	<0.1	0.30	<0.18	<0.016	0.10	Failed Cd
TCLP Limit	1.00	5.00	5.00	0.20	100.00	1.00	5.00	5.00	

Table 27. Results of simulated pore solutions for each waste.

Waste	Solution	Time	[OH-] start	[OH-] end	Cd	Pb	Cr	Ba
P1	0.1M	1	0.0993	0.0790	0.02	31.70	92.54	0.05
P1	0.1M	28	0.0998	0.0687	0.029	30.68	89.06	0.03
P1	1M	1	0.993	0.963	0.17	77.29	102.7	0.27
P1	1M	28	0.998	0.945	0.09	84.98	104.5	0.28
P2	0.1M	1	0.0993	0.0818	<0.017	25.69	88.48	0.04
P2	0.1M	28	0.0998	0.0685	0.026	27.62	86.87	0.03
P2	1M	1	0.993	0.960	0.19	74.11	113.8	0.26
P2	1M	28	0.998	0.954	0.11	88.75	106.7	0.30
P3	0.1M	1	0.0993	0.0929	<0.017	8.86	23.22	0.03
P3	0.1M	28	0.0998	0.0887	<0.017	12.49	27.69	0.03
P3	1M	1	0.993	0.980	<0.017	18.01	38.14	0.25
P3	1M	28	0.998	0.980	0.03	21.93	39.95	0.37
P4	0.1M	1	0.0993	0.0935	<0.007	8.91	21.72	<0.03
P4	0.1M	28	0.0998	0.0894	<0.017	13.83	28.00	0.03
P4	1M	1	0.993	0.983	<0.017	18.41	32.00	0.24
P4	1M	28	0.998	0.979	0.04	23.96	36.72	0.39
G5	0.1M	1	0.0993	0.0968	<0.017	2.07	0.129	<0.03
G5	0.1M	28	0.0998	0.0973	<0.017	3.74	0.12	<0.03
G5	1M	1	0.993	0.989	0.31	1.42	0.053	0.05
G5	1M	28	0.989	0.976	0.28	4.71	0.067	0.06
G6	0.1M	1	0.0993	0.0983	<0.017	<0.066	0.032	<0.03
G6	0.1M	28	0.0998	0.0988	<0.017	0.10	0.038	<0.03
G6	1M	1	0.993	0.993	0.28	0.37	0.038	0.04
G6	1M	28	0.989	0.979	0.089	0.60	0.062	<0.03
S7	0.1M	1	0.0993	0.0964	<0.017	0.42	1.258	<0.03
S7	0.1M	28	0.0998	0.0957	<0.017	0.37	1.43	<0.03
S7	1M	1	0.989	0.975	0.019	2.01	1.44	0.29
S7	1M	28	0.993	0.984	<0.017	1.96	1.50	0.13
S8	0.1M	1	0.0993	0.0980	<0.017	0.12	0.144	<0.03
S8	0.1M	28	0.0998	0.0977	<0.017	0.14	0.17	<0.03
S8	1M	1	0.993	0.987	0.18	0.46	0.29	0.09
S8	1M	28	0.989	0.977	0.018	0.48	0.22	0.08

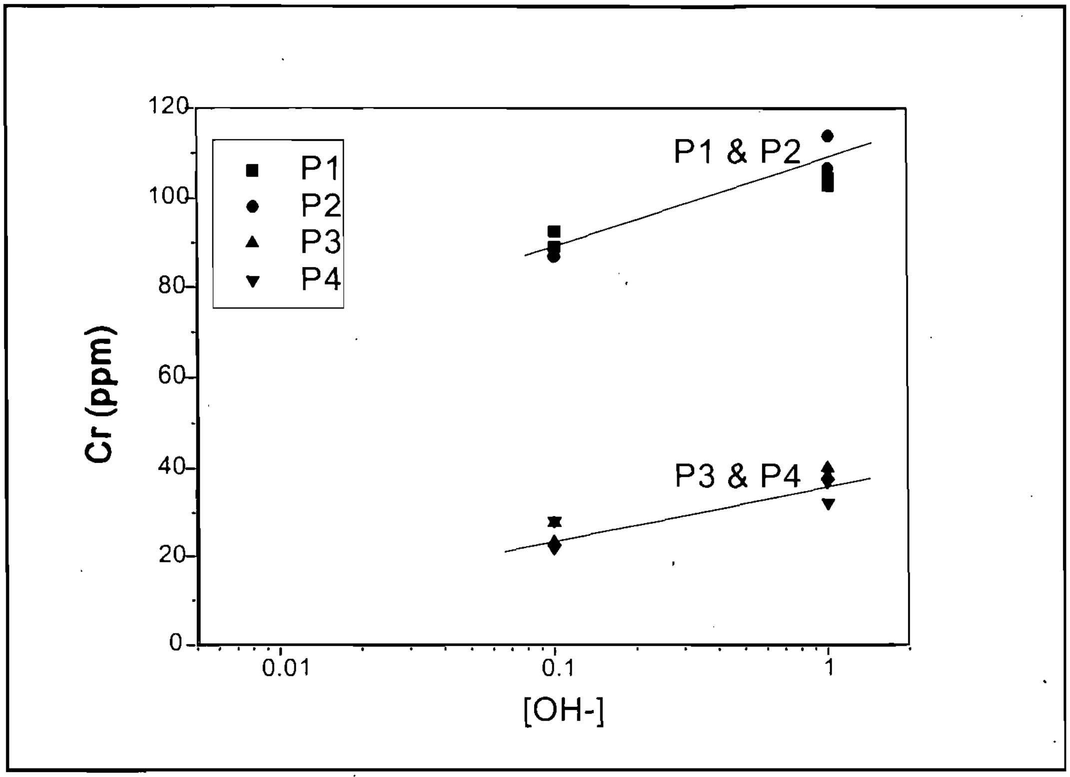


Figure 4. Dependence of chromium concentration on [OH-] of model pore solutions.

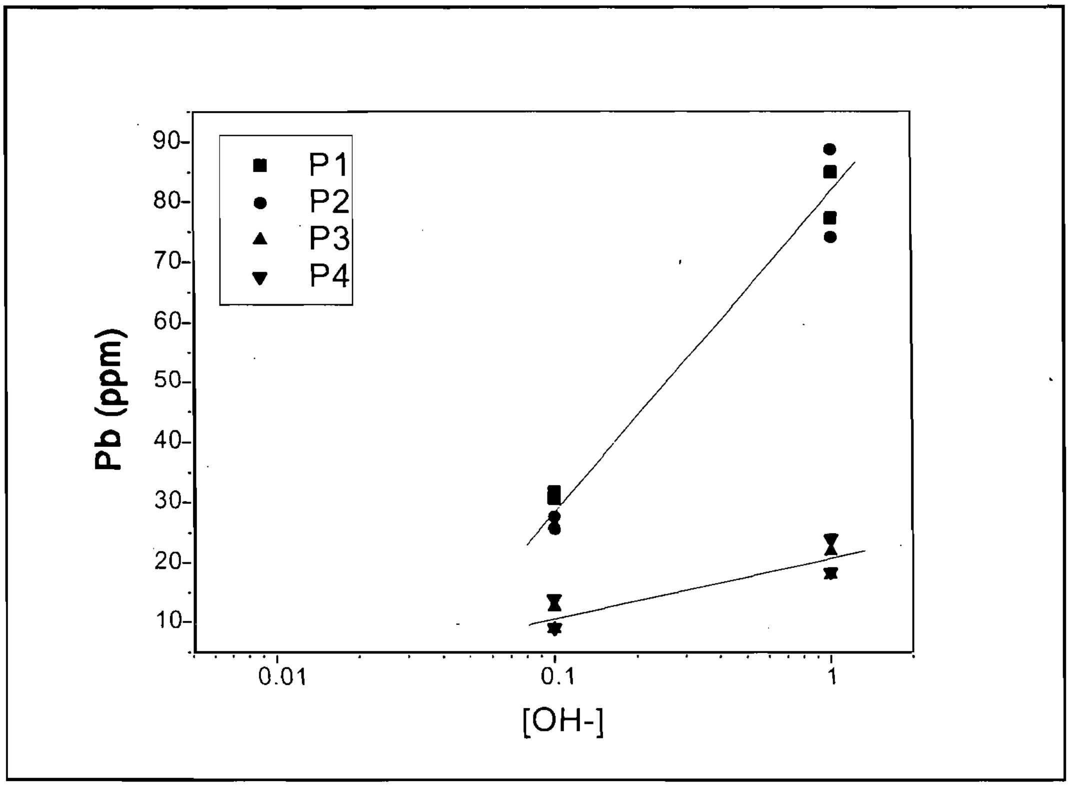


Figure 5. Dependence of lead concentration on [OH-] of model pore solutions.

Table 28. X-ray fluorescence analysis of low- and high-alkali cements.

Oxide Equivalent	Low Alkali Cement	High Alkali Cement
SiO_2	24.04	20.45
Al_2O_3	2.58	5.41
Fe_2O_3	0.28	2.00
CaO	68.90	64.21
MgO	1.07	2.72
K_2O	0.03	1.07
Na_2O	0.14	0.24
TiO_2	0.13	0.27
P_2O_5	0.10	0.13
MnO	0.02	0.044
SO_3	2.31	2.93
Totals	99.60	99.47

Table 29. Chemical analysis of expressed pore solutions in low- and high-alkali Portland cement (1-day hydration).

Waste	Cement	Hydration days	Water/ Cement (Wt.)	[OH-] end	pH end*	Cd ppm	Pb ppm	Cr ppm	Ba ppm
P1	Low Alk.	1	1.22	0.0160	12.20	0.37	14.9	652	0.58
P1	High Alk.	1	1.21	0.0188	12.27	<0.17	7.7	1310	0.32
P2	Low Alk.	1	1.22	0.0178	12.25	0.30	16.4	612	0.83
P2	High Alk.	1	1.22	0.0200	12.30	<0.17	7.5	1330	<0.30
P3	Low Alk.	1	0.69	0.0728	12.89	<0.17	<0.66	21.5	2.85
P3	High Alk.	1	0.69	0.2390	13.37	<0.17	<0.66	155	2.14
P4	Low Alk.	1	0.69	0.0610	12.79	<0.17	<0.66	11.8	3.27
P4	High Alk.	1	0.69	0.2900	13.46	<0.17	<0.66	87.5	1.32
G5	Low Alk.	1	0.57	0.1115	13.05	<0.17	<0.66	<0.07	1.24
G5	High Alk.	1	0.56	0.5760	13.76	0.189	2.32	0.13	0.45
G6	Low Alk.	1	0.57	0.0820	12.91	<0.17	<0.66	0.07	1.34
G6	High Alk.	1	0.56	0.5212	13.70	<0.17	<0.66	0.40	0.37
S7	Low Alk.	1		0.0751	12.87	<0.17	<0.66	0.36	1.81
S7	High Alk.	1		0.2990	13.48	<0.17	0.78	1.50	1.07
S8	Low Alk.	1		0.0812	12.91	<0.17	<0.66	0.08	1.29
S8	High Alk.	1		0.3558	13.55	<0.17	<0.66	0.16	0.73

*calculated

Table 30. Chemical analysis of expressed pore solutions in low- and high-alkali Portland cement (28-day hydration).

Waste	Cement	Hydration days	Water/ Cement (Wt.)	[OH-] end	pH end*	Cd ppm	Pb ppm	Cr ppm	Ba ppm
P1	Low Alk.	28	1.22	0.0180	12.25	0.30	18.1	333	1.05
P1	High Alk.	28	1.21	0.0242	12.38	<0.17	8.46	1080	0.45
P2	Low Alk.	28	1.22	0.0196	12.29	0.29	19.0	263	1.18
P2	High Alk.	28	1.22	0.0252	12.40	<0.17	8.33	1040	0.40
P3	Low Alk.	28	0.69	0.0921	12.96	0.37	1.71	0.40	N/A
P3	High Alk.	28	0.69	0.9572	13.98	<0.17	7.57	49.5	3.16
P4	Low Alk.	28	0.69	0.0773	12.89	<0.17	<0.66	5.26	2.38
P4	High Alk.	28	0.69	0.6730	13.82	<0.17	4.25	30.61	2.71
G5	Low Alk.	28	0.57	0.2520	13.40	<0.17	<0.66	0.25	0.40
G5	High Alk.	28	0.56	0.8620	13.93	<0.17	3.15	1.02	0.46
G6	Low Alk.	28	0.57	0.1916	13.28	<0.17	<0.66	0.13	0.65
G6	High Alk.	28	0.56	0.7745	13.89	<0.17	<0.66	1.09	0.48

*calculated

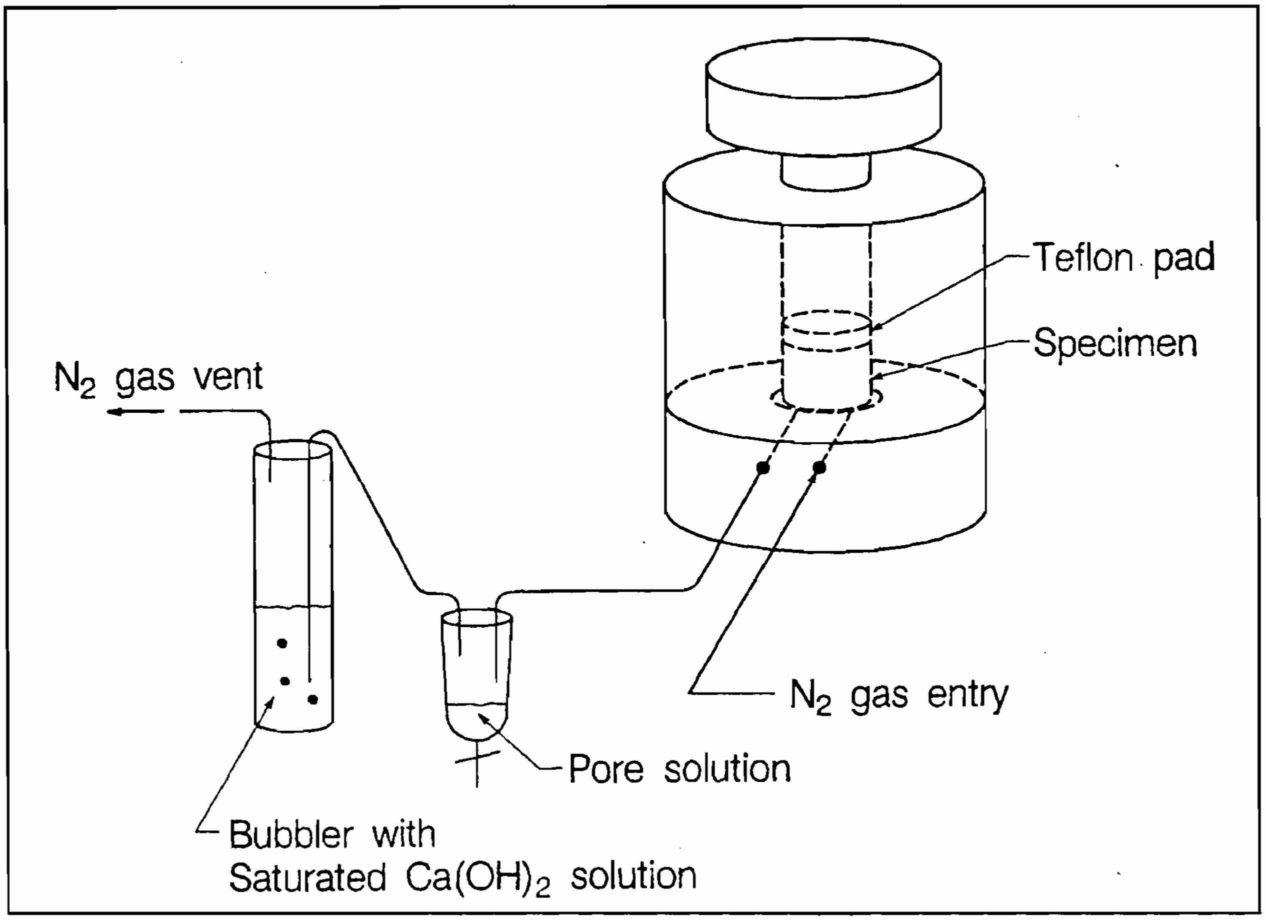
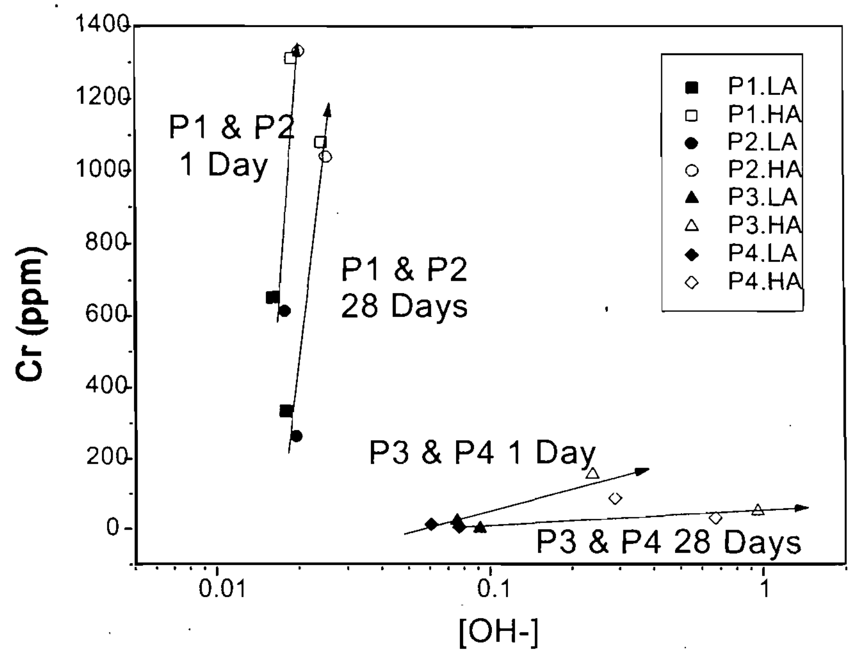
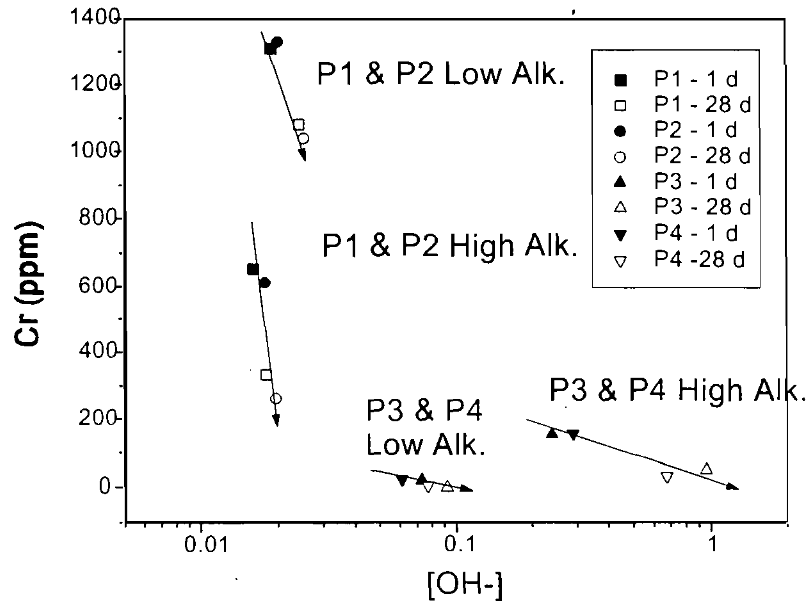


Figure 6. Schematic of pore expression apparatus.



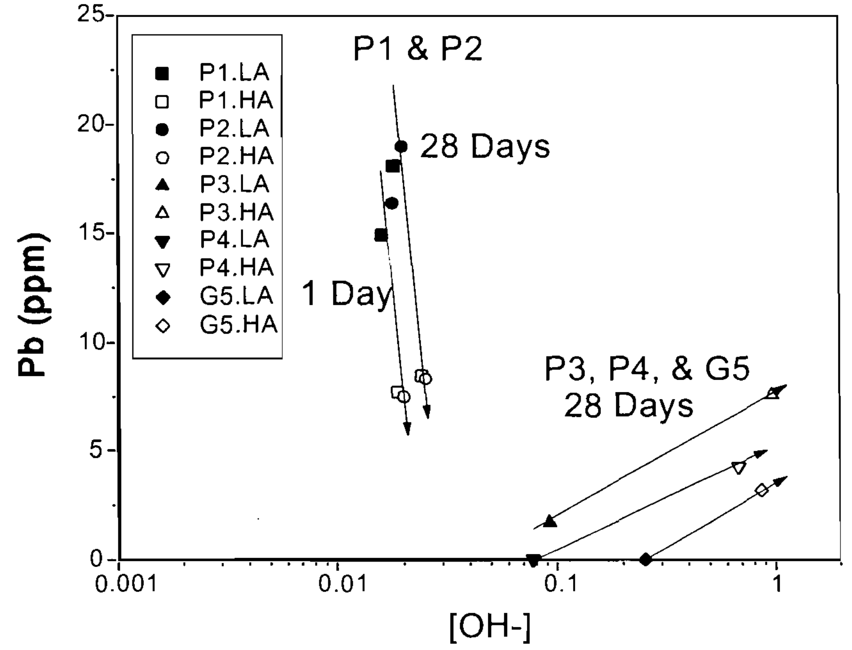
Note: Arrows indicate increasing alkali content.

Figure 7. Increase in chromium concentration of expressed pore solutions with alkali content of the expressed pore solution.



Note: Arrows indicate increasing alkali content of cement.

Figure 8. The effect of time on the chromium concentration in expressed pore solution.



Note: Arrows indicate increasing hydration time.

Figure 9. Dependence of lead concentration on the [OH-] of the expressed pore solutions.

Table 31. Composition of the solid residue retained after pore solution expression.

Waste	Cement	Hydration	pH start	[OH] end	pH end	Cd ppm	Pb ppm	Cr ppm	Ba ppm	TCLP Status
P1	Low Alk.	1	2.92	0.0239	12.37*		0.296	19.11	0.43	Failed Cr
P1	High	1	2.92	0.0174	12.24*		0.142	18.81	0.41	Failed Cr
P1	Low Alk.	28	2.91	0.0188	12.27*		0.18	23.83	0.32	Failed Cr
P1	High	28	2.91	0.0163	12.21*		0.13	9.87	0.38	Failed Cr
P2	Low Alk.	1	2.90	0.0261	12.41*		0.42	20.47	0.51	Failed Cr
P2	High	1	2.90	0.0207	12.31*		0.25	14.96	0.53	Failed Cr
P2	Low Alk.	28	2.91	0.0195	12.29*		0.19	24.84	0.37	Failed Cr
P2	High	28	2.91	0.0210	12.32*		0.16	10.80	0.52	Failed Cr
G5	Low Alk.	1	2.84		10.50		<0.066	<0.007	0.28	Passed
G5	High	1	2.84		11.74		<0.066	0.045	0.31	Passed
G5	Low Alk.	28	2.87		10.09		<0.066	0.016	0.34	Passed
G5	High	28	2.87		11.70		<0.066	0.024	0.42	Passed
G6	Low Alk.	1	2.87		10.05		<0.066	0.007	0.31	Passed
G6	High	1	2.87		11.70		<0.066	0.063	0.30	Passed
S7	Low Alk.	1	2.86		9.65		<0.066	0.142	0.46	Passed
S7	High	1	2.83		11.70		<0.066	0.288	0.46	Passed
S8	Low Alk.	1	2.85		10.57		<0.066	<0.007	0.36	Passed
S8	High	1	2.85		11.82		<0.066	0.032	0.47	Passed
TCLP Limits						1.0	5.0	5.0	100.0	

*calculated

Table 32. TCLP results for virgin concrete waste samples without pore solution expression.

Waste	Cement	Hydration days	pH start	[OH] end	pH end	Cd ppm	Pb ppm	Cr ppm	Ba ppm	TCLP Status
P1	Low Alk	77	2.90	0.0246	12.39*		0.255	22.72	0.39	Failed Cr
P1	High	77	2.90	0.0118	12.07*		<0.066	15.07	0.37	Failed Cr
P2	Low Alk.	28	2.91	0.0278	12.44*		0.29	16.11	0.43	Failed Cr
P2	High	28	2.91	0.0141	12.14*		0.08	15.32	0.36	Failed Cr
TCLP Limit						1.0	5.0	5.0	100.0	

*calculated

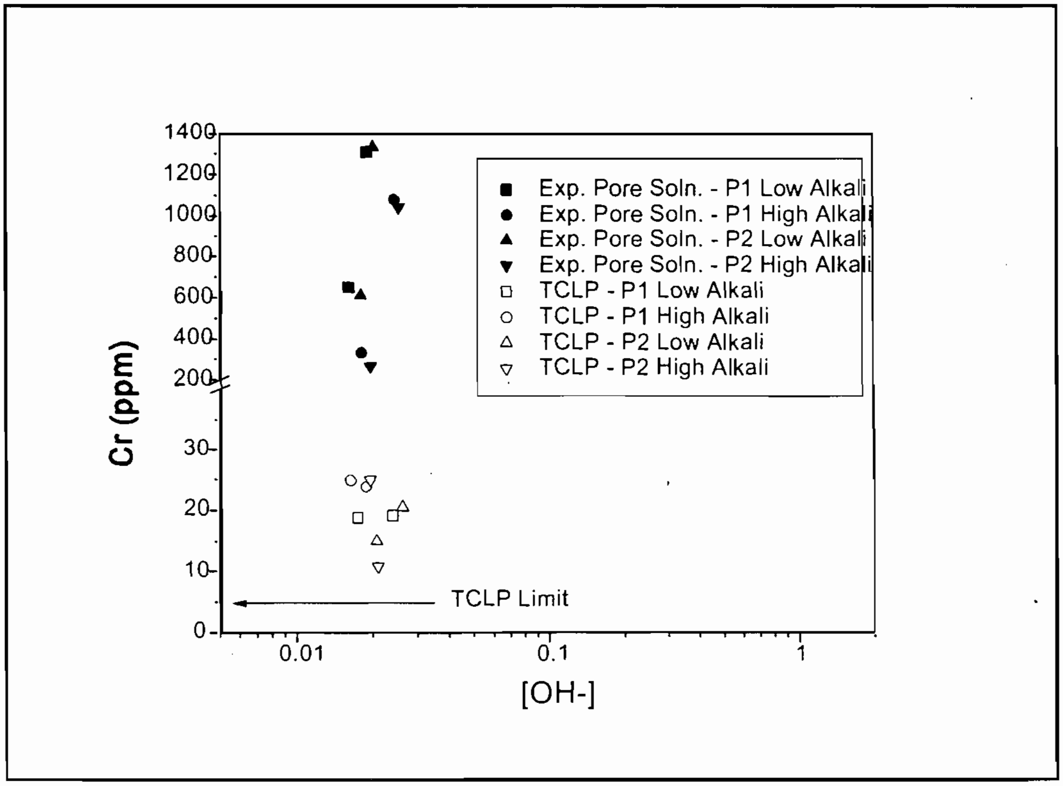
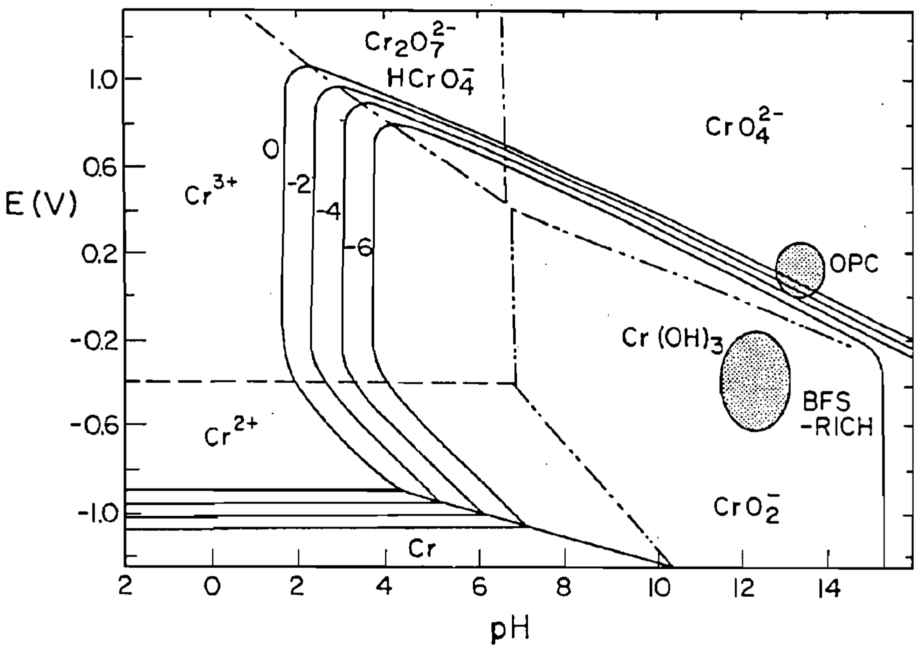


Figure 10. Control of the chromium concentration of both the expressed pore solution and TCLP by the [OH-].



(Source: Pourbaix 1974. ©NACE International, Houston, TX. Reprinted with permission.)

Figure 11. Potential pH for system chromium in waste.

Table 33. X-ray fluorescence analysis of blast furnace slag.

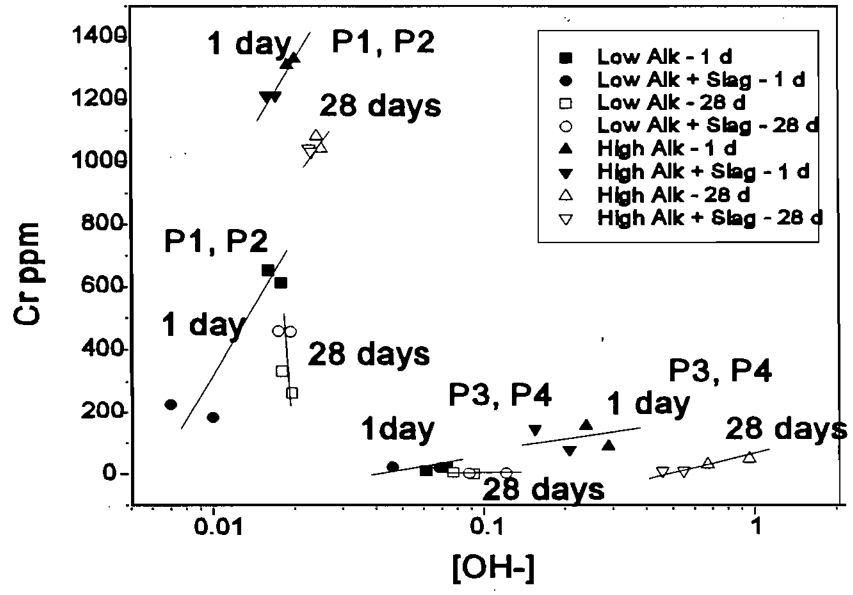
Oxide Equivalent	Blast Furnace Slag
SiO_2	37.55
Al_2O_3	7.45
Fe_2O_3	0.18
CaO	39.07
MgO	11.32
K_2O	0.36
Na_2O	0.30
TiO_2	0.37
P_2O_5	0.01
MnO	0.55
SO_3	2.80
Total	99.96

Table 34. Chemical analysis of expressed pore solutions in high-alkali cement with blast furnace slag (75% waste, 19% cement, 6% slag).

Waste	Cement matrix	Hydration Days	Water/Cement Wt., Vol.	$[OH^-]$	pH	Cr (mg/l)
P1	High Alkali	1	1.21, 3.79	0.0188	12.27*	1310
P1	H.A. + Slag	1	1.21, 3.79	0.0188	12.27*	1210
P1	High Alkali	28	1.21	0.0242	12.38*	1080
P1	H.A. + Slag	28	1.24	0.0227	12.35*	1040
P2	High Alkali	1	1.21, 3.79	0.0200	12.30*	1330
P2	H.A. + Slag	1	1.21, 3.79	0.0171	12.23*	1210
P2	High Alkali	28	1.21	0.0252	12.40*	1040
P2	H.A. + Slag	28	1.24	0.0231	12.36*	1030
P3	High Alkali	1	0.69, 2.15	0.2390	13.38*	155
P3	H.A. + Slag	1	0.71, 2.15	0.1550	13.19*	144
P3	High Alkali	28	0.69	0.9572	13.98*	49.5
P3	H.A. + Slag	28	0.70	0.5486	13.74*	9.22
P4	High Alkali	1	0.69, 2.15	0.2900	13.46*	87.5
P4	H.A. + Slag	1	0.69, 2.15	0.2080	13.32*	76.6
P4	High Alkali	28	0.69	0.6730	13.83*	30.61
P4	H.A. + Slag	28	0.70	0.4578	13.66*	8.37

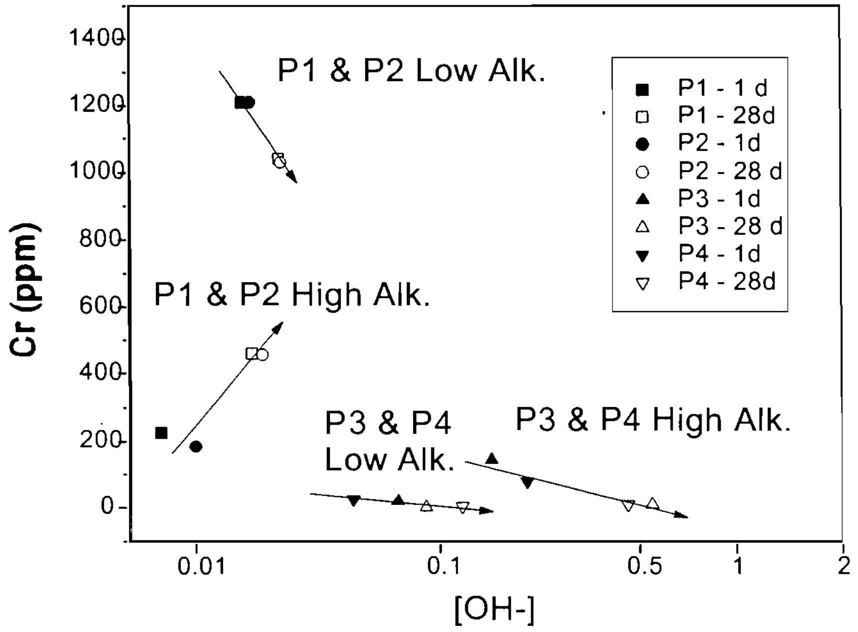
Table 35. Chemical analysis of expressed pore solutions in low-alkali cement with blast furnace slag (75% waste, 19% cement, 6% slag).

Waste	Cement matrix	Hydration Day	Water/Cement Wt., Vol.	$[OH^-]$	pH	Cr (mg/l)
P1	Low Alkali	1	1.22, 3.79	0.016	12.20*	652
P1	L.A. + Slag	1	1.22, 3.79	0.007	11.84*	227
P1	Low Alkali	28	1.22	0.018	12.25*	333
P1	L.A. + Slag	28	1.22	0.0175	12.24*	459
P2	Low Alkali	1	1.22, 3.79	0.0178	12.25*	612
P2	L.A. + Slag	1	1.22, 3.79	0.010	12.00*	185
P2	Low Alkali	28	1.22	0.0196	12.29*	263
P2	L.A. + Slag	28	1.25	0.0194	12.28*	456
P3	Low Alkali	1	0.69, 2.15	0.0728	12.86*	21.5
P3	L.A. + Slag	1	0.69, 2.15	0.0688	12.84*	20.9
P3	Low Alkali	28	0.69	0.09214	12.96*	N/A
P3	L.A. + Slag	28	0.68	0.08845	12.95*	2.32
P4	Low Alkali	1	0.69, 2.15	0.0610	12.78*	11.8
P4	L.A. + Slag	1	0.71, 2.15	0.0460	12.66*	23.3
P4	Low Alkali	28	0.69	0.07731	12.89*	5.26
P4	L.A. + Slag	28	0.71	0.1214	13.08	3.02



Note: Lines link cements having similar alkali contents and hydration times.

Figure 12. Effects of slag addition on [OH-] and chromium concentration of expressed pore solution.



Note: Arrows indicate increasing time.

Figure 13. Effects of hydration on [OH-] and chromium concentrations of expressed pore solutions.

Table 36. TCLP results for solid residue retained after pore solution expression (75% waste, 19% cement, 6% slag).

Waste	Cement	Slag	Hydration Days	pH Start	$[OH^-]$ End	pH End*	Cr (mg/l)	TCLP Status
P1	L.A.	Slag	1	2.92	0.0164	12.2	15.51	Failed Cr
P1	H.A.	Slag	1	2.92	0.0082	11.9	16.00	Failed Cr
P2	L.A.	Slag	1	2.90	0.0175	12.2	16.92	Failed Cr
P2	H.A.	Slag	1	2.90	0.0097	12.0	23.16	Failed Cr
P1	L.A.	Slag	28	2.89	0.0158	12.2	17.38	Failed Cr
P1	H.A.	Slag	28	2.89	0.0059	11.8	7.72	Failed Cr
P2	L.A.	Slag	28	2.91	0.0210	12.3	10.8	Failed Cr
P2	H.A.	Slag	28	2.91	0.0110	12.0	9.00	Failed Cr
TCLP Limit							5.00	

*pH calculated from ionic concentrations

Table 37. TCLP results for virgin concrete waste samples (75% waste, 19% cement, 6% slag).

Waste	Cement	Slag	Hydration Days	pH Start	$[OH^-]$ End	pH End*	Cr (mg/l)	TCLP Status
P2	L.A.	No	28	2.92	0.0278	12.4	16.11	Failed Cr
P2	H.A.	No	28	2.92	0.0174	12.1	15.23	Failed Cr
P2	L.A.	Slag	28	2.92	0.0234	12.4	15.99	Failed Cr
P2	H.A.	Slag	28	2.92	0.0094	12.0	19.42	Failed Cr
TCLP Limit							5.00	

*pH calculated from ionic concentrations

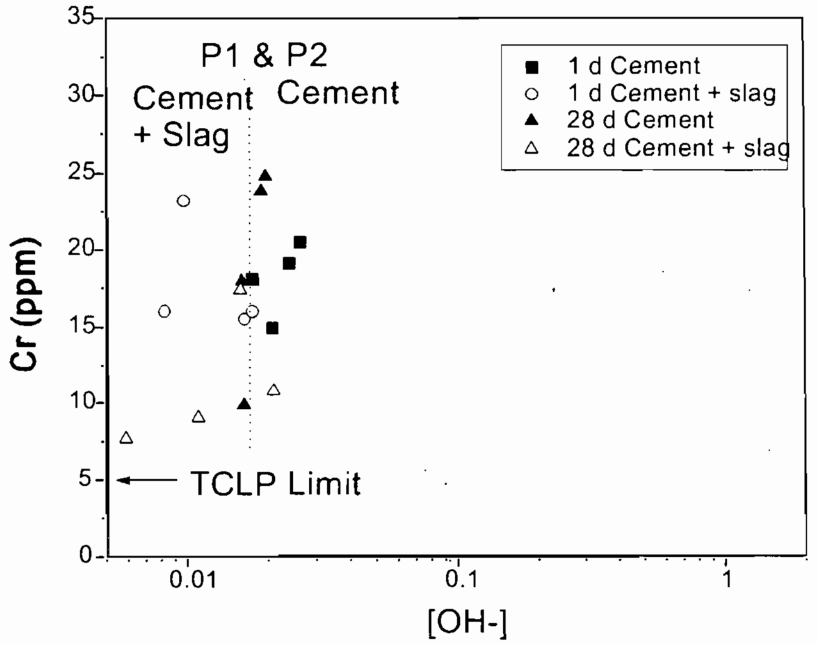


Figure 14. Effects of blast furnace slag additions on final [OH-] and chromium concentrations of the TCLP extraction fluid.

9 Chemical Stabilization, Fixation, and Recycling

Background

Red River Army Depot (RRAD) is the Army Center of Technical Excellence (CTX) for chemical stabilization of blast media waste. RRAD has conducted an evaluation of a chemical stabilization and fixation process. The treatment process reduces the level of leachable contaminants, allowing the waste to be classified as non-RCRA, which permits disposal in a Class II landfill. RRAD has received approval from the Texas Natural Resource Conservation Commission to use a Class II landfill for its chemically stabilized paint blast media waste. Chemical stabilization and fixation is not waste-specific.

Process

RRAD contracted for chemical stabilization and fixation services with Perma-Fix Environmental Services Inc., Grand Prairie, TX. The Perma-Fix proprietary two-step process involves chemical reduction followed by fixation. The process is conducted in an onsite mobile unit. The ingredients are properly mixed and poured in containers of 20–30 cu yd.[*] The containers are covered and stored onsite until analytical data are received. If the waste is classified as non-RCRA, it is disposed of in a Class II landfill.

Between 1 February 1994 and 1 May 1994 RRAD treated and disposed of (onsite) 170,000 kg of paint blast media waste. The treatment costs were estimated to be $0.33/kg. Cost savings obtained using chemical stabilization, fixation, and disposal in an onsite Class II landfill were estimated at $240,000. Based on the approximately 340,000 kg of paint blast media used in calendar year 1993, the estimated annual cost savings using the Perma-Fix process at RRAD are $480,000.

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[*] 1 cu yd = 0.7646 m^3.

USACERL personnel observed the Perma-Fix process at RRAD in July 1994. Samples of both untreated paint blast media wastes and of wastes treated using the Perma-Fix process were obtained and chemically analyzed. In addition to dry blast media waste, a blast media wash sludge is generated at RRAD. This sludge is generated from water jet washing used to remove residual media from vehicles after abrasive blasting. The principal blast media wastes at RRAD consist of sand and garnet.

Chemical analysis indicated that samples of paint blast media waste and blast media wash sludge contained high concentrations of Cr and Pb contaminants (Table 38). All samples of paint blast media waste and one sample of blast media wash sludge failed TCLP for Cd and/or Cr. Samples treated by the Perma-Fix process successfully met TCLP levels for the eight RCRA metals tested. The petroleum hydrocarbon content determined for the blast media wash sludge passed EPA disposal limits (1500 mg/kg) for both the untreated and treated sludge (Table 39).

Discussion

Perma-Fix chemical stabilization and fixation has been found to yield abrasive paint blast media wastes nonleachable by TCLP for the 8 RCRA metals. The use of the Perma-Fix chemical stabilization and fixation process is recommended for the treatment of paint blast media wastes contaminated with the eight RCRA metals. Other commercial chemical stabilization and fixation processes may also be suitable. Additional cost savings can accrue with disposal at an onsite Class II landfill. Paint blast media waste contaminated with hydrocarbons in excesses of EPA disposal limits may require additional treatment prior to disposal.

Table 38. RRAD metals data for the Perma-Fix stabilization and fixation process.

Sample	Test	As (ppm)	Ba (ppm)	Cd (ppm)	Cr (ppm)	Pb (ppm)	Hg (ppm)	Se (ppm)	Ag (ppm)	Status
Wash Sludge 1	Total Metals	<150	110	<75	880	390	<1.0	<150	<75	
Wash Sludge 2	Total Metals	<150	220	<75	2400	940	<1.0	<150	<75	
Wash Sludge 3	Total Metals	<150	<75	<75	470	250	<1.0	<150	<75	
Wash Sludge 1	TCLP	<0.50	1.2	0.39	0.84	1.3	<0.002	<0.10	<0.50	Passed
Wash Sludge 2	TCLP	<0.50	1.0	2.4	2.8	1.6	<0.002	<0.10	<0.50	Failed Cd
Wash Sludge 3	TCLP	<0.50	<1.0	0.46	<0.50	<0.50	<0.002	<0.10	<0.50	Passed
Treated Wash Sludge A	Total Metals	<150	320	<75	520	250	<1.0	<150	<75	
Treated Wash Sludge B	Total Metals	<150	350	<75	520	270	<1.0	<150	<75	
Treated Wash Sludge A	TCLP	<0.50	<1.0	1.04	<0.50	<0.50	<0.002	<0.10	<0.50	Passed
Treated Wash Sludge B	TCLP	<0.50	<1.0	0.52	<0.50	<0.50	<0.002	<0.10	<0.50	Passed
Blast Waste 1	Total Metals	<150	510	<75	5700	1800	<1.0	<150	<75	
Blast Waste 2	Total Metals	<150	490	<75	6200	1700	<1.0	<150	<75	
Blast Waste 1	TCLP	<0.50	1.3	7	7.9	6	<0.002	<0.10	<0.50	Failed Cd, Cr
Blast Waste 2	TCLP	<0.50	1.3	7.2	8.2	6.1	<0.002	<0.10	<0.50	Failed Cd, Cr
Treated Blast Waste A	Total Metals	<150	730	<75	2900	730	<1.0	<150	<75	
Treated Blast Waste B	Total Metals	<150	<75	<75	<75	<75	<1.0	<150	<75	
Treated Blast Waste A	TCLP	<0.50	<1.0	0.12	<0.50	<0.50	<0.002	<0.10	<0.50	Passed
Treated Blast Waste B	TCLP	<0.50	<1.0	<0.10	4.3	3.1	<0.002	<0.10	<0.50	Passed
	TCLP LIMIT	5.0	100.0	1.0	5.0	5.0	0.2	1.0	5.0	

Table 39. RRAD hydrocarbons data for the Perma-Fix stabilization and fixation process.

Sample	Test	Method	H-C's (mg/kg)	Limit (mg/kg)
Wash Sludge 1	Total Hydrocarbon	EPA 418.1	560	1500
Wash Sludge 2	Total Hydrocarbon	EPA 418.1	560	1500
Treated Wash Sludge A	Total Hydrocarbon	EPA 418.1	860	1500
Treated Wash Sludge B	Total Hydrocarbon	EPA 418.1	710	1500

10 Lease and Recycle of Plastic Blast Media

Background

This alternative to separation and treatment involves the leasing of plastic media to the Army depot. The depot uses the blast media in much the same way as purchased media, with the exception that the used media is returned to the manufacturer for reprocessing. It is acceptable for the returned blast media waste to contain paint residues and heavy metal contaminants—even at hazardous concentrations. If 100% of the returned blast media, including paint residue and contaminants, are used or reused as ingredients in an industrial process to make new products, the used media is, according to interpretations of RCRA Section 261.2(e), not considered to be a solid or hazardous waste (Neitzel 1993).

Commercial Processes

Two commercial lease/recycle processes have been identified:

1. U.S. Technology Corp., Canton, OH, uses spent paint blast media as filler in the manufacturing of molded plastic products. All processing is done in the United States.
2. Solidstrip, Inc., Newark, DE, ships spent paint blast media to a processing facility where it is broken down into methylmethacrylate monomer, which in turn is used to make acrylic sheet stock. The processing is done at a facility in Bombay, India.

Personnel at Corpus Christi Army Depot (CCAD) reviewed these commercially available lease/recycle programs and noted the advantages and disadvantages.

Advantages:

- The implementation of lease/recycle agreements is fully compatible with current paint blast operations.
- All types of plastic blast media used at Army depot facilities can be recycled by U.S. Technology Corp.

- The U.S. Technology Corp. process uses the spent plastic blast media in an industrial process to produce cast plastic products. U.S. Technology Corp. assumes liability for the spent media, so the liability of the Army facility is limited.
- The U.S. Technology Corp. plant is located in Canton, OH, and is regulated both by the Federal EPA and the Ohio State EPA.
- The U.S. Technology Corp. process has received approval from the Texas Water Commission for the use at CCAD.

Disadvantages:

- Solidstrip will also recycle thermoset media in a manner similar to U.S. Technology Corp.
- The Solidstrip process accepts only Type V thermoplastic acrylic media. The polymer cracking process used on Type V acrylic media may possibly be classified as a reclamation process such that the original purchaser may retain liability for the waste. The liability issues of this process remain ambiguous.
- The Solidstrip processing facility is located in India, and is not subject to regulation by the Federal EPA.

Pricing of U.S. Technology Corp. plastic blast media lease/recycle program depends on the media type and size purchased, the expected overall volume of the purchases planned during the contract period, the quantity of the shipments both ways, and the shipping distance/freight costs. The annual price for the complete media supply and recycling program ranged between \$2.40/lb to \$2.80/lb.*

Discussion

The use of lease/recycle agreements for plastic media waste is recommended. Reuse of the spent blast media effectively eliminates the waste stream from the Army facility. The Solidstrip process accepts only one type of blast media waste and is less universally applicable than the U.S. Technology Corp. process. The ambiguous liability issues associated with the Solidstrip process must be resolved before the process could be implemented. The U.S. Technology Corp. process—and others like it that use spent media as filler in the subsequent manufacture of molded plastic parts—is a recommended alternative to landfilling.

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* 1 lb = 0.4536 kg.

11 Conclusions and Recommendations

Conclusions

In this project seven categories of processing and recycling options for hazardous paint blast waste media were investigated. The work included both laboratory investigations and evaluation of existing technologies including commercially available processes. It is concluded that most of the options studied are not suitable for Army requirements:

- physical separation processes could not effectively isolate hazardous components from plastic media blast wastes
- low-temperature ashing effectively reduced waste volumes but produced the air pollutants phenol and hydrogen cyanide, which could not be filtered out of the combustion gases
- chemical separation through acid extraction and digestion reduced heavy metal concentrations in waste samples by only a small fraction
- biodegradation through a proprietary microbial digestion process reduced the volume of starch-based blast media (ground walnut shells) only, but walnut shells are not a major depaint medium on Army depots; bioremediation in general is complex, and it requires special expertise and equipment not available at most Army depots
- self-encapsulation of plastic media blast waste has been found to be effective only for Type V thermoplastic media, making the technique of limited use on Army depots
- waste stabilized in Portland cement (and Portland cement blended with blast furnace slag) failed the TCLP for chromium.

A commercial chemical stabilization, fixation, and recycling process such as those described in Chapter 9 may be a suitable and cost-effective way for the Army to eliminate some hazardous waste streams from depot depaint operations. When plastic-based hazardous blast media waste is 100% reprocessed and incorporated into a new product, it leaves the waste-disposal regulatory jurisdiction of the Resource Conservation and Recovery Act (RCRA). It appears that some commercial options would relieve the Army of continuing liability for the affected hazardous wastes. However, each commercial process would have to be reviewed carefully for clarification of liability issues, regulation of the contractor, technical effectiveness, etc.

Recommendations

It is recommended that the Army should not at this time pursue further study of the unsuitable blast media waste treatment options listed above.

It is recommended that Army depot depaint operations consider processing hazardous blast media waste through properly regulated private-sector contractors that provide safe, effective, and economical stabilization, fixation, and recycling processes. Due consideration should include an appropriate legal review of liability and regulatory issues.

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Appendix A: TCLP Metals and Testing Results for Depot Blast Media Wastes

Table A1. Chemical analysis of Sacramento Army Depot blast media waste.

Depot	Material	Sample ID	Test	Lab	Date	As	Ba	Cd	Cr	Pb	Hg	Se	Ag	Status
SAAD	Plastic	800864	TCLP	Lab A	3/18/93	<0.100	0.369	6.23	189	<0.100	<0.001	<0.120	<0.170	Failed Cd, Cr
SAAD	Sand	800865	TCLP	Lab A	3/18/93	<0.100	1.62	0.669	1.04	<0.100	<0.001	<0.120	<0.170	Passed
SAAD	Plastic	800864	TCLP	Lab B	2/4/93			5.22	N/A	BDL				Failed Pb
SAAD	Sand	800865	TCLP	Lab B	2/4/93			0.5	1.49	BDL				Passed
		LIMIT	TCLP			5.0	100.0	1.0	5.0	5.0	0.2	1.0	5.0	
SAAD	Plastic	800864	Metals	Lab B	5/3/93			191.8	3100	3791.6				

Table A2. Chemical analysis of Anniston Army Depot inorganic blast media waste.

Depot	Material	Sample ID	Test	Lab	Date	As	Ba	Cd	Cr	Pb	Hg	Se	Ag	Status
ANAD	Coal Slag	800863	TCLP	Lab A	3/18/93	<0.100	2.12	0.628	0.947	4.96	<0.001	<0.120	<0.170	Cond. Pass
ANAD	Coal Slag	800863	TCLP	Lab A	4/30/93	<0.120	0.596	17.4	7.08	0.254	<0.0005	<0.120	<0.170	Fail Cd, Cr
ANAD	Walnut	800866	TCLP	Lab A	3/18/93	<0.100	0.314	0.374	1.78	0.201	<0.001	<0.120	<0.170	Passed
ANAD	Mg/Fe Silicates	800867	TCLP	Lab A	3/18/93	<0.100	0.229	<0.100	<0.100	<0.100	<0.001	<0.120	<0.170	Passed
ANAD	Steel	800868	TCLP	Lab A	3/18/93	<0.100	3.35	<0.130	<0.120	0.607	<0.001	<0.120	<0.170	Passed
ANAD	Coal Slag	800863	TCLP	Lab B	2/4/93			BDL	0.37	BDL				Passed
ANAD	Walnut	800866	TCLP	Lab B	2/4/93			0.35	1.49	BDL				Passed
ANAD	Mg/Fe Silicates	800867	TCLP	Lab B	2/4/93			0.165	1.67	BDL				Passed
ANAD	Steel	800868	TCLP	Lab B	2/4/93			BDL	BDL	BDL				Passed
		BLANK	TCLP	Lab B	2/4/93			BDL	BDL	BDL				Passed
		LIMIT	TCLP			5.0	100.0	1.0	5.0	5.0	0.2	1.0	5.0	
ANAD	Coal Slag	800863	Metals	Lab A	4/6/93	<25.0	145	386	259	40.7	<0.051	<25.0	<2.00	
ANAD	Coal Slag	800863	Metals	Lab B	5/3/93			8.6	280.5	727.8				
ANAD	Walnut	800866	Metals	Lab B	5/3/93			9.8	124.5	189.2				
ANAD	Mg/Fe Silicates	800867	Metals	Lab B	5/3/93			BDL	17.3	34.7				
ANAD	Steel	800868	Metals	Lab B	5/3/93			96.3	3000	7322.2				

Table A3. Chemical analysis of Anniston Army Depot organic blast media waste.

Depot	Material	Sample ID	Test	Lab	Date	As	Ba	Cd	Cr	Pb	Hg	Se	Ag	Status
ANAD	Walnut	800900	TCLP	Lab A	3/18/93	<0.100	0.291	0.187	1.26	0.185	<0.001	<0.120	<0.170	Passed
ANAD	Walnut	800901	TCLP	Lab A	3/18/93	<0.100	0.285	0.45	1.45	0.281	<0.001	<0.120	<0.170	Passed
ANAD	Walnut	800900	TCLP	Lab B	3/1/94			0.5	1.7	0.7				Passed
ANAD	Walnut	800901	TCLP	Lab B	3/1/94			0.7	1.7	1.1				Passed
		Blank	TCLP	Lab B	3/1/94			BDL	BDL	BDL				
		LIMIT	TCLP			5.0	100.0	1.0	5.0	5.0	0.2	1.0	5.0	
ANAD	Walnut	800900	Metals	Lab B	5/3/93			3.8	125.7	164.9				
ANAD	Walnut	800901	Metals	Lab B	5/3/93			BDL	BDL	229.2				

Table A4. TCLP analysis of Corpus Christi Army Depot blast media waste.

Depot	Material	Sample ID	Test	Lab	Date	As	Ba	Cd	Cr	Pb	Hg	Se	Ag	Status
CCAD	Glass	800958	TCLP	Lab A	6/30/93	<0.120	0.510	23.3	1.77	0.274	<0.0005	<0.120	<0.170	Failed Cd
CCAD	Plastic 5	800959	TCLP	Lab A	6/30/93	<0.180	2.07	1.40	179.0	<0.120	<0.0005	<0.120	<0.170	Failed Cd, Cr
CCAD	Plastic 2	800960	TCLP	Lab A	6/30/93	<0.120	0.525	0.499	10.7	<0.120	<0.0005	<0.120	<0.170	Failed Cr
CCAD	Glass	800961	TCLP	Lab A	4/13/93	<0.110	0.17	0.72	<0.10	5.05	<0.001	<0.110	<0.39	Failed Pb
CCAD	Plastic 5	800962	TCLP	Lab A	6/30/93	<0.120	1.83	1.17	127.0	<0.120	<0.0005	<0.120	<0.170	Failed Cd, Cr
CCAD	Mix	800963	TCLP	Lab A	6/30/93	<0.120	1.90	0.783	0.649	4.41	<0.0005	<0.120	<0.170	Passed
CCAD	Star Blast	800964	TCLP	Lab A	6/30/93	<0.120	0.790	0.783	2.51	0.146	<0.0005	<0.120	<0.170	Passed
CCAD	Glass	800958	TCLP	Lab B	3/22/93			31.6	2.3	0.7				Failed Cd
CCAD	Plastic 5	800959	TCLP	Lab B	3/22/93			1.8	199.5	0.1				Failed Cd, Cr
CCAD	Plastic 2	800960	TCLP	Lab B	3/22/93			0.6	15.1	0.1				Failed Cr
CCAD	Glass	800961	TCLP	Lab B	3/22/93			1.3	BDL	5.6				Failed Cd, Pb
CCAD	Plastic 5	800962	TCLP	Lab B	3/22/93			1.5	112.1	0.1				Failed Cd, Cr
CCAD	Mix	800963	TCLP	Lab B	3/22/93			27.1	7.5	0.3				Failed Cd, Cr
CCAD	Star Blast	800964	TCLP	Lab B	3/22/93			1.3	4.0	0.2				Failed Cd
		Limit	TCLP			5.0	100.0	1.0	5.0	5.0	0.2	1.0	5.0	

Table A5. Metals analysis of Corpus Christi Army Depot blast media waste.

Depot	Material	Sample ID	Test	Lab	Date	As	Ba	Cd	Cr	Pb	Hg	Se	Ag	Status
CCAD	Glass	800958	Metals	Lab A	6/30/93	<25.0	6.17	472	91.4	13.6	<0.051	<25.0	<2.00	
CCAD	Plastic 5	800959	Metals	Lab A	6/30/93	<25.0	366	115	5370	1990	<0.051	<25.0	<2.00	
CCAD	Plastic 2	800960	Metals	Lab A	6/30/93	<25.0	9.5	10.9	188	8.97	<0.051	<25.0	<2.00	
CCAD	Glass	800961												
CCAD	Plastic 5	800962	Metals	Lab A	6/30/93	<25.0	236	42.9	3320	856	<0.051	<25.0	<2.00	
CCAD	Mix	800963	Metals	Lab A	6/30/93	<25.0	370	16.7	256	888	<0.051	<25.0	<2.00	
CCAD	Star Blast	800964	Metals	Lab A	6/30/93	<25.0	57.8	18.9	194.	300	<0.051	<25.0	<2.00	
CCAD	Glass	800958	Metals	Lab B	5/3/93			464.1	92.2	10.3				
CCAD	Plastic 5	800959	Metals	Lab B	5/3/93			88.2	5172.5	2553.6				
CCAD	Plastic 2	800960	Metals	Lab B	5/3/93			16.7	623.9	48.9				
CCAD	Plastic 2	800960	Metals	Lab B	5/3/93			19.2	730.4	54.3				
CCAD	Glass	800961	Metals	Lab B	5/3/93			20.7	17.9	142.1				
CCAD	Plastic 5	800962	Metals	Lab B	5/3/93			38.1	3495.9	898.8				
CCAD	Mix	800963	Metals	Lab B	5/3/93			6434.2	608.3	68.9				
CCAD	Star Blast	800964	Metals	Lab B	5/3/93			19.4	161.6	268.2				

Table A6. TCLP analysis of Sacramento Army Depot blast media waste.

Depot	Material	Sample ID	Test	Lab	Date	As	Ba	Cd	Cr	Pb	Hg	Se	Ag	Status
SAAD	Plastic	800969	TCLP	Lab A	4/13/93	<0.100	1.03	0.84	6.01	0.23	<0.001	<0.11	<0.39	Failed Cr
SAAD	Sand	800970	TCLP	Lab A	4/13/93	<0.100	1.26	0.75	0.94	0.79	<0.001	<0.11	<0.39	Passed
SAAD	Plastic	800968	TCLP	Lab B	4/16/93			1.5	11.0	BDL				Failed Cd, Cr
SAAD	Plastic	800969	TCLP	Lab B	4/16/93			1.0	8.0	BDL				Failed Cr
SAAD	Sand	800970	TCLP	Lab B	4/16/93			0.7	1.0	0.2				Passed
		BLANK	TCLP	Lab B	4/16/93			BDL	BDL	BDL				
		Limit	TCLP			5.0	100.0	1.0	5.0	5.0	0.2	1.0	5.0	
SAAD	Plastic	800968	Metals	Lab B	4/16/93			39.4	704	727..8				
SAAD	Plastic	800969	Metals	Lab B	4/16/93			20.9	448.3	389.2				
SAAD	Sand	800970	Metals	Lab B	4/16/93			14	79.3	105.3				

Table A7. TCLP analysis results for additional Corpus Christi blast media wastes.

Depot	Material	Sample ID	Test	Lab	Date	As	Ba	Cd	Cr	Pb	Hg	Se	Ag	Status
CCAD	Plastic	1093 A	TCLP	Lab A	11/9/93	<0.500	<10.0	7.01	<0.500	0.675	<0.002	<0.100	<0.500	Failed Cd
CCAD	Plastic	1093 B	TCLP	Lab A	11/9/93	<0.500	<10.0	0.329	5.07	<0.500	<0.002	<0.100	<0.500	Failed Cr
		Limit	TCLP			5.0	100.0	1.0	5.0	5.0	0.2	1.0	5.0	
CCAD	Plastic	1093 A	Metals	Lab A	11/9/93	<4.00	6.20	160	3.00	26.0	0.259	<4.00	14.2	
CCAD	Plastic	1093 B	Metals	Lab A	11/9/93	<4.00	<4.00	2.52	41.5	9.36	<0.050	<4.00	<2.00	

Table A8. TCLP and metals test results for Corpus Christi Army Depot blast media waste.

Depot	Material	Sample ID	Test	Lab	Date	As	Ba	Cd	Cr	Pb	Hg	Se	Ag	Status
CCAD	Plastic	Plastic 1	TCLP	Lab C	5/12/94	<0.50	<1.0	1.3	66	<0.50	<0.002	<0.10	<0.50	Failed Cd, Cr
CCAD	Plastic	Plastic 3	TCLP	Lab C	5/25/94	<0.50	1.1	1.9	78	<0.50	<0.002	<0.10	<0.50	Failed Cd, Cr
		Limit	TCLP			5.0	100.0	1.0	5.0	5.0	0.2	1.0	5.0	
CCAD	Plastic	Plastic 1	Metals	Lab C	5/12/94	<2.0	330	74	2900	2900	<1.0	<2.0	<2.0	
CCAD	Plastic	Plastic 3	Metals	Lab C	5/25/94	<2.0	325	60	2700	2800	<1.0	<2.0	<2.0	

Table A9. Chemical analysis results for Tooele Army Depot blast media waste.

Depot	Material	Sample ID	Test	Lab	Date	As	Ba	Cd	Cr	Pb	Hg	Se	Ag	Status
TEAD	Plastic	T1	TCLP	Lab C	2/14/94	<5.0	<1.0	1.8	<0.50	<0.50	<0.002	<0.10	<0.5	Failed Cd
TEAD	Plastic	T2	TCLP	Lab C	2/14/94	<5.0	<1.0	1.5	<0.50	<0.50	<0.002	<0.10	<0.5	Failed Cd
TEAD	Ag	T3	TCLP	Lab C	2/14/94	<5.0	1.6	2.9	0.91	0.85	<0.002	<0.10	<0.5	Failed Cd
		Limit	TCLP			5.0	100.0	1.0	5.0	5.0	0.2	1.0	5.0	
TEAD	Plastic	T1	Metals	Lab C	2/14/94			220	2200	7000				
TEAD	Plastic	T2	Metals	Lab C	2/14/94			260	2400	7800				
TEAD	Ag	T3	Metals	Lab C	2/14/94			68	320	840				

Table A10. TCLP results for Red River Army Depot blast media waste.

Media	Date	Cd	Cr	Pb	TCLP Status
Steel	Apr.-94	190	BDL	BDL	Failed Cd
Sand/Garnet 1	Apr.-94	9.4	15	BDL	Failed Cd Cr
Sand/Garnet 2	Apr.-94	2.3	2	BDL	Failed Cd
Prefix	Apr.-94	BDL	BDL	BDL	Passed

Appendix B: Detailed Experimental Procedure for Low-Temperature Ashing (LTA)

Determination of Feed Material Mass During LTA

Samples of urea formaldehyde, acrylic, and ground walnut shell blast media were subjected to thermogravimetric (TG) analysis using a Netzsch Model 429 simultaneous thermal analysis instrument. Samples were heated in an air atmosphere with an airflow rate of 100 cc/minute. Samples ranging from 100–180 mg were weighed and heated at a rate of 10 °C per minute until no additional weight loss could be observed. Sample mass loss was expressed as a percentage of sample weight and in terms of percent sample weight/minute (see Figures 1, 2, and 3 in main text, Chapter 4).

Determination of Gaseous Volume Produced During LTA

Experiments were designed to simulate LTA conditions of the three paint blast media samples at 575 °C. Gaseous volumes generated during LTA of the media samples were calculated to estimate the actual gaseous volume that would be produced during waste processing of spent paint blast media. The experimental arrangement included charcoal-filtered high-purity compressed air delivered to the quartz tube housed in a tube furnace capable of achieving temperature of 1100 °C. Gaseous effluent and particulate generated during ashing were passed through a heat exchanger immersed in a water bath for cooling the effluent before mass-flow measurements. Mass-flow measurements were taken with a Sierra Instruments 820 mass-flow meter. Effluent gaseous volume of each sample was determined with a Waugh Controls V/F Integrator (basically, a digital counter). Each combustion experiment was timed with a stopwatch. Integrator count readings were taken at 0.5 minute intervals. Combustion effluent flow rates in liters/minute were calculated from integrated flow volume data and plotted versus time to generate the graphs shown in Figures B1 and B2. The total air volume passed through the quartz tube furnace during combustion experiments was subtracted from the total gaseous volume generated with each media sample to yield the net combustion volume produced from each sample.

Determination of Significant Volatile Organic Compounds (VOCs) Produced

Thermal desorption (TD) gas chromatography mass spectrometry (GC/MS) analyses were conducted on volatile organic compounds (VOCs) produced from LTA of test media and subsequently collected on triple sorbent traps (TSTs). LTA combustion experiments were carried out at air purge flow rates of 2 L/min. VOCs were sampled immediately after smoke was generated and mixed inside a sealed chamber. Triple sorbent traps (76 mm x 4 mm inside diameter) containing Carbotrap C, Carbotrap, and Carbosieve S-III were prepared and conditioned according to the procedure described in Oak Ridge National Laboratory (ORNL) Standard Operating Procedure AC-OP-000-0907. Before sample collection, two blank traps randomly selected from a batch of 30 freshly prepared traps were analyzed by TD and GC/MS to ensure the cleanliness of the traps.

VOCs collected on the triple sorbent traps were thermally desorbed and transferred to GC capillary column for subsequent GC/MS analysis. GC/MS analysis was carried out on an HP 5895 GC/MS system equipped with dual ion source. Typically, a TST was first purged with helium at a flow rate of 200 ml/min for 5 minutes in the same direction of the sampling flow to remove excess absorbed moisture. The trap was then placed in a tube furnace held at 300 °C and purged with helium at a flow rate of 50 ml/min. for 5 minutes in the opposite direction of sampling flow. The desorbed material was transferred directly through a quartz glass liner in the GC injection port to the Cryoloop at the head of the capillary column (60 m × 0.32 mm inside diameter fused-silica capillary column bonded with DB-5 of 1.0 μm film thickness). The cryoloop was constructed with a 20 cm stainless steel tube (0.04 in. inside diameter [ID], 1/16 in. outside diameter [OD]), and was immersed in a liquid nitrogen bath during the desorbing process. GC oven temperature program was initiated when the liquid nitrogen temperature bath was removed from the cryoloop. The GC oven temperature was held at 50 °C for 5 minutes and then increased to 250 °C at a rate of 10 °C/minutes. Electron impact (EI) mass spectra of the eluate was obtained with an electron energy of 70 eV and emission current of 300 μA. Source temperature was set at 200 °C. GC injector and transfer line temperatures were set at 280 °C. Mass spectral data was acquired over a mass range or 15-500 amu at a scan rate of 266 amu/sec for all but the TST #29 sample trap (the first trap analyzed). TST #29 (Agrashell) was scanned over a mass range of 30-500 amu, the mass range normally employed for routine analysis in this laboratory. Chamber blank traps which were collected before sample combustion were also analyzed in the same manner as the sample traps. In order to estimate the quantities of major components present in the sample traps, a blank TST was soiled with 0.5 ml of 3.8 μg/ml d_6-benzene vapor phase standard which was generated using the static dilution method. Quantities of the major components in the sample traps (measured in terms of μg/L) were estimated based on the response factor of d_6-benzene as an external calibration.

The reconstructed total ion chromatograms from a chamber blank and for the vapor phase samples generated from the combustion of paint blast materials of the ground walnut shell, acrylic, and urea formaldehyde media are presented in Figures B3, B4, and B5. Because of the complex and overly abundant constituents present in each of the vapor phase samples, the effort was focused on the identification of major components. Those components represent a chromatographic area equal to or greater than 1.0% of the total chromatographic area.

The selective ion mode was used to obtain mass chromatograms of m/z 27 and 26 (the two most abundant ions for hydrogen cyanide) to search for the presence of hydrogen cyanide (Figure B6). As shown in Figure B7, mass spectra retrieved from the component eluting at 2.57 min. showed an m/z ratio of 27 ion (100 percent) and an m/z 26 ion (41 percent), which may be related to hydrogen cyanide. This component, representing less than 0.2% of the total chromatographic area, also contained ions generated from water (m/z 18), oxygen (m/z 32, 16), nitrogen (m/z 28), and carbon dioxide (m/z 44). A similar procedure was employed to search for the presence of formaldehyde; none of the early eluting components exhibited the expected characteristic ions generated from formaldehyde.

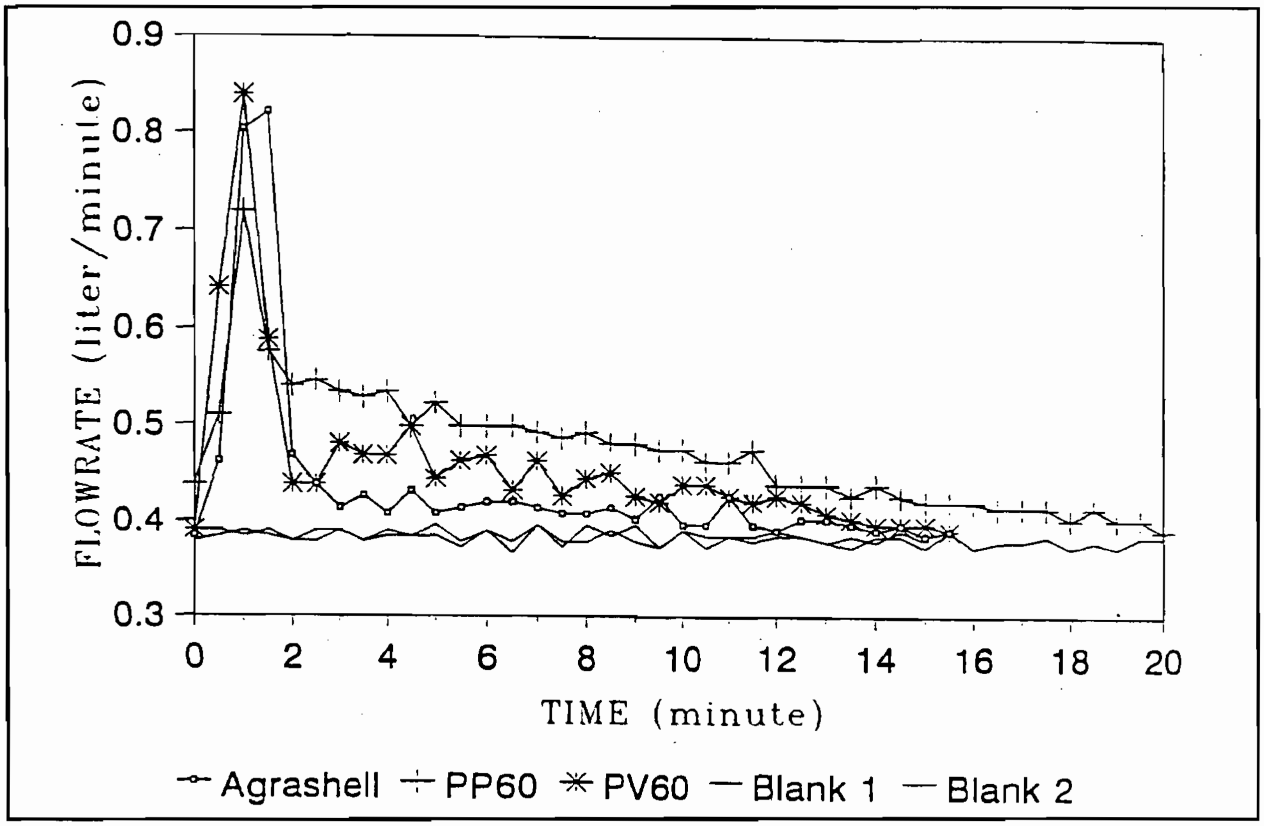

Figure B1. Combustion gas effluent flow rate plotted against time.

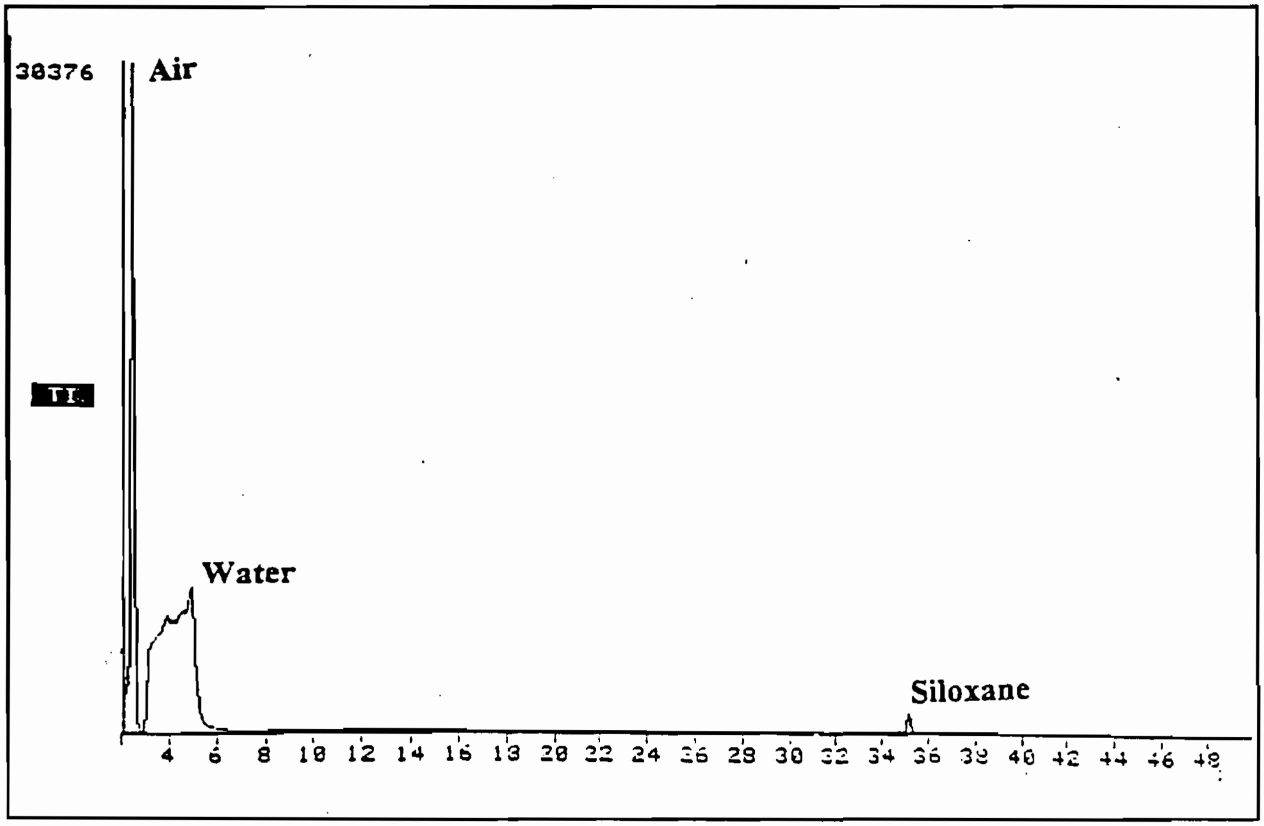

Figure B2. Gas chromatography, chamber blank.

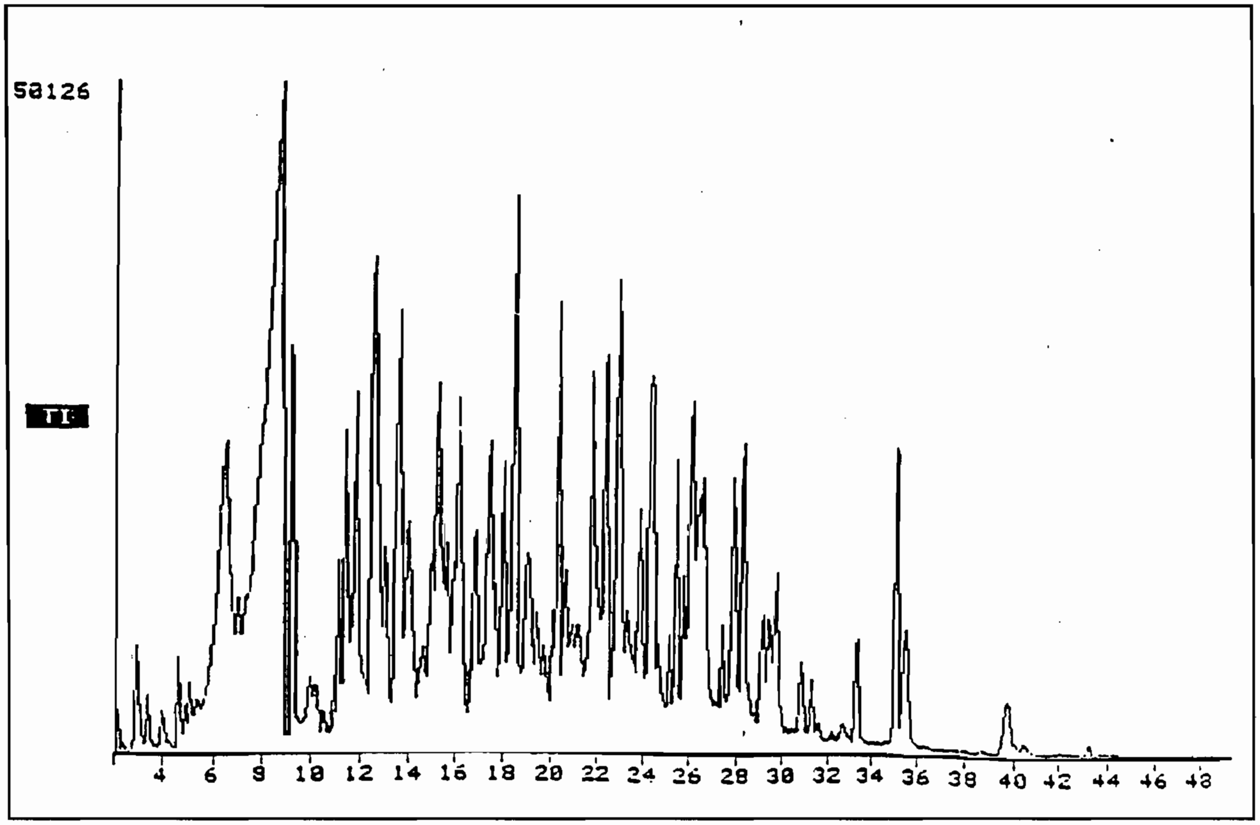

Figure B3. Gas chromatography plot for ground walnut shell blast media treated with LTA.

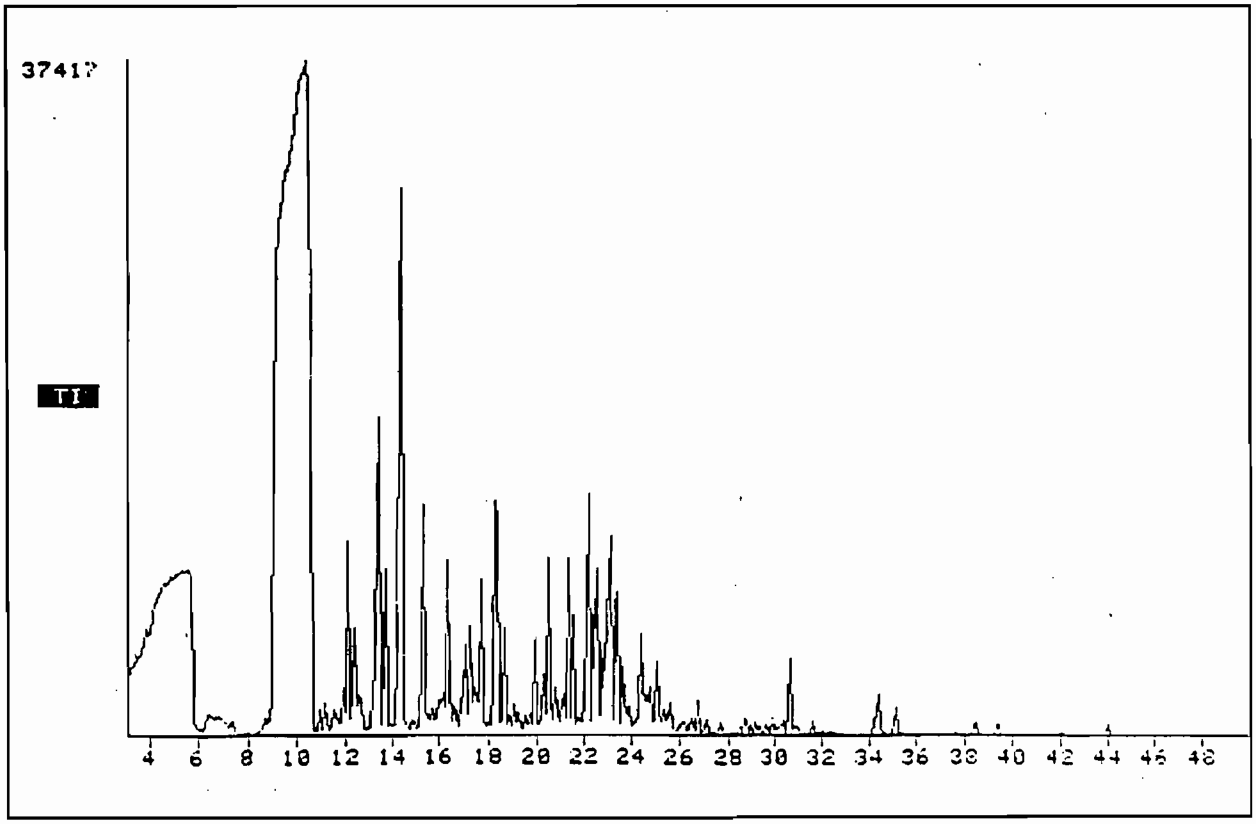

Figure B4. Gas chromatography plot for acrylic blast media treated with LTA.

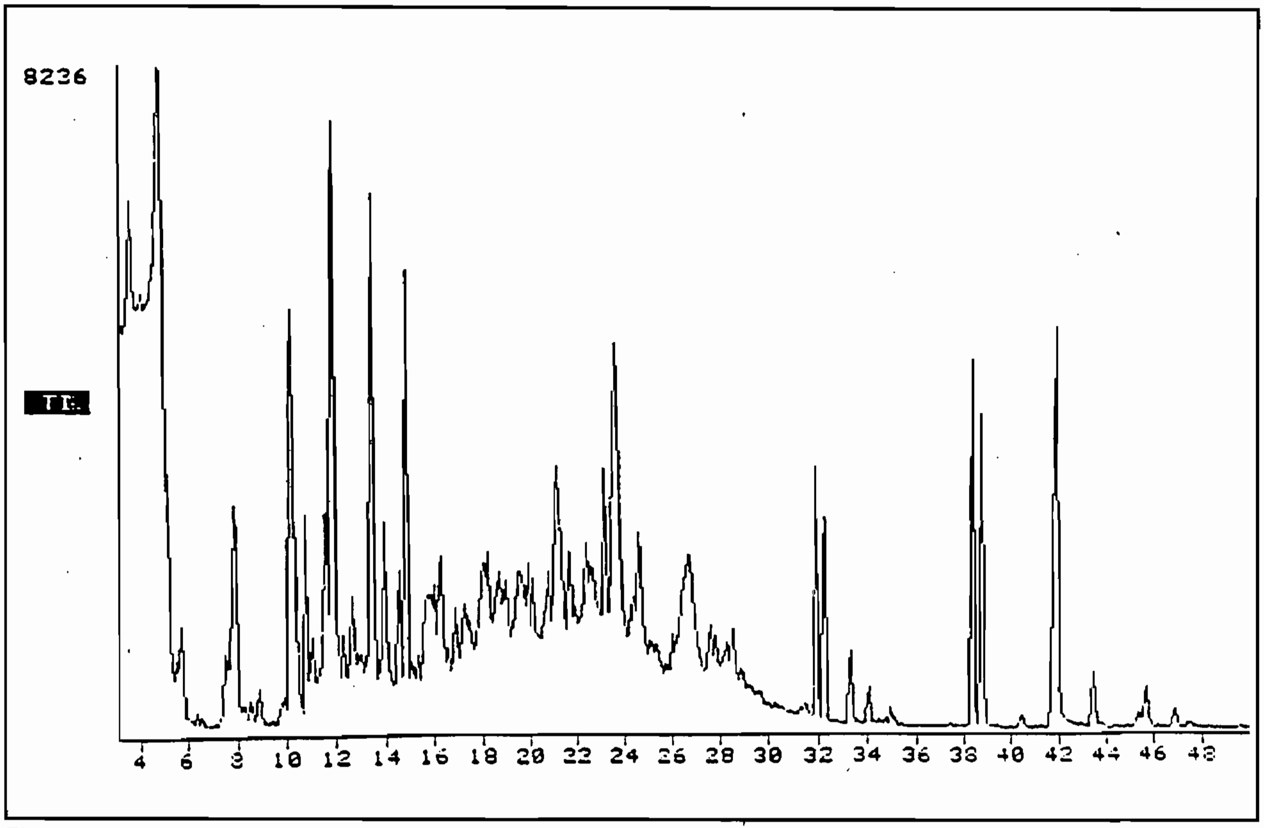

Figure B5. Gas chromatography plot for urea formaldehyde blast media treated with LTA.

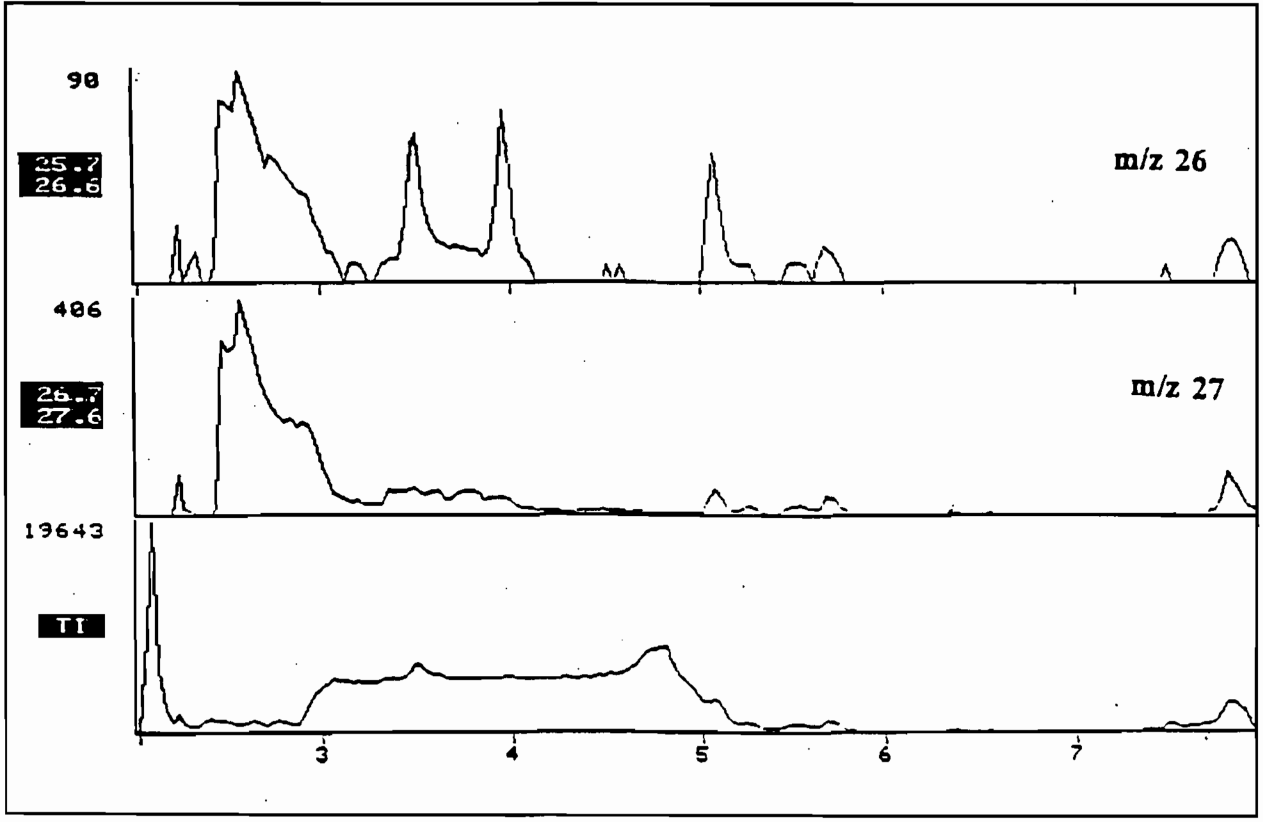

Figure B6. Mass chromatography plot for m/z 26 and m/z 27 treated with LTA.

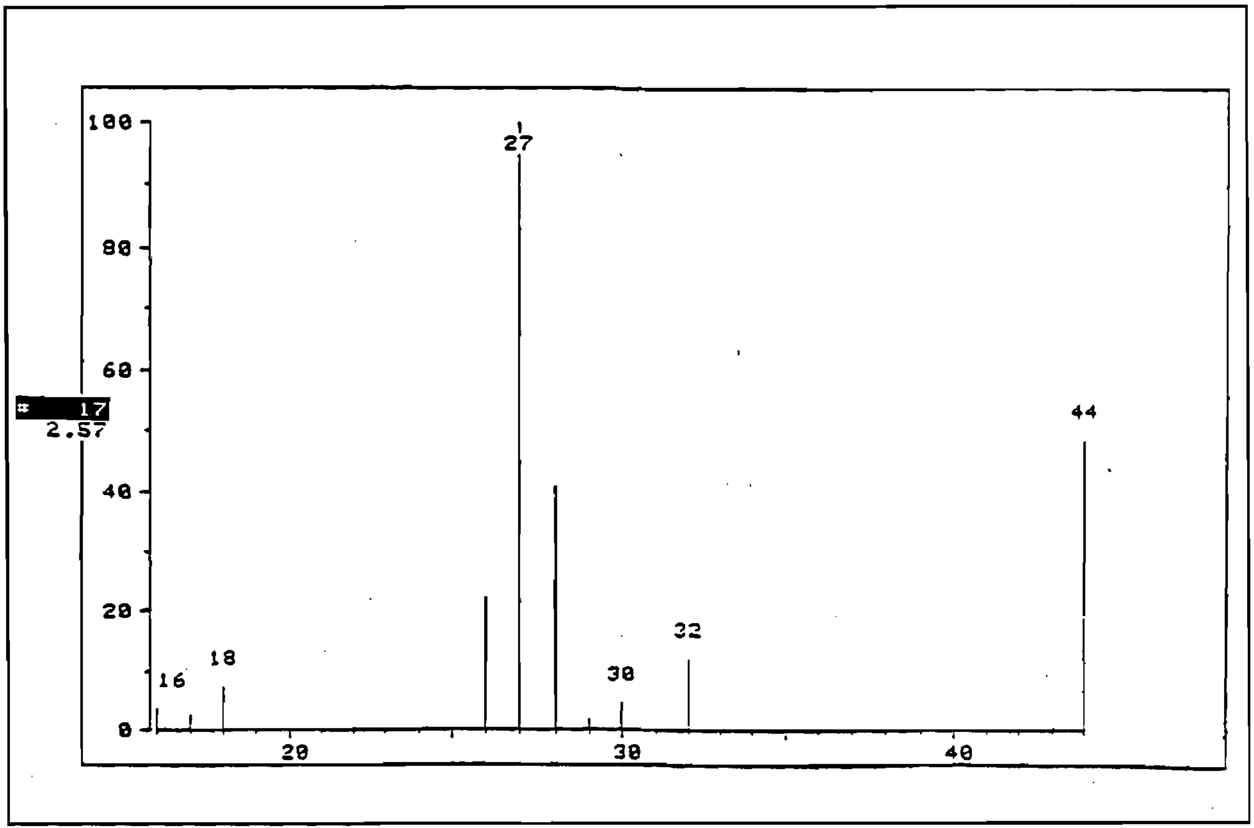

Figure B7. Electron impact mass spectrum for components at 2.57 minutes.

Appendix C: Data for Cement-Based Stabilization Studies

Table C1. Complete chemical results for cement-based stabilization process.

No.	METHOD	SAMPLE NAME	OHorpH start	[OH]orpH end	Cd ppm	Pb ppm	Cr ppm	Ba ppm	Ca ppm	Al ppm	K ppm	Na ppm	Si ppm	S ppm	Fe ppm	Mg ppm
10	TCLP	blank	4.91	4.88	<0.017	<0.066	<0.007									
11	TCLP	Pb3O4-Al2O3	4.89	5.20	0.037	0.24	0.379									
12	TCLP	ZnCrO4-Al2O3	4.91	5.36	0.047	0.068	4.399									
13	TCLP	Pb3O4-Al2O3	4.92	5.22	0.028	0.30	0.214	Zn 17.57								
14	TCLP	ZnCrO4-Al2O3	4.93	5.35	0.034	<0.066	2.406	Zn 42.30								
15	TCLP	same13+0.450mgPb	4.91	5.23	0.027	0.36	0.193	Zn 17.01								
16	TCLP	same14+5.0mgCr	4.92	5.38	0.034	0.082	3.550	Zn 42.14								
17	TCLP	blank	4.88	4.88	<0.017	<0.066	<0.007									
18	TOTAL HNO3+HCl	Al2O3+Pb3O4(0.1%)			6	754	20									
19	TOTAL H2SO4	Al2O3+ZnCrO4(0.1%)			8		64									
20	TOTAL	Al2O3+Pb-LiBO2			10	740	92									
21	TOTAL	Al2O3+Cr-LiBO2			8	48	92									
22	PORE SOLUTION-S	Al2O3+Pb-0.1M1d	0.0902	0.0879	<0.017	2.13	0.009	Zn 9.76								
23	PORE SOLUTION-S	Al2O3+Pb-1M1d	0.8920	0.8910	<0.017	13.86	0.008	Zn 18.79								
24	PORE SOLUTION-S	Al2O3+Cr-0.1M1d	0.0902	0.0877	<0.017	0.72	1.094	Zn 15.20								
25	PORE SOLUTION-S	Al2O3+Cr-1M1d	0.8910	0.8870	<0.017	0.99	1.647	Zn 36.49								
26	PORE SOLUTION-S	1PM-1M1d	0.9953	0.952	0.214	81.44	45.62									
27	PORE SOLUTION-S	3PM-1M1d	0.9953	0.976	<0.017	16.24	12.83									
28	PORE SOLUTION-S	5GB-1M1d	0.9953	0.986	0.343	1.40	0.081									
29	PORE SOLUTION-S	7SB-1M1d	0.9953	0.986	<0.017	2.20	0.613									
30	TOTAL	8SB-LiBO2			86		40	704								
31	TOTAL	8SB-LiBO2			82		38	765								
32	TOTAL	Al2O3-LiBO2			8		51	Zn 313								
33	TOTAL	Al2O3-LiBO2			13		45	Zn 429								
34	TCLP	blank	4.91	4.92	<0.017	<0.066	<0.007									
35	TCLP	SAND-Pb	4.94	4.95	<0.017	2.77	<0.007	<0.03								
36	TCLP	35#+Pb-ICP	4.94	4.95	<0.017	9.33	<0.007									
37	TCLP	SAND-Cr	4.91	4.94	0.031	<0.066	2.40	Zn 28.80								
38	TCLP	37#+Cr+Zn-ICP	4.91	4.94	0.023	<0.066	4.96	Zn 51.46								
39	TCLP	same13#														
40	TCLP	same14#														
41	TCLP	39#+Pb-ICP				6.06										
42	TCLP	40#+Cr-ICP					4.72									
43	TCLP	1PM	4.89	5.25	4.90	<0.066	43.07	0.65								
44	TCLP	2PM	4.91	5.25	5.15	<0.066	44.73	0.74								
45	TCLP	3PM	4.92	4.96	1.35	<0.066	18.01	0.55								
46	TCLP	4PM	4.91	4.96	1.35	<0.066	16.32	0.56								
47	TCLP	5GB	4.90	5.00	28.17	4.86	0.16	0.19								
48	TCLP	6GB	4.90	4.93	1.93	0.24	0.03	0.17								
49	TCLP	7SB	4.90	4.98	0.62	0.18	0.47	1.03								
50	TCLP	8SB	4.90	4.93	4.85	0.10	0.10	0.30								
51	TCLP	blank	4.91	4.93	<0.017	0.40	<0.007	<0.03								
52	TCLP	51#+Pb+Cr-ICP			<0.017	4.81	4.52									

No.	METHOD	SAMPLE NAME	OHorpH	[OH]orpH	Cd	Pb	Cr	Ba	Ca	Al	K	Na	Si	S	Fe	Mg
			start	end	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
53	TCLP	46#+Pb+Cr-ICP			1.27	4.44	20.43									
54	TCLP	50#+Pb+Cr-ICP			4.66	4.50	4.69									
55	PORE SOLUTION-S	1PM-0.1M1d	0.0993	0.0790	0.02	31.70	92.54	0.05								
56	PORE SOLUTION-S	2PM-0.1M1d	0.0993	0.0818	<0.017	25.69	88.48	0.04								
57	PORE SOLUTION-S	3PM-0.1M1d	0.0993	0.0929	<0.007	8.86	23.22	0.03								
58	PORE SOLUTION-S	4PM-0.1M1d	0.0993	0.0935	<0.007	8,91	21.72	<0.03								
59	ICP-STANDARD	8-element														
60	PORE SOLUTION-S	55#+8element			ICP?	ICP?	ICP?									
61	PORE SOLUTION-S	same#55			ICP?	ICP?	ICP?									
62	PORE SOLUTION-S	5GB-0.1M1d	0.0993	0.0968	<0.017	2.07	0.129	<0.03								
63	PORE SOLUTION-S	6GB-0.1M1d	0.0993	0.0983	<0.017	<0.066	0.032	<0.03								
64	PORE SOLUTION-S	7SB-0.1M1d	0.0993	0.0964	<0.017	0.42	1.258	<0.03								
65	PORE SOLUTION-S	8SB-0.1M1d	0.0993	0.0980	<0.017	0.12	0.144	<0.03								
66	PORE SOLUTION-S	1PM-1M28d	0.998	0.945	0.09	84.98	104.5	0.28								
67	PORE SOLUTION-S	2PM-1M28d	0.998	0.954	0.11	88,75	106.7	0.30								
68	PORE SOLUTION-S	3PM-1M28d	0.998	0.980	0.03	21.93	39.95	0.37								
69	PORE SOLUTION-S	4PM-1M28d	0.998	0.979	0.04	23.96	36.72	0.39								
70	ICP-STANDARD	8-element														
71	PORE SOLUTION-S	69#+8element			85%	97%	89.6%	102%								
72	ICP-same55#															
73	ICP-same56#															
74	ICP-same57#															
75	ICP-same58#															
76	ICP-same62#															
77	ICP-same63#															
78	ICP-same64#															
79	ICP-same65#															
80	ICP-same60#															
81	ICP-same61#															
82	PORE SOLUTION-S	5GB-1M28d	0.989	0.976	0.28	4.71	0.067	0.06								
83	PORE SOLUTION-S	6GB-1M28d	0.989	0.979	0.089	0.60	0.062	<0.03								
84	PORE SOLUTION-S	7SB-1M28d	0.989	0.975	0.019	2.01	1.44	0.29								
85	PORE SOLUTION-S	8SB-1M28d	0.989	0.977	0.018	0.48	0.22	0.08								
86	ICP-STANDARD	8-element														
87	ICP-STANDARD	Ag-Cr														
88	ICP	blank			<0.017	<0.066	<0.007	<0.030								
89	PORE SOLUTION-S	1PM-0.1M28d	0.0998	0.0687	0.029	30.68	89.06	0.03								
90	PORE SOLUTION-S	2PM-0.1M28d	0.0998	0.0685	0.026	27.62	86.87	0.03								
91	PORE SOLUTION-S	3PM-0.1M28d	0.0998	0.0887	7 <0.017	12.49	27.69	0.03								
92	PORE SOLUTION-S	4PM0.1M28d	0.0998	0.0894	<0.017	13.83	28,00	0.03								
93	PORE SOLUTION-S	85#+8-element														
94	PORE SOLUTION-S	5GB-0.1M28d	0.0998	0.0973	<0.017	3,74	0.12	<0.03								
95	PORE SOLUTION-S	6GB-0.1M28d	0.0998	0.0988	<0.017	0.10	0.038	<0.03								

No.	METHOD	SAMPLE NAME	OHorpH	[OH]orpH	Cd	Pb	Cr	Ba	Ca	Al	K	Na	Si	S	Fe	Mg
			start	end	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
96	PORE SOLUTION-S	7SB-0.1M28d	0.0998	0.0957	<0.017	0.37	1.43	<0.03								
97	PORE SOLUTION-S	8SB-0.1M28d	0.0998	0.0977	<0.017	0.14	0.17	<0.03								
98	PORE SOLUTION-S	94#+8-element			93.7%	94.1%	103%	98.3%								
99	ICP-STANDARD	8-element														
100	PORE SOLUTION-S	same89#ICP														
101	PORE SOLUTION-S	same90#ICP														
102	PORE SOLUTION-S	1PM-1M1d	0.993	0.963	0.17	77.29	102.7	0.27								
103	PORE SOLUTION-S	2PM-1M1d	0.993	0.960	0.19	74.11	113.8	0.26								
104	PORE SOLUTION-S	3PM-1M1d	0.993	0.980	<0.017	18.01	38.14	0.25								
105	PORE SOLUTION-S	4PM1M1d	0.993	0.983	<0.017	18.41	32.00	0.24								
106	PORE SOLUTION-S	5GB-1M1d	0.993	0.989	0.31	1.42	0.053	0.05								
107	PORE SOLUTION-S	6GB-1M1d	0.993	0.993	0.28	0.37	0.038	0.04								
108	PORE SOLUTION-S	7SB-1M1d	0.993	0.984	<0.017	1.96	1.50	0.13								
109	PORE SOLUTION-S	8SB-1M1d	0.993	0.987	0.18	0.46	0.29	0.09								
110	PORE SOLUTION-S	109#+8-element			78.4	78.8%	95.1%	83.9%								
111	ICP-STANDARD	8-element														
112	ICP	blank			<0.017	<0.066	<0.007	<0.030								
113	TOTAL	blank(HNO3)			<0.017	<0.066	<0.007	<0.030								
114	TOTAL	8SB-HNO3			0.93	0.21	0.19	0.27								
115	TOTAL	8SB-HNO3			0.94	0.15	0.19	0.21								
116	same92#															
117	92#+standard															
118	same95#															
119	95#+standard															
120	same97#															
121	same93#															
122	same99#															
123	TOTAL	blank(HNO3)			<0.017	<0.066	<0.007	<0.030								
124	TOTAL	1PM-HNO3			1.79	34.01	22.99	30.22								
125	TOTAL	1PM-HNO3			1.65	33.08	22.58	30.51								
126	TOTAL	1PM-HNO3			93.4%	95.1%	97.5%	100.5%								
127	TOTAL	125#+standard														
128	TOTAL	3PM-HNO3			0.41	5.53	6.92	4.36								
129	TOTAL	3PM-HNO3			0.38	5.86	6.91	4.54								
130	TOTAL	3PM-HNO3+standard			88.6%	96.4%	91.5%	99.2%								
131	TOTAL	3PM-HNO3+standard			88.5%	96.7%	92.7%	98.3%								
132	TOTAL	129#+standard														
133	TOTAL	2PM-HNO3			1.57	30.14	20.88	28.02								
134	TOTAL	2PM-HNO3			1.46	28.04	19.95	27.16								
135	TOTAL	4PM-HNO3			0.35	5.39	5.47	4.98								
136	TOTAL	4PM-HNO3			0.39	5.55	5.76	5.13								
137	ICP-STANDARD	8-element-standard														
138	TOTAL	5GB-HNO3			4.69	1.38	0.10	0.03								

No.	METHOD	SAMPLE NAME	OHorpH start	[OH]orpH end	Cd ppm	Pb ppm	Cr ppm	Ba ppm	Ca ppm	Al ppm	K ppm	Na ppm	Si ppm	S ppm	Fe ppm	Mg ppm
139	TOTAL	5GB-HNO3			4.44	1.20	0.10	0.03								
140	TOTAL	5GB-HNO3+standard			121%	102%	93.3%	98.4%								
141	TOTAL	5GB-HNO3+standard			91.1%	93.5%	93.1%	98.2%								
142	TOTAL	6GB-HNO3			0.52	0.39	0.21	0.14								
143	TOTAL	6GB-HNO3			0.39	0.26	0.13	0.09								
144	TOTAL	143#+standard			92.1%	88.4%	88.3%	91.6%								
145	TOTAL	7SB-HNO3			0.15	0.75	0.60	1.22								
146	TOTAL	7SB-HNO3			0.15	0.79	0.58	1.15								
147	TOTAL	146#+standard			91.3%	89.3%	90.3%	94.4%								
148	ICP-STANDARD	8-element														
149	TOTAL	LiBO2-blank					2	<3								
150	TOTAL	5GB-LIBO2					4	9								
151	TOTAL	5GB-LIBO2					13	11								
152	TOTAL	7SB-LiBO2					810	887								
153	TOTAL	7SB-LiBO2					819	899								
154	TOTAL	same144#														
155	TOTAL	6GB-LIBO2					45	25								
156	TOTAL	6GB-LIBO2					35	12								
157	TOTAL	4PM-HNO3-LIBO2					6842	518								
158	TOTAL	4PM-HNO3-LIBO2					6865	508								
159	TOTAL	1PM-LIBO2					20557	3044								
160	TOTAL	1PM-LIBO2					17199	2580								
161	TOTAL	2PM-LiBO2					18470	2780								
162	TOTAL	2PM-LIBO2					18955	2672								
163	TOTAL	3PM-LiBO2					9219	478								
164	TOTAL	3PM-LiBO2					9165	455								
165	TOTAL	7SB-HNO3			14.5	85	70	121								
166	TOTAL	7SB-HNO3			15.5	69	60.35	126								
167	TOTAL	7SB-LiBO2 (after165#)					689.5	818								
168	TOTAL	7SB-LIBO2 (after166#)					726.5	804								
169	PORE SOLUTION-S	same117#														
170	TCLP	sand	4.93	4.93	<0.017	<0.066	0.008	0.06								
171	TCLP	white cement	2.88	10.45	<0.017	<0.066	<0.007	0.98								
172	STANDARD	8-element-ICP														
173	STANDARD	8-element-ICP														
174	PORE SOLUTION-E	WC-sand		0.0969	<0.17	<0.66	<0.07									
175	PORE SOLUTION-E	WC-sand		0.1182	<0.17	<0.66	<0.07									
176	PORE SOLUTION-E	WC-sand		0.0916	<0.17	<0.66	<0.07									
176A	STANDARD	8-element														
177	PORE SOLUTION-E	5GB-WC1d		0.1115	<0.17	<0.66	<0.07	1.24	431	0.66	261	2174	<1.6	5.78	<0.10	<0.14
178	PORE SOLUTION-E	5GB-HAC1d		0.5760	0.189	2.32	0.13	0.45	102	5.06	18532	2919	35.6	97.2	4.95	<0.14
179	PORE SOLUTION-E	6GB-WC1d		0.0820	<0.17	<0.66	0.07	1.34	521	0.33	101	1386	<1.6	0.63	<0.10	<0.14
180	PORE SOLUTION-E	6GB-HAC1d		0.5212	<0.17	<0.66	0.40	0.37	89.0	5.22	15918	2331	<1.6	55.3	6.58	<0.14

No.	METHOD	SAMPLE NAME	OHorpH	[OH]orpH	Cd	Pb	Cr	Ba	Ca	Al	K	Na	SI	S	Fe	Mg
			start	end	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
181	PORE SOLUTION-E	7SB-WC1d		0.0751	<0.17	<0.66	0.36	1.81	757	0.32	246	1043	<1.6	9.24	<0.10	<0.14
182	PORE SOLUTION-E	7SB-HAC1d		0.2990	<0.17	0.78	1.50	1.07	139	3.37	10500	1586	<1.6	36.4	1.99	<0.14
183	PORE SOLUTION-E	8SB-WC1d		0.0812	<0.17	<0.66	0.08	1.29	573	0.38	217	1239	<1.6	5.36	<0.10	<0.14
184	PORE SOLUTION-E	8SB-HAC1d		0.3558	<0.17	<0.66	0.16	0.73	138	3.78	11014	1817	<1.6	21.5	2.86	<0.14
185	PORE SOLUTION-E	BLANK-WC2d(W/C=0.53)		0.0964	<0.17	<0.66	<0.07	1.06	405	0.59	311	1617	<1.6	5.67	<0.10	<0.14
186	PORE SOLUTION-E	BLANK-WC2d(W/C=0.78)		0.0795	<0.17	<0.66	<0.07	1.30	530	0.56	203	1124	<1.6	2.42	<0.10	<0.14
187	PORE SOLUTION-E	BLANK-HAC2d(W/C=0.53)		0.6160	<0.17	<0.66	0.41	0.35	69.7	6.60	19513	2502	5.25	77.3	7.72	<0.14
188-1	PORE SOLUTION-E	BLANK-HAC2d(W/C=0.78)		0.3850	<0.17	<0.66	0.18	0.44	105	4.47	12632	1575	<1.6	18.3	3.38	<0.14
188	PORE SOLUTION-E	5GB-WC28d		0.3240	0.178	<0.66	0.09	<0.3	107	4.88	599	8175	118	117	0.62	<0.14
189	PORE SOLUTION-E	5GB-HAC28d		0.8480	0.220	2.76	0.98	0.32	85.7	10.8	20815	7977	424	482	8.10	<0.14
190	TCLP	5GB-WC1d	2.84	10.50	<0.017	<0.066	<0.007	0.28								
191	TCLP	5GB-HAC1d	2.84	11.74	<0.017	<0.066	0.045	0.31								
192	TCLP	6GB-WC1d	2.87	10.05	<0.017	<0.066	0.007	0.31								
193	TCLP	6GB-HAC1d	2.87	11.70	<0.017	<0.066	0.063	0.30								
194	TCLP	7SB-WC1d	2.86	9.65	<0.017	<0.066	0.142	0.46								
195	TCLP	7SB-HAC1d	2.83	11.70	<0.017	<0.066	0.288	0.46								
196	TCLP	8SB-WC1d	2.85	10.57	<0.017	<0.066	<0.007	0.36								
197	TCLP	8SB-HAC1d	2.85	11.82	<0.017	<0.066	0.032	0.47								
198	TCLP	197+standard-ICP			91.2%	93.7%	96.4%	99.1%								
199	STANDARD	8-element														
200	TCLP	HAC	2.88	10.50	<0.007	<0.066	0.576	0.73								
201	TCLP	5GB-WC28d	2.87	10.09	<0.017	<0.066	0.016	0.34								
202	TCLP	5GB-HAC28d	2.87	11.70	<0.017	<0.066	0.024	0.42								
203	TCLP	BFS	2.91	9.47	<0.017	<0.066	<0.007	0.38								
204	STANDARD	8-element														
205	TCLP	PP-60	2.86	4.81	<0.017	<0.066	<0.007	3.04								
206	TCLP	PV														
207	PORE SOLUTION-S	PP-60-0.1M1d	0.1023	0.0956	<0.017	<0.066	<0.007	0.91								
208	PORE SOLUTION-S	BFS-0.1M1d	0.1023	0.0988	<0.017	<0.066	<0.007	0.06								
209	PORE SOLUTION-S	PP-60-1M1d	1.0235	0.9900	<0.017	<0.066	<0.007	3.72								
210	PORE SOLUTION-S	BFS-1M1d	1.0235	1.0010	<0.017	<0.066	<0.007	0.19								
211	STANDARD	8-element														
212	PORE SOLUTION-S	PP-60-1M28d	1.0128	0.9930	<0.007	<0.066	0.008	4.55								
213	PORE SOLUTION-S	BFS-1M28d	1.0128	0.9570	<0.017	<0.066	<0.007	0.19								
214	PORE SOLUTION-S	PV-1M28d														
215	PORE SOLUTION-S	PP-60-0.1M28d	0.1023	0.0912	<0.017	<0.066	<0.007	0.90								
216	PORE SOLUTION-S	BFS-0.1M28d	0.1023	0.0974	<0.017	<0.066	<0.007	0.08								
217	STANDARD	8-element														
218	PORE SOLUTION-S	Pb-sand-0.1M1d	0.1024	0.1010	<0.007	2.51	<0.007	<0.03								
219	PORE SOLUTION-S	Cr-sand-0.1M1d	0.1024	0.1011	<0.007	0.23	4.94	<0.03								
220	PORE SOLUTION-S	Pb-sand-1M1d	1.0205	1.0040	<0.007	26.98	<0.007	<0.03								
221	PORE SOLUTION-S	Cr-sand-1M1d	1.0205	1.0070	<0.007	0.23	3.65	<0.03								
222	STANDARD	8-element														

No.	METHOD	SAMPLE NAME	OHorpH	[OH]orpH	Cd	Pb	Cr	Ba	Ca	Al	K	Na	Si	S	Fe	Mg
			start	end	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
223	PORE SOLUTION-S	Cu2O-sand-0.1M1d	0.1021	0.0996	<0.017	<0.066	<0.007	Cu1.63								
224	PORE SOLUTION-S	Cd-sand-0.1M1d	0.1021	0.0995	0.028	<0.066	<0.007	<0.03								
225	PORE SOLUTION-S	Cu2O-sand-1M1d	1.0034	1.0041	<0.017	<0.066	<0.007	Cu8.67								
226	PORE SOLUTION-S	Cd-sand-1M1d	1.0034	1.0041	0.265	0.068	<0.007	<0.03								
227	PORE SOLUTION-E	1PM-WC-1d		0.0160	0.37	14.9	652	0.58	4820	1.88	212	236	20.6	329	1.56	<0.14
228	PORE SOLUTION-E	1PM-WC-BFS-1d		0.0070	<0.17	6.9	227	1.08	2600	13.9	345	371	17.5	49.7	1.96	<0.14
229	PORE SOLUTION-E	1PM-HAC-1d		0.0188	<0.17	7.7	1310	0.32	1700	0.54	6560	848	21.3	1160	1.19	<0.14
230	PORE SOLUTION-E	1PM-HAC-BFS-1d		0.0158	<0.17	<0.66	1210	<0.30	3080	0.65	4980	720	25.0	1380	0.55	<0.14
231	PORE SOLUTION-E	2PM-WC-1d		0.0178	0.30	16.4	612	0.83	4350	1.94	380	353	24.9	66.1	0.84	<0.14
232	PORE SOLUTION-E	2PM-WC-BFS-1d		0.0100	0.21	<0.66	185	1.27	2490	18.2	379	395	19.4	50.7	3.44	<0.14
233	PORE SOLUTION-E	2PM-HAC-1d		0.0200	<0.17	7.5	1330	<0.30	1950	0.67	6760	879	23.5	1270	0.96	<0.14
234	PORE SOLUTION-E	2PM-HAC-BFS-1d		0.0171	<0.17	<0.66	1210	<0.30	2760	0.57	4970	725	23.0	1340	0.45	<0.14
235	PORE SOLUTION-E	3PM-WC-1d		0.0728	<0.17	<0.66	21.5	2.85	987	<0.17	259	714	10.7	57.7	<0.10	<0.14
236	PORE SOLUTION-E	3PM-WC-BFS-1d		0.0688	<0.17	<0.66	20.9	2.59	1390	<0.17	239	546	13.4	43.2	<0.10	<0.14
237	PORE SOLUTION-E	3PM-HAC-1d		0.2390	<0.17	<0.66	155	2.14	173	0.84	13980	1640	22.8	467	0.46	<0.14
238	PORE SOLUTION-E	3PM-HAC-BFS-1d		0.1550	<0.17	<0.66	144	1.93	260	0.25	9230	1140	21.6	311	0.17	<0.14
239	PORE SOLUTION-E	4PM-WC-1d		0.0610	<0.17	<0.66	11.8	3.27	1120	0.20	310	709	8.87	32.5	<0.10	<0.14
240	PORE SOLUTION-E	4PM-WC-BFS-1d		0.0460	<0.17	<0.66	23.3	3.82	939	<0.17	292	627	9.40	49.6	<0.10	<0.14
241	PORE SOLUTION-E	4PM-HAC-1d		0.2900	<0.17	<0.66	87.5	1.32	247	1.55	14070	1630	20.3	275	0.84	<0.14
242	PORE SOLUTION-E	4PM-HAC-BFS-1d		0.2080	<0.17	<0.66	76.6	1.70	333	1.06	10200	1270	16.7	161	0.47	<0.14
243	PORE SOLUTION-S	Pb-sand-0.1M28d	0.1024	0.1009	<0.17	3.90	<0.007	<0.03								
244	PORE SOLUTION-S	Cr-sand-0.1M28d	0.1024	0.1007	<0.17	0.13	4.11	<0.03								
245	PORE SOLUTION-S	Pb-sand-1M28d	1.0207	1.0117	<0.17	26.94	<0.007	<0.03								
246	PORE SOLUTION-S	Cr-sand-1M28d	1.0207	1.0117	<0.17	0.21	2.96	<0.03								
247	PORE SOLUTION-E	5GB-WC-1d		0.0824	<0.17	<0.66	0.15	0.98	247	<0.17	175	1879	14.3	10.9	<0.10	<0.14
248	PORE SOLUTION-E	5GB-HAC-1d		0.5078	<0.17	2.96	0.28	0.58	119	5.70	17059	2683	50.2	61.1	3.99	<0.14
249	PORE SOLUTION-E	6GB-WC1d		0.0766	<0.17	<0.66	0.17	2.01	645	0.65	81.5	1242	7.83	<1.9	<0.10	<0.14
250	PORE SOLUTION-E	6GB-HAC-1d		0.4560	<0.17	<0.66	1.40	0.50	117	4.49	15963	2130	16.5	49.7	4.71	<0.14
251	PORE SOLUTION-E	1PM-WC-28d		0.0180	0.30	18.1	333	1.05	6400	1.63	479	479	68.6	61.0	0.96	<0.14
252	PORE SOLUTION-E	1PM-WC-BFS-28d		0.0175	0.29	11.5	459	0.72	6700	1.11	453	427	70.2	128	0.67	<0.14
253	PORE SOLUTION-E	1PM-HAC-28d		0.0242	<0.17	8.46	1080	0.45	5680	1.10	7080	910	83.9	802	2.25	0.56
254	PORE SOLUTION-E	1PM-HAC-BFS-28d		0.0227	<0.17	5.90	1040	0.31	6590	0.59	5190	739	79.6	950	1.23	0.22
255	PORE SOLUTION-E	2PM-WC-28d		0.0196	0.29	19.0	263	1.18	6060	1.38	474	468	71.9	62.3	0.88	<0.14
256	PORE SOLUTION-S	Cr-BFS-0.1M1d	0.1024	0.0975	<0.017	0.10	4.33	<0.03								
257	PORE SOLUTION-S	Cr-BFS-1M1d	1.0163	0.9975	<0.017	<0.066	3.35	0.13								
258	PORE SOLUTION-E	2PM-WC-BFS-28d		0.0194	<0.17	13.8	456	0.77	7030	1.21	461	474	75.7	142	0.77	<0.14
259	PORE SOLUTION-E	2PM-HAC-28d		0.0252	<0.17	8.33	1040	0.40	5660	0.76	6830	872	80.7	864	2.07	0.30
260	PORE SOLUTION-E	2PM-HAC-BFS-28d		0.0231	<0.17	6.94	1030	0.38	6760	0.77	5180	757	81.6	922	1.51	0.38
261	PORE SOLUTION-E	3PM-WC-28d		0.0921	0.37	1.71	0.40		15.0	0.30	<15.8	15.7	2.57	<1.9	0.70	7.56
262	PORE SOLUTION-E	3PM-WC-BFS-28d		0.0885	<0.17	<0.66	2.32	2.58	696	0.54	1377	2534	30.0	250	0.47	<0.14
263	PORE SOLUTION-E	2PM-WC-HighBFS-1d		0.0131	<0.17	2.46	770	0.45	3759	0.55	213	273	17.6	354	0.11	0.70
264	PORE SOLUTION-E	2PM-HAC-HighBFS-1d		0.0131	<0.17	2.32	845	0.19	3797	0.44	1254	402	19.4	770	0.17	0.80
265	PORE SOLUTION-E	3PM-HAC-28d		0.9572	<0.17	7.57	49.5	3.16	124	6.04	46030	8137	132	327	5.06	<0.14

No.	METHOD	SAMPLE NAME	OHorpH	[OH]orpH	Cd	Pb	Cr	Ba	Ca	Al	K	Na	Si	S	Fe	Mg
			start	end	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
266	PORE SOLUTION-E	3PM-HAC-BFS-28d		0.5486	<0.17	1.18	9.22	3.86	176	5.14	25595	5649	85.4	427	2.92	<0.14
267	PORE SOLUTION-E	4PM-WC-28d		0.0773	<0.17	<0.66	5.26	2.38	812	0.34	786	2511	26.3	38.9	<0.10	<0.14
268	PORE SOLUTION-E	4PM-WC-BFS-28d		0.1214	<0.17	<0.66	3.02	8.51	692	0.71	2849	4859	44.1	472	<0.10	<0.14
269	PORE SOLUTION-E	4PM-HAC-28d		0.6730	<0.17	4.25	30.61	2.71	121	4.26	33414	5994	92.4	248	2.81	<0.14
270	PORE SOLUTION-E	4PM-HAC-BFS-28d		0.4578	<0.17	0.91	8.37	2.63	175	4.14	21161	4478	62.6	375	1.74	<0.14
271	PORE SOLUTION-S	Cd-sand-0.1M28d	0.1024	0.0998	0.037	<0.066	0.084	<0.03								
272	PORE SOLUTION-S	Cu2O-sand-0.1M28d	0.1024	0.1002	<0.017	<0.066	0.014	Cu0.33								
273	TCLP	2PM-WC-BFS-28d-NOT-E	2.92	0.0234	<0.017	0.33	15.99	0.47	2913	0.19	13.09	17.87	1.70	78.6	0.01	0.08
274	TCLP	2PM-HAC-BFS-28d-NOT-E	2.92	0.0094	<0.017	0.079	19.42	0.40	2480	0.28	118.1	24.58	3.72	154	0.03	0.19
275	PORE SOLUTION-E	5GB-WC-28d		0.2520	<0.17	<0.66	0.25	0.40	141	1.49	521	6549	116	67.9	0.22	<0.14
276	PORE SOLUTION-E	5GB-HAC-28d		0.8620	<0.17	3.15	1.02	0.46	67.3	9.26	23862	7115	480	244	4.79	<0.14
277	PORE SOLUTION-E	6GB-WC-28d		0.1916	<0.17	<0.66	0.13	0.65	215	1.13	438	4227	41.2	20.8	<0.10	<0.14
278	PORE SOLUTION-E	6GB-HAC-28d		0.7745	<0.17	<0.66	1.09	0.48	58.3	8.55	23049	4783	28.2	162	7.20	<0.14
279	PORE SOLUTION-S	Cd-sand-1M28d	1.0035	1.0079	0.347	<0.006	<0.007	<0.03								
280	PORE SOLUTION-S	Cu2O-sand-1M28d	1.0035	1.0022	<0.017	<0.066	0.011	Cu32.15								
281	TCLP	Cr-BFS	2.86	9.49	<0.017	<0.066	<0.007	0.33								
282	TCLP	Pb-BFS	2.86	9.48	<0.017	<0.066	<0.007	0.32								
283	PORE SOLUTION-S	Cr(metal)-0.01M1d					0.009									
284	PORE SOLUTION-S	Cr(metal)-0.1M1d					<0.007									
285	PORE SOLUTION-S	Cr(metal)-1M1d					<0.007									
286	PORE SOLUTION-S	Pb-BFS-0.1M1d	0.1021	0.0994	<0.017	<0.066	<0.007	0.06								
287	PORE SOLUTION-S	Pb-BFS-1M1d	1.0213	1.0041	<0.017	<0.066	<0.007	0.14								
288	PORE SOLUTION-E	2PM-WC-HighBFS-28d		0.0155	0.09	2.50	959	0.48	8950	1.7	448	355	262	451	0.20	1.3
289	PORE SOLUTION-E	2PM-HAC-HighBFS-28d		0.0134	0.04	1.71	960	0.34	8940	1.3	1609	471	148	814	0.40	2.1
290	TCLP	2PM-WC-HighBFS-1d	2.91	0.0012	<0.017	<0.066	9.73	0.38	1942	0.15	15.23	14.03	15.88	67.65	0.01	52.21
291	TCLP	2PM-HAC-HighBFS-1d	2.91	0.0012	<0.017	<0.066	8.38	0.41	2082	0.14	29.74	15.67	12.86	75.74	<0.01	72.59
292	TCLP	2PM-WC-28d-NOT-E	2.91	0.0278	<0.017	0.29	16.11	0.43	2623	0.29	12.08	19.12	3.43	88.1	0.01	0.07
293	TCLP	2PM-HAC-28d-NOT-E	2.91	0.0141	<0.017	0.08	15.32	0.36	2452	0.29	166.2	27.54	5.28	177.2	0.01	0.14
294	TCLP	2PM-WC-28d	2.91	0.0195	<0.017	0.19	24.84	0.37	2432	0.46	4.92	10.89	3.33	84.7	<0.01	0.06
295	TCLP	2PM-WC-BFS-28d	2.91	0.0160	<0.017	0.14	17.98	0.39	2347	0.44	6.58	11.45	2.81	82.6	<0.01	0.07
296	TCLP	2PM-HAC-28d	2.91	0.0210	<0.017	0.16	10.80	0.52	2408	0.20	59.55	14.61	3.31	93.93	<0.01	0.06
297	TCLP	2PM-HAC-BFS-28d	2.91	0.0110	<0.017	0.08	9.00	0.39	2291	0.73	40.35	12.56	4.10	140.5	<0.01	0.09
298	PORE SOLUTION-S	Cr-BFS-0.1M28d	0.1017	0.0969	<0.017	<0.066	2.42	0.07								
299	PORE SOLUTION-S	Cr-BFS-1M28d	1.0171	0.9984	<0.017	<0.066	2.65	0.15								
300	TCLP	2PM-WC-HighBFS-28d	2.91	0.0009	<0.017	<0.066	5.89	0.39	1945	0.12	14.12	14.85	13.97	67.51	0.02	83.15
301	TCLP	2PM-HAC-HighBFS-28d	2.91	0.0009	<0.017	<0.066	6.28	0.40	1848	0.13	23.71	13.61	16.37	74.39	0.02	175.2
302	TCLP	1PM-WC-28d	2.91	0.0188	<0.017	0.18	23.83	0.32	2486	0.53	4.54	8.56	3.00	95.30	<0.01	0.58
303	TCLP	1PM-HAC-28d	2.91	0.0163	<0.017	0.13	9.87	0.38	2450	0.19	52.37	11.13	4.00	151.2	<0.01	0.26
304	TCLP	1PM-WC-BFS-28d	2.89	0.0158	<0.017	0.14	17.38	0.36	2385	0.52	6.39	10.31	3.35	90.31	0.01	0.19
305	TCLP	1PM-HAC-BFS-28d	2.89	0.0059	<0.017	<0.066	7.72	0.36	2240	0.39	47.11	12.27	6.87	156.0	0.01	0.59
306	PORE SOLUTION-S	Pb-BFS-0.1M28d	0.1021	0.0978	<0.017	0.098	<0.007	0.07								
307	PORE SOLUTION-S	Pb-BFS-1M28d	1.0213	0.9998	<0.017	<0.066	<0.007	0.15								
308	TCLP	0.1%ZnCrO4-BFS(MIX)	2.91	9.50			<0.007									

No.	METHOD	SAMPLE NAME	OHorpH start	[OH]orpH end	Cd ppm	Pb ppm	Cr ppm	Ba ppm	Ca ppm	Al ppm	K ppm	Na ppm	Si ppm	S ppm	Fe ppm	Mg ppm
309	TCLP	1%ZnCrO4-BFS	2.91	9.46			3.41									
310	TCLP	2%ZnCrO4-BFS(MIX)	2.91	9.50			0.66									
311	TCLP	2PM-WC-1d	2.90	0.0261	<0.017	0.42	20.47	0.51	2607	0.38	19.07	17.84	9.01	99.18	<0.01	0.10
312	TCLP	2PM-HAC-1d	2.90	0.0207	<0.017	0.25	14.96	0.53	2491	0.30	74.23	18.66	9.31	120.4	<0.01	0.10
313	TCLP	2PM-WC-BFS-1d	2.90	0.0175	<0.017	0.19	16.92	0.43	2307	0.58	14.74	14.74	3.73	89.55	<0.01	0.10
314	TCLP	2PM-HAC-BFS-1d	2.90	0.0097	<0.017	0.14	11.94	0.41	2318	0.76	56.29	16.60	4.51	164.1	<0.01	0.10
315	Cr-standard-BFS	Cr-standard-BFS					23.16									
316	TCLP	Cd-sand	4.92	4.97	52.18	<0.066	<0.007	<0.03								
317	TCLP	Cu2O-sand	4.89	4.91	0.021	<0.066	<0.007	Cu23.53								
318	TCLP	1%ZnCrO4-BFS(MIX)	2.91	9.44			0.011									
319	TCLP	1PM-WC-NOT-E	2.90	0.0246	<0.017	0.255	22.72	0.39	2579	0.38	11.55	17.43	13.71	73.26	0.01	0.41
320	TCLP	1PM-HAC-NOT-E	2.90	0.0118	<0.017	<0.066	15.07	0.37	2389	0.42	158.6	25.20	11.39	159.5	0.01	0.20
321	TCLP	1PM-WC-BFS-NOT-E	2.91	0.0179	<0.017	0.162	15.94	0.39	2444	0.43	13.09	17.14	6.84	83.4	0.01	0.10
322	TCLP	1PM-HAC-BFS-NOT-E	2.91	0.0072	<0.017	<0.066	16.54	0.37	2364	0.60	127.8	24.02	31.75	172.2	0.02	0.20
323	TCLP	1PM-WC-1d	2.92	0.0239	<0.017	0.296	19.11	0.43	2472	0.35	9.59	14.47	2.90	83.20	<0.01	0.10
324	TCLP	1PM-HAC-1d	2.92	0.0174	<0.017	0.142	18.81	0.41	2399	0.18	113.6	20.08	3.76	158.0	<0.01	0.10
325	TCLP	1PM-WC-BFS-1d	2.92	0.0164	<0.017	0.168	15.51	0.37	2325	0.54	10.00	13.98	2.56	85.54	<0.01	0.10
326	TCLP	1PM-HAC-BFS-1d	2.81	0.0082	<0.017	0.066	16.00	0.37	2270	0.52	91.55	18.79	4.68	168.9	0.01	0.20
327	PORE SOLUTION-E	RRAD PERMAFIX D 7d		0.0062	<0.17	0.09	0.10	0.35	676	71.6	5788	12624	19.8	10144	3.3	2.0
328	TCLP	RRAD PERMAFIX D 7d	2.92	6.49	0.030	<0.066	0.052	0.38	2251	5.54	42.93	66.97	22.65	774.4	84.35	68.18
329	PORE SOLUTION-E	RRAD PERMAFIX C 28d		0.0063	<0.17	0.15	0.23	0.30	732	70.6	5079	11981	75.0	7384	2.8	7.0

Abbreviations and Acronyms

amu	atomic mass unit
CFC	chlorofluorocarbon
CTX	Center for Technical Excellence
DESCOM	U.S. Army Depot Systems Command
DI	deionized
EI	electron impact
EDTA	ethylenediaminetetraacetic acid
EPA	U.S. Environmental Protection Agency
GC/MS	gas chromatography/mass spectroscopy
HCN	hydrogen cyanide
ID	inside diameter
$LiBO_2$	lithium metaborate
LTA	low-temperature ashing
M	molar concentration
MPa	megapascals
MSDS	Material Safety Data Sheet
m/z	mass/atomic number
OD	outside diameter
ORNL	Oak Ridge National Laboratory
PMB	plastic media blasting
RCRA	Resource Conservation and Recovery Act
RRAD	Red River Army Depot
TCLP	Toxicity Characteristic Leaching Procedure
TD	thermal desorption
TG	thermogravimetric (analysis)
TST	triple sorbent trap
USACERL	U.S. Army Construction Engineering Research Laboratories
USAEC	U.S. Army Environmental Center
VOC	volatile organic compound

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NAVAL FACILITIES ENGINEERING SERVICE CENTER
Port Hueneme, California 93043-4370

Technical Memorandum
TM-2178-ENV

RECYCLING AND REUSE OPTIONS FOR SPENT ABRASIVE BLASTING MEDIA AND SIMILAR WASTES

by

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13. ABSTRACT *(Maximum 200 words)*

This handbook is designed to help Navy personnel with waste minimization and pollution prevention efforts by assisting them to identify and apply recycling and resuse options for mineral-based spent abrasive blasting media (ABM) and similar waste materials. The handbook is intended as a technology transfer document to increase the awareness of recycling and reuse options for spent ABM and similar wastes. The following types of information will be included in the handbook: (1) defining the contaminant and matrix characteristics for ABM and similar wastes, (2) outlining specific technologies for recycling and reusing these wastes, and (3) describing how to identify and evaluate options for recycling and reusing these wastes.

Recycling spent ABM has the potential to significantly reduce waste generation while saving money. The reported production rate of spent ABM from eight U.S. Navy shipyards is in the range of 75,000 to 100,000 tons (68,000 to 90,800 metric tons) per year (Bryan et al., 1990). Promising waste minimization alternatives are available for managing ABM.

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ACRONYMS AND ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ABM	abrasive blasting media
ARRA	Asphalt Recycling and Reclaiming Association
ASTM	American Society for Testing and Materials
BDAT	Best Demonstrated Available Technology
BDL	below detection limit
Caltrans	California Department of Transportation
C&D	construction and demolition
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	*Code of Federal Regulations*
DNR	Department of Natural Resources
DTSC	(California) Department of Toxic Substances Control
EAF	electric arc furnace
EPA	Environmental Protection Agency
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FOB	free on board
FR	*Federal Register*
IGT	Institute of Gas Technology
MTPY	metric tons per year
NFESC	Naval Facilities Engineering Service Center
OAR	Oregon Administrative Rules
OMB	Office of Management and Budget
PCB	polychlorinated biphenyl
ppm	parts per million
R&D	research and development
RCRA	Resource Conservation and Recovery Act
SIC	Standard Industrial Classification
SITE	Superfund Innovative Technology Evaluation
SSPC	Steel Structures Painting Council
STLC	(California) Soluble Threshold Limit Concentration
TCLP	Toxicity Characteristic Leaching Procedure
TIM	(Washington Department of Ecology) Technical Information Memorandum
UCD	use constituting disposal

VISITT	Vendor Information System for Innovative Treatment Technologies
WAC	Washington Administrative Code
WET	(California) Waste Extraction Test

RECYCLING AND REUSE OPTIONS
FOR SPENT ABRASIVE BLASTING MEDIA
AND SIMILAR WASTES

1.0 INTRODUCTION

This handbook is designed to help Navy personnel with waste minimization and pollution prevention efforts by assisting them to identify and apply recycling and reuse options for mineral-based spent abrasive blasting media (ABM) and similar waste materials. The handbook is intended as a technology transfer document to increase the awareness of recycling and reuse options for spent ABM and similar wastes. The following types of information will be included in the handbook:

- defining the contaminant and matrix characteristics for ABM and similar wastes
- outlining specific technologies for recycling and reusing these wastes
- describing how to identify and evaluate options for recycling and reusing these wastes.

The handbook does not address steel shot, glass beads, plastic beads, sodium bicarbonate, or wheat starch ABM.

Recycling spent ABM has the potential to significantly reduce waste generation while saving money. The reported production rate of spent ABM from eight U.S. Navy shipyards is in the range of 75,000 to 100,000 tons (68,000 to 90,800 metric tons) per year (Bryan et al., 1990). Promising waste minimization alternatives are available for managing ABM.

Specific processes and vendors are mentioned in many sections of this technology transfer report. Mention of a process or a vendor does not constitute a recommendation or endorsement. All descriptions and data are taken from literature data. None of the reported results are based on data collected by or first-hand knowledge of the authors.

2.0 WASTE CHARACTERISTICS

This section describes the physical properties and chemical composition of slag and mineral ABM and the contaminant content of spent ABM and similar wastes.

2.1 Characteristics of Abrasive Blasting Media

This section describes the types of ABM used to remove paint from ships, bridges, and similar large structures documents the physical and chemical characteristics of the ABM.

2.1.1 Types of Abrasive Blasting Media used at Shipyards

Many types of ABM are used to remove paint, coatings, and/or corrosion from industrial structures. Any ABM used at a U.S. Navy shipyard or at a private shipyard working on U.S. Navy vessels must meet Mil-A-22262b(SH) specifications. The qualified ABM are listed in Appendix A. Processed coal and metallurgical slags are popular sources for ABM, but natural mineral materials may also be used. Slag blasting media are typically used once in a blasting operation and then discarded, although tougher materials such as garnet can be cleaned and reused.

One widely used type of ABM is made as a byproduct of coal combustion. The ABM is a fused ferro-alumino-silicate formed when molten slag from a coal combustion boiler is quenched in water. The water quench cools the slag quickly, resulting in an amorphous, noncrystalline particulate. Thermal shock from the rapid cooling fractures the slag into rough, angular particles. ABM can be produced from the slag particles simply by segregating different particle-size grades using screens (Austin, 1995). Higher quality ABM can be made by performing an initial crushing and screening followed by magnetic separation to remove metal particles. The upgraded slag particulate is then screened to separate size grades. The 11 companies that supply ABM made from coal slag had total volume and sales in 1992 of 442,000 tons (401,000 metric tons) and $19,500,000, respectively. Reed Minerals, the largest volume producer supplying about 62% of the sales, makes a product called Black Beauty™ (the use of trade names in this report does not necessarily constitute endorsement for use). Due to the dominance of the Black Beauty™ in the coal slag ABM market, many users incorrectly use the trade name as a generic term for coal slag ABM. Similar materials made by the other companies are marketed under other trade names such as Stan-Blast™ made by Stan-Blast Abrasives (17% of sales) and Black Diamond™ made by Foster Dixianan (10% of sales) (Paumanok, 1992).

ABM is also made from slag produced by pyrometallurgical processing to recover copper or nickel. The metallurgical slags are quenched to produce glassy fragments and then screened in the same manner as the coal slag. As with the coal slag, magnetic separation may be used to remove metal particles.

Copper slag is a mixture of ferrosilicate, ferro-alumino silicate, calcium silicate, magnesium silicate, and silica with trace amounts of antimony, arsenic, copper, and lead. Seven companies supply ABM made from copper slag with total volume and sales in 1992 of 187,000 tons (170,000 metric tons) and $10,300,000, respectively. The largest suppliers are Kleen-Blast Abrasives (37% of sales volume), Minerals Research and Recovery (29% of sales volume), RDM Multi-Enterprises (21% of sales volume), and MDC Industries (7.5% of sales volume) (Paumanok, 1992). The copper slag materials are marketed under trade names such as Sharp Shot™, Apache Black Hawk™, and Copper Blast™. The copper slag ABM product trade-named Kleen Blast™ is imported from Canada.

Nickel slag is a mixture of magnesium ferro-silicate and silica with trace amounts of other metals (Austin, 1995). There are two suppliers of nickel slag ABM in the United States market. Green Diamond Abrasives produces Green Diamond™ nickel slag using slag from a smelter near Riddle, Oregon, with total volume and sales in 1992 of 45,000 tons (40,800 metric tons) and $3,200,000, respectively. Kayway Industries imports about 5,000 tons/yr (4,540 metric tons/yr) of nickel slag ABM from Canada for sale in the United States (Paumanok, 1992).

Physical and chemical characteristics influence the recyclability of slag ABM. The regulatory status is the single most important factor because waste management practices controlled by the Resource Conservation and Recovery Act (RCRA) or state hazardous waste regulations reduce the flexibility in selecting and implementing recycling options. Physical properties such as particle size and shape and chemical properties such as total composition also affect the acceptance of spent ABM in commercial applications.

ABM produced from slag may contain elevated background levels of regulated metals. ABM from coal slag will typically contain nickel and vanadium and a variety of other metals depending on the coal that was used as the source of the slag. Copper slag from primary smelters contains elevated copper and barium levels and lower but significant levels of cobalt, trivalent chromium, and nickel. Copper slag from secondary smelters may contain significant levels of lead and arsenic. Nickel slag typically contains elevated concentrations of nickel, copper, and trivalent chromium and lower levels of cobalt and vanadium. Arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver are used to determine leachable metal toxicity by the U.S. Environmental Protection Agency (U.S. EPA) under RCRA. Some states, for example California, consider additional metals and total content as well as leachability in their definition of hazardous waste. It is unlikely but possible that unused ABM will be classified as a hazardous material by virtue of its background soluble or total metal content. A high background metals content in the virgin ABM means that the addition of a relatively small amount of metals-containing dust during blasting may cause the spent ABM to be classified as hazardous.

Most ABM are produced in at least three different particle size grades. In general, the coarser grades are more compatible with recycling as aggregate for portland cement concrete or asphaltic concrete because they mix better. Rounded particles are more suitable for use in portland cement, whereas sharp, angular particles are better for use in asphaltic concrete.

The chemical composition can affect the performance of spent ABM. The dark colors of slag ABM may limit acceptance in products with an appearance function where the slag materials replace lighter colored natural minerals. High chloride concentrations are undesirable in many applications. Sulfate concentrations or high alkali reactivity would make the ABM unsuitable for use as aggregate in portland cement.

Natural minerals such as silica sand, garnet, or staurolite are also used for ABM. Silica sand ABM is typically composed of mostly quartz with some garnet and feldspar and traces of lithic fragments such as hornblende. The fine silica particles produced by blasting with sand create a significant health concern, so use of sand as ABM is declining. Garnet is a general name for a family of complex silicate minerals having similar physical properties and crystal form. The general formula for garnet is $A_3B_2(SiO_4)_3$, where A can be calcium, magnesium, ferrous iron, or manganese and B can be aluminum, ferric iron, chromium, or (in rare cases) titanium. The most common garnet minerals for use as ABM are $Mg_3Al_2(SiO_4)_3$ (pyrope), $Fe_3Al_2(SiO_4)_3$ (almandite), and $Ca_3Fe_2(SiO_4)_3$ (andradite). Almandite and almandite-pyrope solid solutions make the best abrasive grains. Andradite is softer and breaks down more easily. Staurolite is $(Fe^{2+},Mg,Zn)_2Al_9(Si,Al)_4O_{23}(OH)_2$.

Mineral ABM may be naturally occurring sand or may be manufactured by crushing and size-grading using screens. Sand for abrasive blasting is produced by 48 companies operating 84 mines (Austin, 1995). Silica sand does not meet the requirements of the MIL-A-22262b(SH) specification due to the high free silica content. Ten firms produce garnet ABM with a total volume and sales in 1992 of 25,000 tons (22,700 metric tons) and $7,800,000, respectively (Paumanok, 1992). DuPont, marketing Starblast™, is the only supplier of staurolite ABM. Unofficial sources estimate the 1992 volume and sales for Starblast™ at 55,000 tons (50,000 metric tons) and $7,700,000, respectively (Paumanok, 1992). Similar to slag ABM, mineral ABM is available in different particle sizes, with the coarse grades more amenable to recycling into asphalt. However, unlike slag ABM, abrasives made from natural minerals contain low background metals concentrations. The matrix of mineral ABM is unlikely to contribute to total or leachable hazardous metals which can make recycling easier.

2.1.2 Physical Characteristics of Abrasive Blasting Media

As discussed above, the physical properties of ABM influence the selection of recycling options. Some key properties of unused slag and mineral ABM are shown in Table 2-1.

Table 2-1. Physical Properties of Unused Abrasive Blasting Media

Parameter	Coal Slag ABM Properties	Copper or Nickel Slag ABM Properties	Silica Sand ABM Properties	Garnet ABM Properties
Physical form	Angular, amorphous grains	Angular, amorphous grains	Rounded irregular, crystalline grains	Subangular, crystalline grains
Mesh sizes available (U.S. screen size)	10 to 100	8 to 80	6 to 270	8 to 300
CAS[(a)] number	68476-96-0	No data	No data	1302-62-1
Melting point (°F)	>2,000	2,400	No data	>2,280
Hardness (Mohs scale)	6 to 7.5	7 to 7.5	5 to 6	6.5 to 9
Bulk density lb/ft^3	75 to 100	84 to 95	100	130 to 147
Specific gravity	2.8	2.8 to 3.6	2.6	3.2 to 4.3
Water solubility	Negligible	Negligible	Negligible	Negligible
Color	Black	Black	White to tan	Wide variation, generally red to brown

(a) CAS is Chemical Abstracts Service.
Source: Compiled from Austin, 1995; Williams, 1991; and manufacturers' literature.

ABM is available in grades, based on particle size, ranging from extra coarse to very fine. The size grading available varies with the grit maker but some example particle size ranges for grades of expendable ABM are indicated in Table 2-2. The correspondence of screen size to screen opening is shown in Table 2-3 along with the Unified Soil Classification size ranges for sand, silt, and clay to provide a basis for comparing the size of ABM with typical soil materials.

Table 2-2. Example Screen Size Ranges for Abrasive Blasting Media[a]

U.S. Screen Size	Coarse (4.0 to 5.5 mil)[b]	Medium (3.0 to 4.0 mil)[b]	Fine (2.0 to 3.5 mil)[b]
6	0	0	0
8	5	0	0
12	25	3	0
16	33	37	0.4
20	17	28	11
30	12	19	43
40	6	9.2	34
50	1.5	3.1	8.5
pan	0.5	0.7	2.9

(a) Percent of sample retained on screen.
(b) Anchor pattern given by grade of grit.

2.1.3 Chemical Characteristics of Abrasive Blasting Media

This section summarizes some recent data about the total composition and leachable metals content of unused and spent ABM. As discussed in Section 2.1.1, slag media may contain elevated levels of regulated metals. Pigments in paint chips removed by ABM increase the leachable metal content of spent ABM. Some common pigments containing RCRA hazardous metals include red lead, white lead, chromium yellow, chromium orange, molybdate orange, zinc yellow, chromium green, and chromium oxide green (U.S. EPA, 1990b, EPA/530-SW-90-059Y). Spent ABM in shipyards can contain paint chips with copper- or tributyltin-based antifouling paints or lead-based primers.

2.1.3.1 Chemical Characteristics of Unused Media. The approximate chemical composition of some example slag and mineral ABM materials in unused condition is shown in Table 2-4. Most coal slag ABM contains only small quantities of RCRA-regulated metals, and the vitrified form provides a leach-resistant matrix, so hazardous metal leachability should be low. For example, all Toxicity Characteristic Leaching Procedure (TCLP) leachable metal concentrations from Black Beauty™ ABM, as shown in Table 2-5, are far below the regulatory level for a toxic leachable characteristic. Metallurgical slag typically will have higher residual metal content but is still unlikely to have a RCRA leachable toxicity characteristic in the unused condition. The natural mineral ABM materials should have low trace metal content (see Table 2-5). The Mil Spec for ABM requires that unused material pass both the RCRA and the California leaching tests.

2.1.3.2 Chemical Characteristics of Media Used on Ships. Mare Island Naval Shipyard in Vallejo, California generated about 2,000 tons (1,800 metric tons) per year of spent ABM from sand-blasting submarines. Mare Island used ABM derived from a slag copper smelting that is sold under the trade name of Kleen Blast™. The average bulk elemental composition of Kleen Blast™ is as follows:

Iron oxide as Fe_2O_3	23%
Silica as SiO_2	45%
Alumina as Al_2O_3	7%
Calcium as CaO	19%
Sodium as Na_2O	<0.2%
Potassium as K_2O	<0.1%
Magnesium as MgO	6%

Table 2-3. Correspondence of Screen Size Number to Opening Size

U.S. Screen Size	Opening Size (mm)	Opening Size (inches)	Unified Soil Classification
4	4.75	0.187	Coarse sand
6	3.35	0.132	
8	2.36	0.0937	
10	2.00	0.0787	
12	1.7	0.0661	Medium sand
14	1.4	0.0555	
16	1.18	0.0469	
18	1.00	0.0394	
20	0.850	0.0331	
30	0.600	0.0234	
40	0.425	0.0165	
50	0.300	0.0117	
60	0.250	0.0098	
70	0.212	0.0083	Fine sand
80	0.180	0.0070	
100	0.150	0.0059	
120	0.125	0.0049	
140	0.106	0.0041	
200	0.075	0.0029	
230	0.063	0.0025	Clay or silt[(a)]
270	0.053	0.0021	
325	0.045	0.0017	

(a) Clay is soil passing a 0.003-in (0.075-mm) screen that is plastic (putty-like) and has strength after drying in the air, and silt is soil passing a 0.003-in (0.075-mm) screen that shows little or no plasticity and has no strength when dried in the air.

Source: ASTM, 1995, Specification E 11 and Standard D 2487.

The total copper content of Kleen Blast™ is about 0.2%. Copper or tributyltin from antifouling paints and lead and other metals from paint pigments may increase the metal loading in the ABM during sandblasting. The types and concentrations of metals depend on the types of paints and coatings being removed. Typical metals concentrations in the spent ABM at Mare Island are shown below:

	mg/kg		mg/kg
Copper (Cu)	3,120	Cobalt (Co)	70
Barium (Ba)	1,080	Nickel (Ni)	62
Zinc (Zn)	197	Lead (Pb)	33
Vanadium (V)	118	Arsenic (As)	25
Chromium (Cr)	90		

Table 2-4. Chemical Composition of Unused Abrasive Blasting Media

Component	Coal Slag ABM Comp. (weight %)	Copper Slag ABM Comp. (weight %)	Silica Sand ABM Comp. (weight %)	Garnet ABM Comp. (weight %)
SiO_2	47.2	32 to 45	>99	36 to 37
Free SiO_2	<1	<1	>99	<1
Al_2O_3	21.4	3.0 to 7.0	0.15	20
FeO				30
Fe_2O_3	19.2	23 to 48	0.045	2 to 33
CaO	6.8	0 to 19	0.011	1 to 2
MgO	1.5	1.5 to 6.0	0.005	3 to 6
K_2O	1.6	<0.1 to 1.2		
TiO_2	1.0		0.013	2
Na_2O	0.6	<0.2		
MnO				1
As	<0.0001	0.01 to 0.04		<0.01
Co	0.00023	0.02 to 0.03		<0.01
Cr	0.00013	0.04 to 0.05		<0.01
Cu	0.00046	0.2 to 0.4		<0.01
Pb	0.00014	0.1 to 0.2		<0.01

Source: Compiled from Austin, 1995; Williams, 1991; and manufacturers' literature.

Table 2-5. Toxicity Characteristic Leaching Procedure Analysis Results for Unused Abrasives

Contaminant	Coal Slag Leachability(a) (mg/L)	Garnet Leachability (mg/L)	Regulatory Limit (mg/L)
Ag	BDL to 0.151	<0.05	5.0
As	BDL to 0.048	<0.1	5.0
Ba	BDL to 0.482	<0.1	100.0
Cd	BDL to 0.007	<0.02	1.0
Cr	BDL	<0.05	5.0
Hg	BDL to 0.041	<0.001	0.2
Pb	BDL to 0.605	<0.5	5.0
Se	BDL to 0.048	<0.1	1.0

(a) BDL = below detection limit.
Source: Reed Minerals, 1995.

2.1.3.3 Chemical Characteristics of Media Used on Bridges. The Commonwealth of Pennsylvania funded a study of beneficial reuse options for spent ABM used to remove lead-based paint from bridges (Weyand and Sutton, 1990). As part of the project, samples of spent coal slag and spent copper slag ABM were analyzed to determine the total composition and TCLP leachability. The total composition is shown in Tables 2-6 and 2-7 for coal and copper slag, respectively. The TCLP results are shown in Tables 2-8 and 2-9 for coal and copper slag, respectively.

Two of the copper slag samples had low TCLP leachable lead (see samples 7 and 9 in Table 2-9). The authors note that all three copper slag samples contain a higher concentration of elemental iron and ferrous iron than the coal slag samples. Elemental iron reduces lead leachability, leading the authors to propose iron stabilization as a possible mechanism. They also note that samples 7 and 9 required significantly more acid addition to maintain a final pH of 4.8. The greater acid requirement indicates more reserve alkalinity which may have reduced lead leachability in the TCLP test.

Table 2-6. Total Chemical Composition for Spent Coal Slag Media

Element	Total Composition of Slag Sample (wt %)					
	1	2	3	5	6	8
Pb	0.15	0.26	0.47	0.20	0.28	0.50
Cu	0.00	0.00	0.00	0.04	0.07	0.01
Zn	0.02	0.03	0.04	0.27	0.42	0.16
Ti	0.59	0.59	0.60	0.62	0.60	0.71
Al	10.8	10.7	10.8	11.4	11.6	11.2
Si	22.5	21.7	22.2	21.6	21.8	20.2
Ca	2.86	2.79	2.93	2.86	2.79	1.22
Fe	16.6	18.4	16.5	15.5	15.0	20.1
Ni[(a)]	0.12	0.06	0.10	0.09	0.12	0.07
Ba[(a)]	0.09	0.09	0.09	0.22	0.22	0.22
Sr[(a)]	0.07	0.07	0.09	0.13	0.15	0.06
Cr[(a)]	0.10	0.07	0.12	0.06	0.07	0.08

(a) Estimated by x-ray fluorescence methods.

Table 2-7. Total Chemical Composition for Spent Copper Slag Media

Element	Total Composition of Slag Sample (wt %)		
	4	7	9
Pb	0.84	0.52	0.92
Cu	0.94	0.69	0.56
Zn	3.75	3.25	3.15
Ti	0.36	0.37	0.40
Al	6.0	7.4	7.1
Si	14.1	15.5	16.1
Ca	6.58	5.36	4.43
Fe	23.6	23.1	23.4
Ni[(a)]	0.20	0.15	0.15
Ba[(a)]	0.19	0.13	0.17
Sr[(a)]	0.03	0.05	No data
Cr[(a)]	0.29	0.21	0.21

(a) Estimated by x-ray fluorescence methods.

Table 2-8. TCLP Results for Spent Coal Slag Media

Element	TCLP Result for Slag Sample (mg/L)					
	1	2	3	5	6	8
Pb	6.9	22.0	25.0	25.0	13.0	23.0
Ag	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
As	<0.003	<0.003	0.005	<0.003	<0.003	<0.003
Ba	0.50	0.60	0.30	0.40	0.40	0.60
Cd	0.022	<0.005	0.036	0.011	0.014	<0.005
Cr	0.41	0.25	0.33	0.02	0.02	0.10
Hg	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Se	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004

Table 2-9. TCLP Results for Spent Copper Slag Media

Element	TCLP Result for Slag Sample (mg/L)		
	4	7	9
Pb	25.0	0.73	1.5
Ag	<0.01	<0.01	<0.01
As	<0.003	<0.003	<0.003
Ba	1.4	1.70	2.10
Cd	0.026	0.016	<0.005
Cr	0.10	<0.01	0.01
Hg	<0.0002	<0.0002	<0.0002
Se	<0.004	<0.004	<0.004

2.2 Characteristics of Other Similar Wastes

As part of the project, other wastes generated at Navy facilities with characteristics similar to ABM will be identified. Data on characteristics of the wastes and where/how they are generated by the Navy will be provided.

Wastes similar to ABM will be defined as a hard, granular matrix with a high silica and/or alumina content contaminated mainly with inorganics. Examples of such materials include:

- metals-contaminated soils
- casting sands
- catalysts
- ashes and condensed fumes
- slags
- construction and demolition debris
- refractory bricks
- metallurgical furnace dust.

2.2.1 Metals-Contaminated Soils

A variety of activities can contaminate soils with metals. The backstop at a firing range collects lead (possibly containing arsenic as a hardening alloy) and copper. Metal waste discharges from activities such as plating and paint removal. Fugitive emissions or leachate from waste piles, landfills, or sludge deposits also can add undesirable metal constituents to soil.

Soils consist of weathered mineral grains and organic materials in varying proportions. Soils typically are heterogeneous and may be stratified due to historical variations during the soil formation process. Soil layers form as a result of interaction between the soil and groundwater, atmosphere, and vegetation. The properties of the upper layers are particularly affected by biological activity of plants and microorganisms. As a result, the surface soil properties are strongly influenced by soil chemistry, moisture content, and climatic conditions.

The wide variations in natural soil properties and contaminant levels encountered in site remediation cannot be overemphasized. Not only do soil and contaminant conditions vary from site to site, but wide ranges of conditions frequently occur within one site. The process or equipment selected to handle contaminated soils must be able to accept wide variations in soil conditions and contaminant levels.

Many systems are available for classifying soil type and constituents. Most of these classifications include particle size as the primary physical parameter. Typical classifications, in order of decreasing size, are:

- gravel
- sand
- silt
- clay

The organic content of soil can vary from less than 1% in dry, sandy soils to more than 20% in soils that are exposed to water much of the time. The chemistry of the organic portion of soils is complex. The soil organic content will consist of high-molecular-weight humic materials and lower-molecular-weight organic acids and bases. The high-molecular-weight humic materials have low water solubility and high affinity for metals. The humic and fulvic acid fraction account for most of the metal immobilization due to soil organic matter. These acids immobilize metals by complexation and chelation mainly due to acidic sites. The lower-molecular-weight organics tend to mobilize metals. These nonhumic materials form water-soluble complexes with metals resulting in more mobile species (Czupyrna et al., 1989).

Other characteristics that help identify soil type and behavior include structure, color, density, type, and amount of organic and inorganic colloidal materials. Typical engineering properties, such as density and Atterberg limits, will indicate the handling properties of the soil. The solubility of metals in soil is controlled by factors such as pH, Eh, the ion exchange capacity, and the complexing and chelating effects of organic matter. Measurement methods and the significance of each of these factors have been described in several documents (Bodek et al., 1988; Cameron, 1992; Sims et al., 1984).

2.2.2 Casting Sands

Foundries use sand to make molds and cores to contain and shape metal during casting. The sand grains are held together with additives called binders. Mold-making techniques may use sand mixed with a small amount of clay and water or more complex binder systems such as silicates or organic resins such as phenolic-urethane polymers.

2.2.3 Catalysts

Catalysts used for industrial processes typically are in the form of a ceramic support carrying a small quantity of metal catalyst such as a chromium, nickel, or platinum group metal. The supporting ceramic often is a sphere of controlled particle size consisting mainly of alumina (Al_2O_3) and silica (SiO_2). In use, the catalyst becomes fouled with reactants or reaction products (Pavel and Elvin, 1994). Catalyst activity often can be recouped by thermal regeneration, but some of the particles break during the regeneration process. Once the catalyst particles become too small to be useful, they can become a waste disposal problem.

2.2.4 Ashes and Condensed Fumes

Fly ash is fine particulate waste collected from off-gas leaving processes such as smelting or coal combustion. Fly ash particles form in a high-temperature gas stream. At the typical combustion or processing temperature of about 2,900°F (1,600°C), the ash material is a molten sphere. As the particles cool, they retain a generally spherical shape. The particulate is collected by baghouses, electrostatic precipitators, or similar off-gas cleaning equipment. The particulate is mainly glassy, spherical silicates and aluminates material with particle sizes in the range of 4E-5 to 6E-3 in (1 to 150 micrometers [im]) (Gera et al., 1991). The fine particulate may be removed from the off-gas cleaning equipment as either a dry powder or a water slurry and then be sent to a storage pile for subsequent disposal or recycling.

Fumes are very fine particulates produced during high-temperature metal processing. Volatile metals or metal oxides evaporate and recondense to form the fume. One common example is condensed silica fume, a fine particulate consisting of over 90% silica. Condensed silica fume is a byproduct of ferroalloy production. Metal impurities may impart a hazardous waste characteristic. The fume is an artificial pozzolan with a very high activity due to its small particle size and amorphous structure. Volatile metals such as cadmium and zinc also are prone to fume formation. The fine-particle fumes are difficult to transfer by conventional materials-handling techniques (Popovic et al., 1991).

2.2.5 Slags

Slag is a fused solid consisting mainly of inorganic oxides of silicon, iron, and calcium with metallic impurities. Slag is a typical waste product from pyrometallurgical metal processing. The slag composition depends on the feed material source and the process used. Slags generally contain silica (SiO_2) as the main constituent along with fluxing salts (e.g., calcium and magnesium) and metal impurities from the ore.

Density, porosity, and leach resistance are the main properties considered in evaluating slag as a contaminated matrix. These properties vary depending on the method of producing the slag. The form of slag produced depends on the conditions used for cooling. Testing has indicated that faster slag cooling is important for reducing the mobility of metals. The general categories of slag are air-cooled, expanded, and granulated.

2.2.6 Construction and Demolition (C&D) Debris

C&D debris is bulky waste resulting from land clearing, building new structures, and remodeling or tearing down old structures (von Stein, 1993). The approximate overall average content of debris from demolishing structures in the United States is 53.8% concrete, 21.2% brick, 22.0% wood, 2.7% iron and steel, and 0.22% glass. Small amounts of a wide range of substances, including copper, lead, aluminum, plastic, paper, gypsum board, and asbestos, make up the rest of the debris. Crushed C&D debris usually has a soil or rocklike appearance and consistency. Concrete in C&D debris may contain steel or iron reinforcing bars which can complicate processing the waste for reuse. Although C&D debris usually is not hazardous waste, the potential for hazardous or toxic contaminants should not be ignored. Possible sources of contaminants in C&D debris include:

- asbestos used for insulation or structural applications
- creosote, pentachlorophenol, or chromated copper arsenate preservatives in wood
- polychlorinated biphenyls (PCBs) in electrical components
- metals (particularly lead) in paint pigments.

2.2.7 Refractory Bricks

Refractory bricks are high-performance ceramic materials used to line high-temperature processing equipment. Refractory bricks are made from chromite or similar chromium oxide materials. The bricks deteriorate in use and are replaced periodically during furnace maintenance (Martin et al., 1987). Many refractory bricks contain percentage levels of chromium and can exhibit the D007 chromium toxicity hazard characteristic. The bricks also may become contaminated by process materials during use.

2.2.8 Metallurgical Furnace Dust

In production of steel in electric arc furnaces (EAFs), feed materials are charged into a refractory-lined furnace and melted by an electric current arcing between electrodes through the metal feed. EAFs accept a high proportion of scrap in the feed. The scrap steel is often galvanized, coated, or plated to improve its function. The most common surface treatments are zinc galvanizing, lead terne coating, and cadmium plating. Each of these plating metals tends partition to the vapor phase as a fume. The fume condenses and is then removed by a dry filtration or wet scrubbing operation. The EAF process removes many metal impurities from the scrap by volatilization. Because of the ability to remove impurities, the EAF processes almost 100% scrap (with a maximum of 30% galvanized scrap feed). The high level of scrap feed to the EAF causes elevated levels of zinc, cadmium, or lead in the fumes from the furnace. Due to the presence of these metals, emission control dust/sludges from EAFs are a RCRA-listed waste (K061).

The composition of the dust formed varies directly with the type of steel being produced and the constituents being volatilized from the furnace. Specifications for carbon steels are generally less restrictive than specifications for high-alloy steels. Carbon steel making can start with an initial charge of scrap containing higher loadings of plating and other impurities. Due to the higher scrap loading, the dust generated from the production carbon steels may contain more lead and other impurities than the dust from the production of specialty, stainless, and alloy steels. Dust from making higher alloy steels will contain more chromium and nickel. Typical concentration ranges for EAF dust from specialty-steel and low-ally producers are shown in Table 2-10.

Table 2-10. Typical Composition Ranges for EAF Emission Control Dust

Element	Metal Content Range for Specialty-Steel Producers (weight %)	Metal Content Range for Low-Alloy Producers (weight %)
Cadmium	0.04 to 0.08	0.01 to 0.07
Lead	0.54 to 1.36	0.21 to 45.28
Zinc	2.27 to 8.52	0.79 to 3.49
Nickel	1.83 to 3.60	0.13 to 0.24
Iron	22.96 to 25.81	4.07 to 43.09
Chromium	7.64 to 11.71	0.01 to 3.43

Source: Hanewald et al., 1992.

3.0 RECYCLING AND REUSE OPTIONS

This section describes the operating features and applications of recycling and reuse options for ABM and similar wastes. The recycling methods are arranged generally in the order of decreasing value of the product produced. Methods to recycle spent ABM are organized into the following groups:

- reconditioning and reuse of spent ABM
- processing to convert spent ABM into high- or medium-value ceramic products
- using spent ABM as a raw material in portland cement
- using spent ABM as aggregate in portland cement concrete
- using spent ABM as aggregate in asphaltic concrete
- using spent ABM as a basic construction material
- processing to convert spent ABM into low-value ceramic products
- using spent ABM as a flux-forming addition in a smelter.

3.1 Reconditioning and Reuse of Spent Abrasive

This section describes methods to process and reuse spent ABM. The spent ABM can be cleaned using physical separation to remove fines and/or hard metal or metal oxide particles and then reused.

3.1.1 Description of Recycling Option

Reclamation of ABM implies collecting the ABM after use and processing to remove undesirable components in the ABM. Reclamation of spent ABM applies simple unit operations, but there are challenges to successful implementation. Collecting and storing the spent media requires equipment and procedures not used in normal blast cleaning done outdoors on large structures such as ships. Once the spent ABM is collected, several processing steps are needed to return the material to its original quality to allow reuse.

Collection and handling of spent ABM can be conducted with minimal concern about adding extraneous contaminants when the spent ABM is to be discarded. Spent ABM collected for disposal usually contains a high proportion of soil and may contain general site trash including paper, cloth, or plastic scraps and small metal parts (e.g., bolts, screws, and brackets). Additional care must be taken to collect the spent ABM for reclamation.

A wide variety of undesirable components including debris from the work area, ABM fragments, and paint particles and contaminants removed from the hull are intermixed with the spent ABM. When the ABM impacts the surface being cleaned, some of the media fracture, producing fine particulates that must be removed during the reclamation process. A high proportion of fines will:

- reduce the effectiveness of coating removal
- increase dust generation when the grit is reused.

Small bits of steel and metal oxide are cut away from the ship hull during the blast cleaning process. If these hard particles are not removed by the reclamation process, they will strike the surface being cleaned creating high residual stress in small areas. These stressed spots can be points of initiation of fatigue fractures or increased corrosion.

Simple screening is unlikely to clean the spent ABM sufficiently to allow reuse. Because the contaminants in the ABM have a wide range of physical and chemical properties, successful reclamation processing requires more sophisticated methods. Screening to remove oversize debris is always the first step. This first simple cleanup is followed by various combinations of magnetic separation, water-assisted beneficiation, and thermal treatment to produce an acceptable reclaimed ABM product.

3.1.2 Advantages of Recycling Option

Reclaiming spent ABM for reuse provides reduction in resource consumption with minimum transportation and handling. Onsite recycling is the next level in the U.S. EPA's waste reduction hierarchy, when waste production cannot be prevented at the source.

3.1.3 Limitations of Recycling Option

Reclamation requires the use of a tough, fracture-resistant ABM which increases the unit cost, and purchasers often prefer to minimize even the initial cost. Sand, the cheapest media, is unsuitable for reclamation. Slag-based media cost more per ton but will survive a few cycles of reuse, and garnet media, which cost even more, can be reused for many cycles. The number of reuse cycles attained in practice will depend on many factors including the air pressure used to apply the ABM, the type of coating removed, and the worker's experience level.

A significant fraction of undesirable materials (e.g., ABM fragments, paint chips, and hard particles) must be removed from the spent ABM. These undesirable components will need to be managed as waste and may be listed as hazardous waste under RCRA.

The possible presence of hard particles in the reclaimed ABM increases the concern for creating high stress points in the ship hull when the ABM is reused.

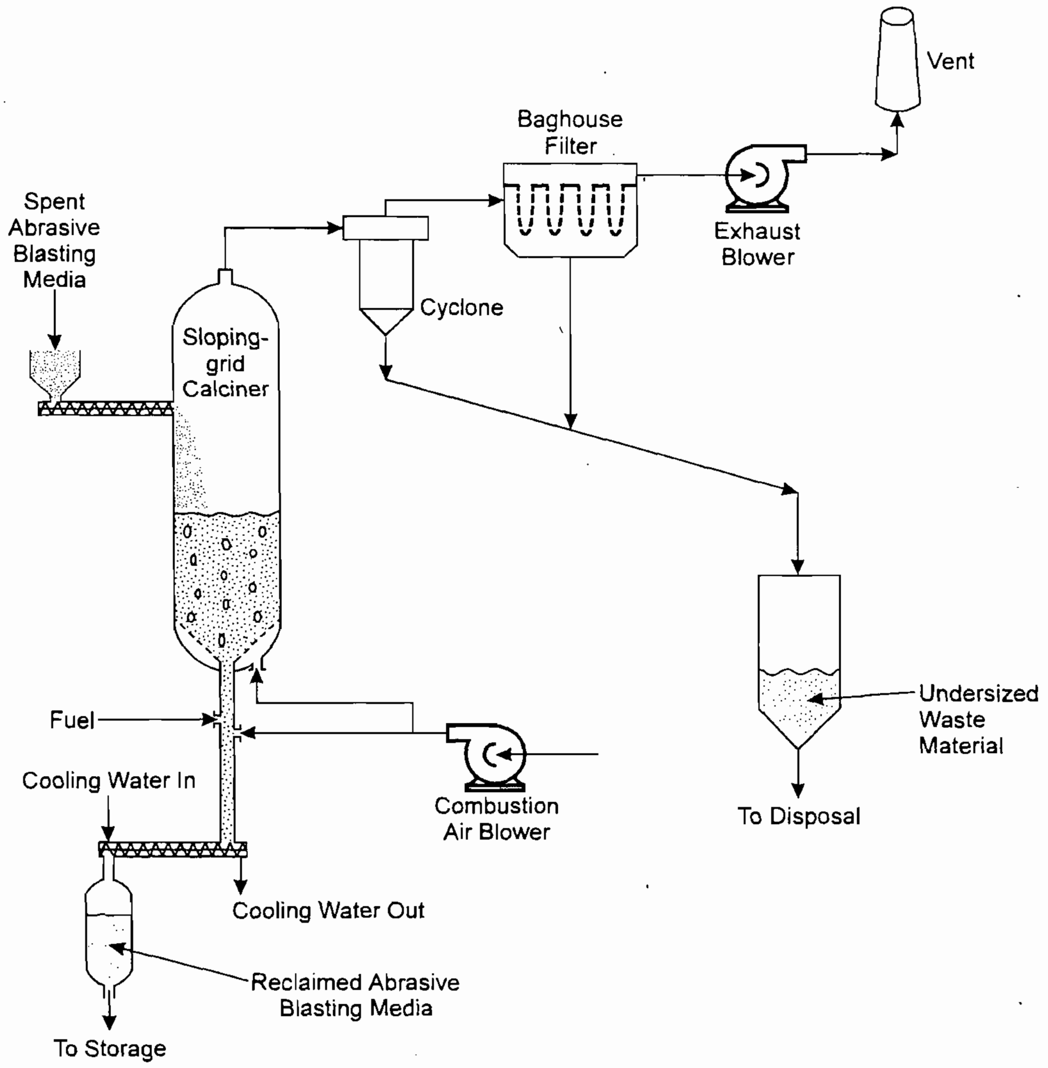
The possible presence of impurities in the reclaimed ABM increases the concern for high airborne contaminant levels in the work areas and for contaminating the ship hull when the ABM is reused.

3.1.4 Example Applications

3.1.4.1 Thermal Processing of Spent ABM. The U.S. Navy and the Institute of Gas Technology (IGT) have been developing and testing thermal processing to reclaim spent ABM. The technology is an extension of a fluidized-bed coal combustion system developed by IGT that has been applied to the reclamation of foundry sand. The fluidized-bed ABM treatment system is illustrated in Figure 3-1.

The spent ABM is conveyed from a storage pile to pass through a grizzly and a 0.5-in (12-mm) vibrating screen to remove oversized debris and then through a magnetic separator to remove ferromagnetic particles. After the initial cleaning, the spent ABM is fed by a screw conveyor into the top of the fluidized-bed calciner. A mixture of gas and air is introduced into a pipe in the bottom center of the bed. The air and natural gas burn directly in the bed to heat the spent ABM to 1,200°F to 1,600°F (650°C to 870°C) and to oxidize the organic portion of paint chips to CO_2, H_2O, and metal oxides.

The gas flow in the calciner provides mixing and size classification in addition to the heating action. The ABM bed is well agitated and heated by the burning gas to ensure good combustion of the paint chips and removal of the fine particulates. Metal oxides from the burned paint chips and undersized particles of broken ABM are entrained in the gas stream and lifted out of the calciner. The clean ABM flows down along the sloped grid and exits the bottom of the calciner past the incoming air and gas.



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Simplified Flow Diagram for Abrasive Blasting Media Reclamation

DESIGNED BY LS	PROJECT NAVY RECYCLING TECHNOLOGY TRANSFER	
DRAWN BY VS		
CHECKED BY LCG	PROJECT NUMBER G9861-3401	DATE 2/96

Source: Lau and Bryan, 1996

ABM1 CDR

Figure 3-1. Simplified Flow Diagram of Abrasive Blasting Media Reclamation

The clean ABM is moved from the bottom of the calciner through a water-cooled screw conveyor and placed into storage for reuse. The process can reclaim between 80% to 90% of the spent ABM.

The metal oxides and fine particles are removed from the off-gas for disposal. Off-gas from the calciner is cooled with a water spray and then passed through a cyclone separator and bag filter to collect particulates for disposal.

3.1.4.2 Physical Reclamation of Spent ABM. Pittsburgh Mineral and Environmental Technology owns and operates mobile units for recovery of spent abrasive contaminated with paint chips containing hazardous metal contaminants. The most common application is treatment of abrasive used to remove lead-based paints from bridges, overpasses, and other steel highway structures. The spent abrasive is a complex mixture of abrasives, paint chips, steel, and rust. The process is reported to separate the spent abrasive stream into three reusable fractions:

- paint chips
- coarse abrasive
- undersized abrasive.

The lead-bearing paint chips can be sent to a lead smelter for reprocessing, the coarse abrasive is reused, and the undersized fines are used as feed for other ceramic products such as bricks.

The abrasive processing unit is mobile and can be set up at the paint removal site to process material at the rate of about 2 to 5 tons (1.8 to 4.5 metric tons) per hour. Spent abrasive is screened to remove coarse materials such as debris and larger paint chips. Magnetic separation then removes the steel particulates and other ferromagnetic materials. The nonmagnetic portion is fed onto a gravity separation table to separate the fine particulate from the coarse abrasive based on the apparent density of the particles (as determined by their respective gravity, shape, texture, and size). The coarse fraction can be reused as abrasive. The fine fraction is further treated by electrostatic separation based on differences in surface conductivity to separate the paint chips from the fine abrasive particles. The paint chips can be fed to a metal smelter, and the fine abrasives can be fed to a brick-making process. The process is reported to be accepted by the U.S. EPA Region III and the Pennsylvania Department of Environmental Resources as a recycling process for abrasive contaminated with lead-bearing paint chips (Gilbert and Weyand, 1990).

3.1.4.3 Soil Washing to Clean Spent ABM. Westinghouse Electric Corporation has developed a cleaning system for spent sandblasting abrasive used to remove lead-containing paint. The technology is based on Westinghouse research in soil washing. The system is reported to operate at a throughput of 20 tons (18 metric tons) per hour. Abrasive is cleaned with water-based leachates, which are continuously recycled in the soil washing system. The end products are cleaned abrasive, which is reported to be suitable for reuse, and the leach solution, which can be treated by chemical precipitation or membrane separation.

3.2 Use Spent Abrasive as a Raw Material in Ceramic Manufacture

This section describes ways to use spent ABM and similar wastes as a raw material in making medium- or high-value ceramic products. Ceramic products made from ABM or similar wastes will be competing with products in the Standard Industrial Classification (SIC) group 32 (OMB, 1987). Economic characteristics indicating the size of the market for products in SIC group 32 are summarized in Table 3-1.

Table 3-1. Summary of Ceramic Product Market Characteristics

Industry/SIC	1987		1992
	Number of Establishments in SIC	Total Value of Shipments ($ million)	Total Value of Shipments and Inventory ($ million)
Stone, clay, and glass products/32	16,166	61,477	62,479
Flat glass/321	81	2,549	2,082
Glassware /322	522	8,339	9,055
Processed glass products/323	1,432	5,429	6,955
Cement/324	215	4,335	4,035
Structural clay products/325	598	2,915	2,864
Pottery/326	1,006	2,416	2,752
Concrete, gypsum, and plaster products/327	9,814	24,427	23,053
Cut stone and stone products/328	745	841	1,007
Misc. nonmetal mineral products/329	1,753	10,226	10,677

Source: U.S. Department of Commerce (1995, Table 1246).

The SIC group 32 has not been a strong growth or profit area for several years. The total value of shipments increased only 1.6% between 1987 and 1992. Most or all of this increase can be accounted for by inflation. Profit for each dollar of sales in 1990 was 1.8 cents. The industry showed a loss of 0.7 cent per dollar of sales in 1992 but rebounded to show a profit of 3.4 cents per dollar of sales in 1993. For comparison, the average profit for all manufacturing concerns was 5.4 cents per dollar of sales in 1993 (U.S. Department of Commerce, 1995, Table 890).

3.2.1 Description of Recycling Option

Spent ABM and similar wastestreams consisting predominantly of silica and/or alumina with low levels of metal contaminants can be processed thermally to form glass or ceramic products or be used as raw materials in ceramic manufacture. The glass or ceramic matrix can effectively immobilize many metal impurities. The metal contaminants may even impart desirable properties such as coloration or increased hardness to the product.

Formation of ceramic products may be accomplished by either sintering or melting. In both processes, prepared waste material is heated to form the ceramic. Most thermal treatment processes require feed material to be within a narrow particle size range. Size reduction and/or pelletization are usually needed to obtain the required size.

In sintering, the waste is prepared by mixing with clay or other silicates and possibly water and additives. The mixture is pressed or extruded to form bricks, pellets, or other shapes. The formed products are treated at high temperature but below the bulk melting temperature where particles join or sinter to form a solid ceramic piece.

Vitrification processes also require feed preparation. The chemical additions and mixing may be used to promote oxidation-reduction reactions to improve the properties and stability of the final product. Silica sources such as sand or clay may also be needed. Vitrification processes operate by heating the pretreated waste to melting temperatures. The molten treated waste flow exits from the melter into a waste-forming or quenching step. The melt can be formed in a metal- or sand-coated mold to form a monolithic product or quenched in a water bath to produce a frit. Vitrification to form low-value aggregates, as described in Section 3.7, uses the same basic approach but typically starts with wastes that contain complex mixtures of contaminants.

Gases released from the thermal treatment unit are processed through an emission control system. Particulates may form due to carryover, metal fuming, or anion fuming. The particulates are removed by knockout boxes, scrubbers, and/or venturi separators. Particulates are separated from the scrubbing fluid by filtration and are returned to the treatment system. Acid gases, such as sulfur dioxide from sulfates, are removed by scrubbing with sodium hydroxide.

A wide range of high- to medium-value products could be made from ABM or similar silicate or aluminate wastes. Possible products include:

- ceramic tile
- finished and rough dimension stone
- brick and structural clay items
- frit.

Ceramic tiles are thin ceramic squares or rectangles, usually with a decorative finish on one surface used for appearance in architectural applications.

Dimension stones are block, panel, or curvilinear shapes used for appearance and/or structural functions. The stone shape can range in size from the base of a pen and pencil set to large building stone.

Brick and tile shapes are made from fired clay and used for load bearing or other applications (e.g., non-load-bearing fire walls, sound absorption walls, or drainage tiles). These ceramic items generally are simple rectangular or cylindrical shapes with moderate surface finish and size tolerance requirements.

Frit is a raw material for ceramic manufacturing. A waste can be vitrified to destroy organic impurities and improve its physical properties and then further processed in an existing manufacturing plant to form products such as refractory fibers or abrasives.

3.2.2 Advantages of Recycling Option

Thermal treatment to produce useful products from wastes has the potential to reduce negative effects on human health and the environment over the product's life-cycle and to reduce the costs for management of wastes (Carter and Tsangaris, 1995). The main purpose for using the vitrification process is to convert a material that would have been a waste into a value-added product. Using waste material to replace raw materials in product manufacture decreases demand on resources and reduces the volume of waste discharged. In addition to value created by the product, costs for treatment and disposal are avoided. The end user of the resulting ceramic product may be closer or more distant, so transportation may have a positive or negative effect on the economics of waste vitrification depending on the location of the vitrification plant and the user.

The high-temperature vitrification or sintering process causes significant changes in the physical or chemical form of the matrix and the contaminants. Organic constituents such as resin in paint chips are oxidized to their mineral components. Metal contaminants are incorporated into a durable, leach-resistant mineral matrix.

3.2.3 Limitations of Recycling Option

Contaminants in the waste product will change the hardness, toughness, color, or texture of ceramic products which may reduce product performance or acceptance. Only selected wastestreams can be converted into high-value ceramic products. To provide a high-value product such as decorative finished dimension stone or frit for making high-performance refractories, the initial wastestream must contain a limited number of contaminants. For example, hydroxide sludge from treatment of plating or etching baths containing a single metal contaminant is converted by vitrification on a commercial scale to high-value products (Hazardous Waste Consultant, 1990). Purely cosmetic features usually are not strong determinants of product acceptance for the structural products but may still reduce acceptance in some applications. For example, the dark or earth tones that occur in vitrified products containing a wide range of metals are undesirable in applications where the item needs to be visible, such as railings, parking lot stops, or road barriers.

The process is capital- and energy-intensive, but the product value and avoided disposal costs will contribute to the economic viability of the option.

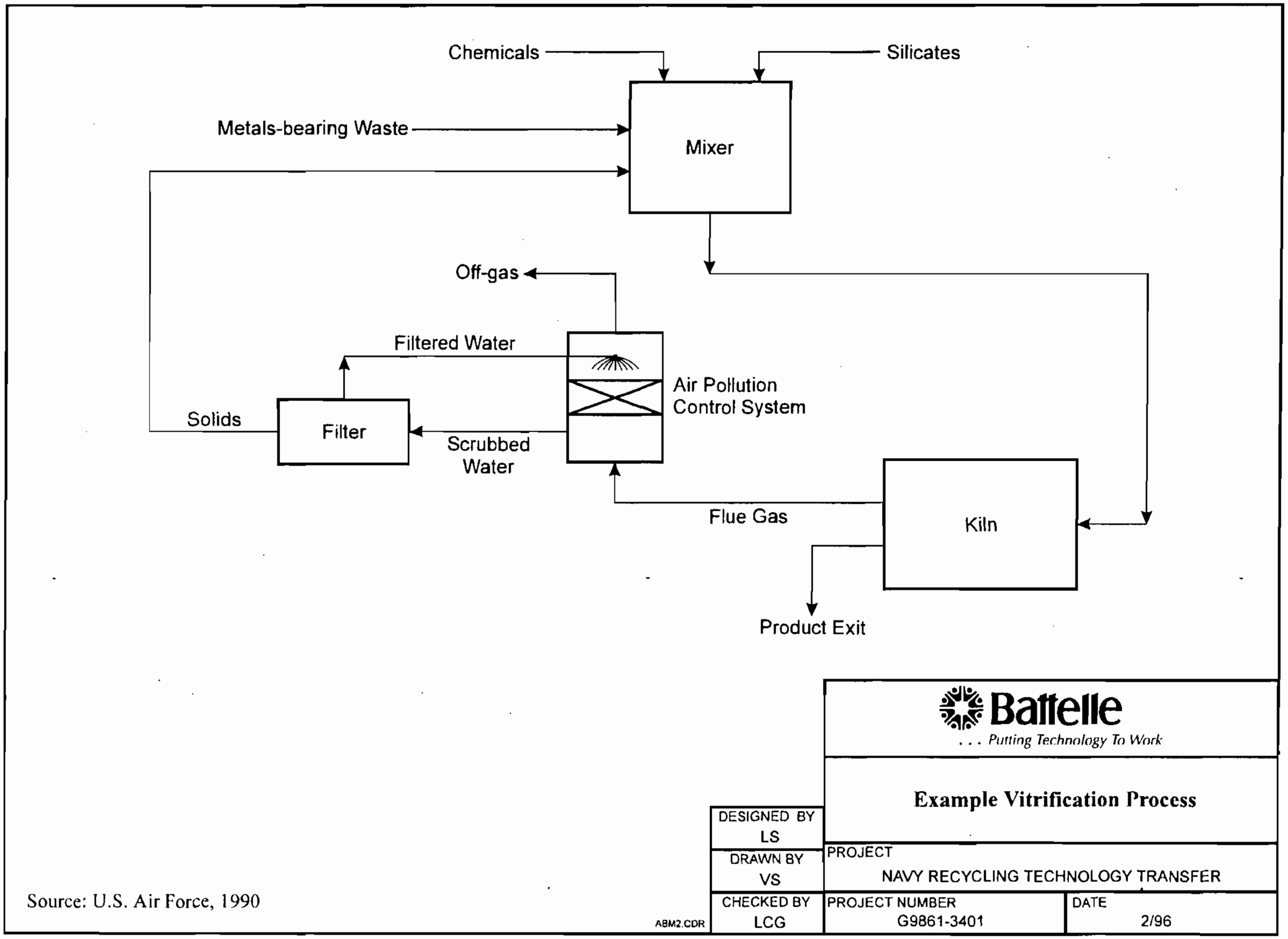
Volatile metals such as arsenic, mercury, or beryllium are difficult to treat and can be present only at low concentrations. Wastes containing arsenic will require some combination of pretreatment, special processing conditions, and/or off-gas treatment systems to minimize arsenic volatilization. If reducing conditions can occur in the melt, cadmium, lead, and zinc can vaporize and enter the off-gas stream (Hollander et al., 1995).

The product potentially would be used in close proximity to the general public and thus would be required to meet high standards of contaminant immobilization and performance.

3.2.4 Example Applications

3.2.4.1 Using Abrasive Blasting Media to Make Bricks. Spent ABM is an ideal candidate for beneficial reuse in the manufacture of structural fired clay products, e.g., bricks. The U.S. Navy, David Taylor Research Center in Annapolis, Maryland, has been studying this alternative for the past several years. The bricks are produced using spent ABM to meet the specifications for strength and absorption, while metals are incorporated into a chemically stable, complex silicate phase during brick firing. Data collected thus far indicate that metal leachability in the final clay product increases with decreasing particle size of the spent ABM (Thomas, 1992).

Pittsburgh Mineral and Environmental Technology performed a study of beneficial reuse of ABM from bridges for the Pennsylvania Department of Transportation. The study concluded that using spent ABM to replace sand in brick making was the most promising option. Test bricks were made with 10%, 20%, and 40% of the normal brick mix. Unprocessed ABM gave poor results. However, when the ABM



Source: U.S. Air Force, 1990

Figure 3-2. Example Vitrification Process.

All incoming generator materials are processed on a batch basis. Prior to entering the reactor, each batch of waste is tested to determine requirements for raw materials addition. The waste is typically a sludge to which water and chemicals are added. The chemical additions and mixing promote a series of oxidation-reduction reactions to improve the properties and stability of the final product. Following the reaction phase, silica sources such as sand or clay are added. The mixed materials are transferred to a surge tank to provide continuous feeding to the vitrification operation.

Vitrification operates continuously with blended/reacted feed entering the vitrifier where it is heated to form a molten mass. The material travels through the vitrification unit to an exit overflow. The operating temperature and residence time of the vitrification unit are determined by laboratory analysis. The molten treated waste flow exits from the melter into a waste-forming or quenching step. The melt can be formed in a sand-coated mold or quenched in a water bath depending on the type of product needed. The resulting ceramic material is packaged for shipment to end users.

Gases released from the vitrification unit are processed through an emission control system. Particulates may form due to carryover, metal fuming, or anion fuming. The particulates are removed by knockout boxes, scrubbers, and/or venturi separators. Particulates are separated from the scrubbing fluid by filtration and are returned to the treatment system. Acid gases, such as sulfur dioxide from sulfates, are removed by scrubbing with sodium hydroxide to form sodium metasulfite. The sodium metasulfite reportedly is collected and sold.

3.2.4.7 Using Fly Ash to Make Clay Products. Fly ash from a coal combustion, steam-generating plant was used in combination with clay, cement, or lime to make extruded bricks. The resulting bricks were tested for shrinkage, weight loss, tensile strength, compressive strength, and mineralogy. Addition of fly ash was reported to improve the quality of the bricks due to the grain size, shape, and the pozzolanic activity of the fly ash (Temini et al., 1991).

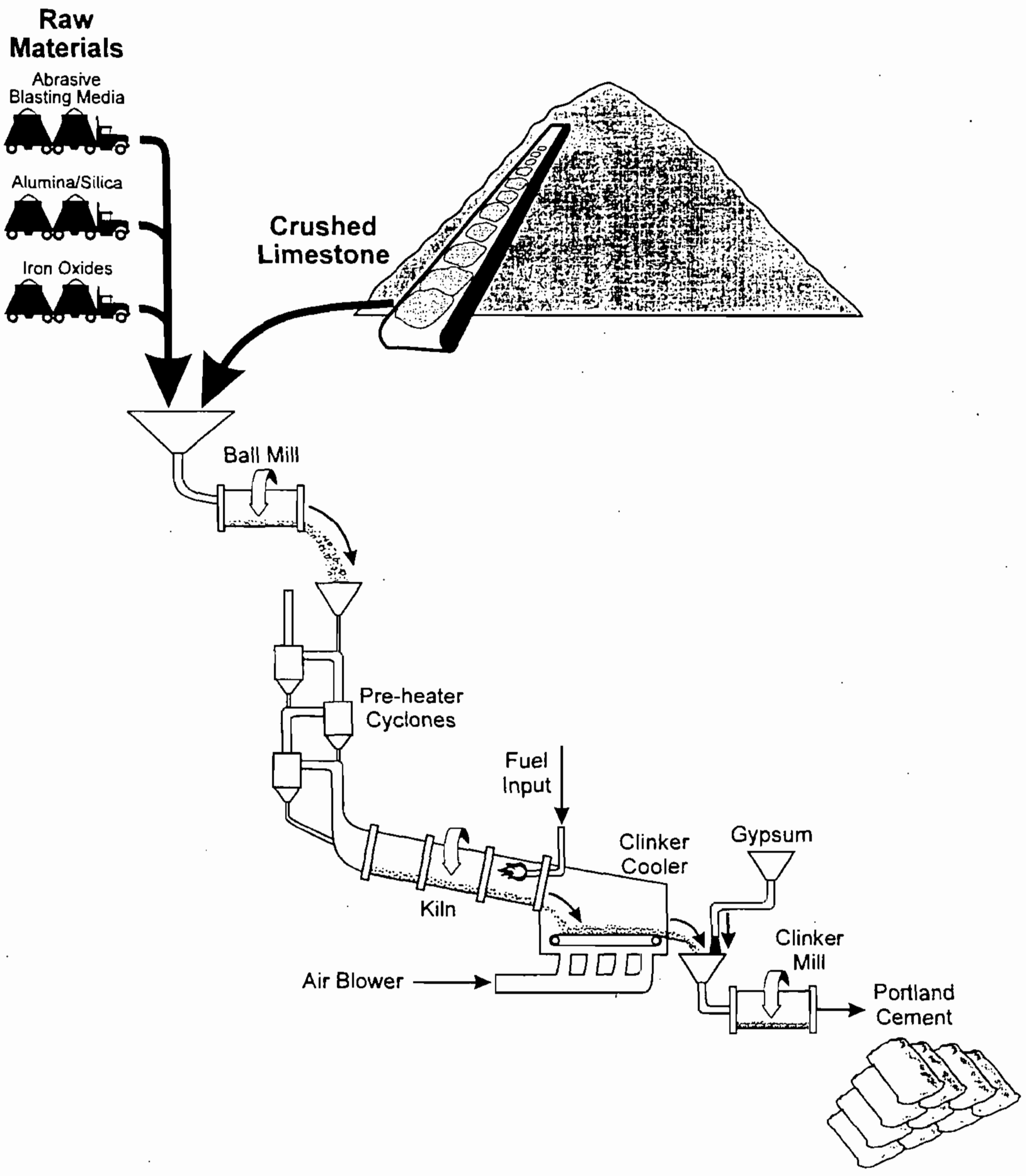
3.3 Use Spent Abrasive as a Raw Material in Portland Cement Manufacture

This section describes use of spent ABM and similar waste as a raw material in making portland cement. Cement is made from a mixture of limestone, sand, and clay prepared and burned to form clinker which is then ground. The expected U.S. production of portland and masonry cement in 1995 is 87,300,000 tons (79,300,000 metric tons). Portland cement makes up about 96% of the total U.S. cement output (Solomon, 1995a). Many sandlike waste materials can provide useful calcium, silica, alumina, or iron inputs for cement makers. Due to the large volume of cement produced, significant quantities of spent ABM can be consumed as replacements for cement raw materials and at the same time conserve resources. The European cement industry reports that use of secondary raw materials, such as granulated blast furnace slag and coal combustion fly ash, has reduced mineral and energy resource consumption (Lawton, 1992).

3.3.1 Description of Recycling Option

Manufacture of hydraulic cement offers possibilities for recycling of contaminated waste materials. Making cement requires a significant input of energy and raw materials. Petroleum-contaminated soils are used as input to cement kilns by a variety of companies. Petroleum-contaminated soils supply both heating value and a silica source (U.S. EPA, 1992, EPA/600/R-92/096). Opportunities also exist for using nonhazardous metals-contaminated solids to make cement, particularly when the waste has a high alumina or iron oxide content.

Portland cement is made by heating mixtures containing lime, silica, alumina, and iron oxide to form clinker which is then ground. About 3% to 5% of calcium sulfate, usually as gypsum or anhydrite,



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LCG

Abrasive Blasting Media in the Cement-Making Process

PROJECT
NAVY RECYCLING TECHNOLOGY TRANSFER

PROJECT NUMBER
G9861-3401

DATE
2/96

Source: Leonard et al., 1992

ABM4 CDR

Figure 3-3. Abrasive Blasting Media in the Cement-Making Process.

Table 3-2. Examples of Compositions of Portland Cement Types

Cement Type	C_3S (wt %)	C_2S (wt %)	C_3A (wt %)	C_4AF (wt %)
I and IA	49.6	24.0	11.0	8.0
II and IIA	40.9	34.4	5.6	12.9
III and IIIA	59.3	14.1	9.3	7.9
IV	25.3	51.5	4.9	11.6
V	41.0	39.0	3.7	10.0

Source: Bogue, 1955.

3.3.2 Advantages of Recycling Option

Cement kilns have the capacity to recycle large quantities of waste. The kilns are widely distributed throughout the country, so long shipping distances can be avoided in many cases. For example, there are 11 cement manufacturers currently operating 20 portland cement kilns in the state of California. In 1989 alone, these operations reported the cumulative production of more than 10,400,000 tons (9,400,000 metric tons) of cement clinker. Due to gaseous losses during the calcining reaction, about 13,500,000 tons (12,250,000 metric tons) of mineral feedstock was required to generate the cement. Therefore, if only one tenth of 1 percent of the required feedstock for each of these kilns were dedicated to recycling of metal-bearing wastes, up to 13,500 tons (12,250 metric tons) of hazardous waste could be diverted from landfill disposal in just the state of California each year (Leonard et al., 1992).

Spent ABM and similar wastes also are good candidates for recycling as replacements for cement raw materials. Wastes high in alumina (such as bottom or fly ash, ceramics, and aluminum potliner) or iron (e.g., slag ABM, iron mill scale, foundry waste) are particularly good candidates. Silica and calcium also are beneficial ingredients, but these usually are provided in sufficient quantities by the quarry rock and therefore are not in as much demand.

Cement kilns provide high operating temperatures and long residence time, which cause significant changes in the physical and chemical form of the matrix and the contaminants. Organic contaminants are oxidized to their mineral components. Metal contaminants are incorporated into the portland cement matrix.

The high alkali reserve of the cement clinker reacts to form alkali chlorides (sodium, potassium, calcium), preventing evolution of acidic vapors in the off-gas. However, the chloride content of the wastes must be limited to avoid excessive kiln dust production. Most of the alkali chlorides vaporize and increase the quantity of kiln dust. Kiln dust containing a high proportion of alkali chlorides cannot be recycled to the cement kiln because soluble chlorides alter the setting rate of the cement product.

3.3.3 Limitations of Recycling Option

Recycling into portland cement is applicable to only certain types of wastes, based on chemical composition, contaminant levels, and other criteria (Bouse and Kamas, 1988a; 1988b):

- Aluminum, iron, and sometimes silica are the primary constituents which the kiln operator needs to purchase to supplement the naturally occurring concentrations in the quarry rock. Ores typically comprise 40 to 50% by weight of these constituents.

Therefore, waste materials should contain at least 20% or more of these constituents to be attractive substitutes for the ore materials.

- Combustion to heat the raw materials and decomposition reactions during formation of cement clinker generate large volumes of off-gas, which must be controlled and cleaned.

- Elevated concentrations of Na, K, S, Cl, Mg, and Ba can degrade the quality of cement or increase the volume of kiln dust waste produced. The plant chemist will be the final authority on whether a given waste material is compatible with the mix design.

- Recycling operations should be designed to avoid significant risk due to metals concentrations in the clinker or off-gas. Total metals concentrations in the recycled wastes should in general be <1%, and the clinker should be tested to ensure that the metals present are not highly leachable. Waste with highly toxic and volatile metals such as As or Hg should not be recycled in this manner.

Cognizant regulators should be contacted prior to proceeding with the recycling project. RCRA regulations discourage the land application of recycled hazardous materials (U.S. EPA, 1990c, Definition of Solid Waste). In most cases, special wastes or state-regulated wastes may be recyclable, subject to state or local restrictions or policies. Nonhazardous silicate and aluminate wastes are used as raw material substitutes in portland cement manufacture on a commercial scale. Using wastes containing RCRA metals may be possible, but commercial application is limited by the requirements of the Boiler and Industrial Furnace regulations.

3.3.4 Example Applications

3.3.4.1 Using Spent Abrasive Blasting Media to Make Cement. The Naval Facilities Engineering Service Center (NFESC) in Port Hueneme, California, along with Southwestern Portland Cement Co., Mare Island Naval Shipyard, Radian Corporation, and Battelle, have been studying the recycling of spent ABM as a raw material for the manufacture of portland Type I cement for construction purposes. The ABM is a silicate slag containing moderate levels of iron (Fe) and replaces some of the iron ore that normally is used in cement manufacture. The silica and alumina in the ABM are also useful ingredients in the cement product.

The spent copper slag ABM was hazardous in the state of California because of its Cu content, but is not classified as a RCRA hazardous waste. Consequently, this recycling demonstration was conducted under a Research & Development (R&D) variance issued by the California EPA.

During the demonstration tests, ABM was introduced as about 1% of the total feedstock of the kiln, and emissions monitoring was conducted to identify any fluctuations in the air emissions concentrations from the process. The final product was then subjected to physical and chemical analysis to determine the structural integrity of the product and whether the metals are bound in the crystalline structure of the cement. The results of these tests showed that the ABM in these proportions did not significantly increase the metals content of the clinker or lead to undesirable air emissions (Leonard et al., 1992).

The spent ABM at Mare Island Naval Shipyard is hazardous in the state of California and, if no recycling and/or reuse option were available, would have to be treated by stabilization/solidification and disposed of in a hazardous waste landfill. This technology makes beneficial reuse of the ABM by incorporating it into portland cement, where resulting metal concentrations are low and the metals are physically and chemically immobilized in the asphaltic concrete matrix.

Using ABM as a raw material in portland cement presents a cost savings for the waste generator and makes money for the operator of the cement kiln. In this Mare Island Naval Shipyard demonstration, the total fee charged by the kiln operator has been about $195/ton for about 4,000 tons (3,600 metric tons) of recycled spent ABM. The kiln operator requires the fee to cover costs for the following activities associated with using the metal-contaminated ABM as raw material:

- transporting the spent ABM from the generator's site in northern California to the cement plant in southern California

- determining feedstock proportions and process modifications to accommodate the waste materials

- sampling and analyzing the clinker

- sampling and analyzing air emissions from the stack

- engaging in regulatory interaction to obtain necessary permits or variances.

The only significant cost element not included in the $195/ton figure is the cost of ABM screening and debris disposal, which was borne by the shipyard and probably amounted to less than $10/ton.

The unit cost for managing the Mare Island Naval Shipyard spent ABM as California hazardous waste was about $660/ton. The waste management unit cost includes characterization, transport, and disposal in a hazardous waste landfill (including any treatment required by the landfill operator). Therefore, the cost savings to the generator are obvious and significant, and the kiln operator is being paid for a raw material that the cement plant usually has to pay for.

3.3.4.2 Using Solid Waste to Make Cement. Industrial Waste Management in St. Louis, Missouri reports the capability to use metals-contaminated waste as a raw materials substitute in cement making. Candidate raw materials are first analyzed to determine their suitability based on their value and contaminant level. The primary raw materials of interest are silica, calcium, aluminum, and iron. Good candidates for raw materials substitution typically contain 95% or more of these constituents. The company reports that its largest current source for substitute feed is fluidized-bed cracking catalyst.

Systech Resource Recovery Services in Xenia, Ohio accepts nonhazardous wastestreams containing low levels of transition metals as feedstock for cement kilns. Systech has a network of 16 cement kilns to process byproduct materials. Examples of acceptable feed materials include:

Alumina sources:

- catalysts
- ceramics and refractories
- coal ash
- adsorbents for gases and vapors

Calcium sources:

- lime sludges

Iron sources:

- coal slag
- foundry baghouse residuals
- iron mill scale

Silica sources:

- abrasives
- ceramics
- clay filters and sludges
- foundry sand
- sandblast media
- water filtration media

3.3.4.3 Using Spent Fluidized-Bed Cracking Catalyst to Make Cement. A company in Bucaramanga, Colombia has described preliminary testing of spent fluidized-bed catalyst as feed to a cement kiln. The catalyst contains about 60% silica (SiO_2), 33% alumina (Al_2O_3), 1% sodium, 2% iron, 0.03% copper, and 0.05% nickel. The catalyst is used as a replacement for clinker in the final grinding. Tests were performed with 30% and 40% catalyst replacing clinker. The resulting cement was reported to give compressive strength similar to the control cement sample. The catalyst cement set faster and required higher water-to-cement ratios to obtain workability. The authors noted that the high catalyst inputs were used to test the limits of possible additions. Input of catalyst to replace 30% of the clinker would use the annual production of catalyst in 1 week of cement making. Thus, in normal practice, lower quantities of catalyst would be used to produce a more conventional portland cement (Cardenosa et al., 1992).

3.4 Use Spent Abrasive as Concrete Aggregate

This section describes use of spent ABM and similar wastes as a portion of the aggregate in portland cement concrete. The value of ABM used as construction aggregate would be low. The average unit price for construction sand and gravel in 1993 was about $3.60/ton (free on board [FOB] at the mill) (Tepordei, 1993b). The cost for crushed stone ranges from about $6.75/ton to $8.42/ton. The cost for construction sand and gravel ranges from about $6.73/ton to $9.84/ton. These costs are current for late 1995 and apply to material delivered to a construction site in truckload quantities (ENR, 1995). The main economic advantage for this option is reduced disposal costs. Use of wastes in asphaltic concrete is described separately (see Section 3.5) due to the different characteristics required for the two different types of aggregate.

3.4.1 Description of Recycling Option

Aggregate is a mineral product from natural or manufactured sources used in concrete making. The specifications for fine and coarse aggregate are described in ASTM 33. The important features of aggregate are size grading; freedom from deleterious materials such as clay lumps, friable particles, and organic materials; and soundness.

The spent ABM could be used to form poured concrete surfaces or concrete blocks or shapes. The cement-making process is illustrated in Figure 3-4. Concrete blocks, bricks, and other shapes are made by combining and forming cement and aggregate. Concrete bricks typically are solid parallelepipeds, whereas blocks have a central opening to reduce weight. A wide variety of specialty shapes also are made from cement and aggregate. Products in this category may be either nonreinforced or reinforced concrete products. Common examples of precast shapes include concrete barriers (New Jersey barriers); precast concrete septic tanks; precast concrete tanks, structures, and cribs; and precast concrete poles. Concrete made by substituting ABM for some of the fine aggregate would be more suitable for applications that do not require high strength such as riprap or fill for protective caissons around bridge pilings (Brabrand and Loehr, 1993).

This recycling technology is straightforward and involves little in the way of operation. Unless the reuse location is on site, the waste aggregate must be transported to the recycler's location. If the aggregate is going to be used as a construction material or as aggregate in concrete, it may be necessary to crush the waste and grade it by particle size. Storage requirements in compliance with any pertinent regulations may involve an impervious liner or bins or hoppers to prevent leaching. Special handling and worker protection also may be required to minimize exposure to dust.

3.4.2 Advantages of Recycling Option

The principal advantages to recycling spent ABM as aggregates are:

- using the spent ABM's favorable structural properties in a beneficial application
- conserving landfill space for the higher hazard waste materials
- reducing waste management cost.

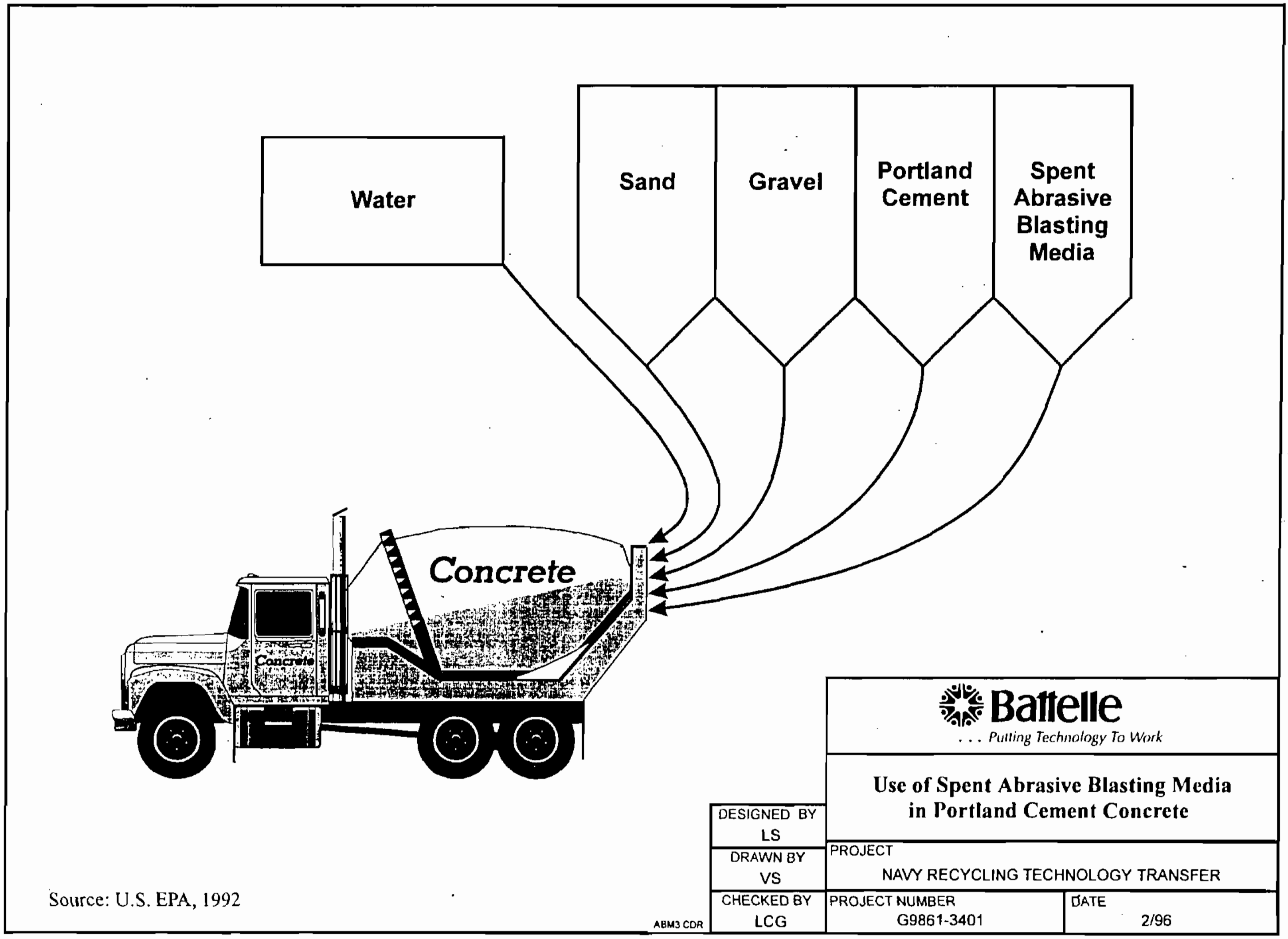
Application of spent ABM as aggregate can recycle large quantities of waste. Also, the use locations are widely distributed throughout the country, so long shipping distances can be avoided in many cases.

3.4.3 Limitations of Recycling Option

Use of spent ABM as a low-value component of a product that often is placed in direct contact with the land may be construed as "use constituting disposal" rather than as a true recycling application. Regulatory agencies responsible for administration of federal and state solid and hazardous wastes should be contacted prior to proceeding with the recycling project. RCRA regulations discourage the land application of recycled hazardous materials (U.S. EPA, 1990c). In most cases special wastes or state-regulated wastes may be recyclable, subject to state or local restrictions or policies. State and local restrictions often are controlled by local agencies such as water quality boards, air quality boards, and local planning commissions. Regulatory considerations are discussed in more detail in Section 4.5.

Use of the spent grit as aggregate chemically and physically immobilizes the contaminants. However, the effectiveness of solidification/stabilization is dependent on the integrity of the cement rather than on fundamental changes in the mineral form of the matrix and contaminant.

Rounded to subangular particle shape is preferred for portland cement concrete aggregate. Spent ABM typically would have more angular particles. Concrete containing a high proportion of spent ABM could have poor mixing, pouring, and setting characteristics (see the first example in Section 3.4.4).



Use of Spent Abrasive Blasting Media in Portland Cement Concrete

DESIGNED BY LS		
DRAWN BY VS	PROJECT NAVY RECYCLING TECHNOLOGY TRANSFER	
CHECKED BY LCG	PROJECT NUMBER G9861-3401	DATE 2/96

Source: U.S. EPA, 1992

Figure 3-4. Use of Spent Abrasive Blasting Media in Portland Cement Concrete.

The alkali reactivity of the cement and aggregate is an important factor in selecting an aggregate. The concern is reaction of an alkali with the aggregate causing a volume increase and/or loss of concrete strength. The alkali causing the reaction usually is the calcium hydroxide released as cement cures. However, in some cases the alkali may come from external sources such as groundwater. There are two basic types of alkali-aggregate reactions:

- reaction of alkali with siliceous rocks or glasses
- reaction of alkali with dolomite in some carbonate rocks.

Some waste slags can exhibit excessive reactivity. For example, four zinc smelter slag samples tested by Oklahoma State University were found to be unsuitable as aggregate for portland cement due to the excessive expansion during curing caused by alkali aggregate reactions (U.S. EPA, 1990, EPA/530-SW-90-070C).

The alkali activity of a potential aggregate can be determined by one of several tests depending on the type of aggregate to be tested. The applicable tests or guides are ASTM C 227, "Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)"; C 289, "Potential Reactivity of Aggregates (Chemical Method)"; C 295, "Petrographic Examination of Aggregates for Concrete"; C 342, "Test Methods for Potential Volume Change of Cement-Aggregate Combinations"; and C 586, "Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregates (Rock Cylinder Method)." Guidance for selecting the appropriate test method is given in C 33, "Standard Specification for Concrete Aggregates."

Waste aggregate used to produce mortar or other cementitious products should have a low metallic aluminum content. Aluminum metal is reactive in the cement paste and corrodes, releasing H_2 gas, causing expansion and decreasing the strength of the cement (Garner et al., 1993).

3.4.4 Example Applications

3.4.4.1 Using Spent ABM as Aggregate in Portland Cement Concrete. Literature was found describing three studies that used spent ABM as aggregate for concrete. The test materials and locations were (1) copper slag used for ship hull blasting in Baharain (Madany et al., 1991), (2) one coal slag and one copper slag used for bridge blasting in Pennsylvania (Weyand and Sutton, 1990), and (3) an unspecified sand from bridge blasting in Texas (Brabrand and Loehr, 1993).

Concentrations of leachable metals exceeded the TCLP limits in some of the unprocessed spent ABM. The Baharain study did not test TCLP leachability. Both the spent coal and copper slag ABM in the Pennsylvania study failed the lead TCLP. In the Texas study, two separate fractions of spent ABM (sand and dust) were collected by vacuum separation. The sand passed the TCLP test but the dust had leachable levels of lead, cadmium, and chromium.

None of the studies noted problems with leachable metals from the final product, but only the Texas study reported TCLP leachability results for the cement product. In the Texas study, metals leachability from both sand and dust materials was significantly reduced by small additions of cement. More cement would be needed to meet strength requirements than would be needed to immobilize the metals.

All of the studies concluded that spent ABM could be used to form low-strength concrete for nonstructural applications. However, in all cases the strength of the product was highly variable and much reduced when ABM was used to replace sand. As a general conclusion, spent ABM is marginally suited as a substitute for the sand portion of concrete aggregate.

3.4.4.2 Aggregate Production from Fly Ash Waste. In the Netherlands, fly ash is sintered to produce a material called Lytag that is suitable as a replacement for sand and gravel in aggregate. The sintering method has four process steps:

- mixing
- pelletizing
- sintering
- final processing

The mixing step combines water and fly ash to produce a paste. The carbon content of the fly ash must be 3% to 5% to provide fuel for the sintering process. If additional carbon is needed, it can be added in the mixing step. The damped powder is formed into pellets and moved by a conveyor to a hopper, which feeds pellets onto a belt in a layer 11.8 in (30 cm) thick and 6.6 ft (2 m) wide. The belt moves horizontally and passes under an ignition hood where, once inside, the upper surface layer of pellets is ignited. Air is drawn down through the pellets so that the combustion zone moves down through the material on the belt. The combustion process results in a temperature of 2,000°F (1,100°C) that causes the pellets to sinter. In the final production step, any pellets that have sintered together are separated by crushing and are screened to produce three size fractions: 0.02 to 0.16 in (0.5 to 4 mm), 0.16 to 0.32 in (4 to 8 mm), and 0.32 to 0.47 in (8 to 12 mm). Particles over 0.47 in (12 mm) are recrushed, and particles under 0.02 in (0.5 mm) are returned to the process.

The Lytag is reported to have a glassy surface due to sintering and, thus, to be leach resistant. The performance of Lytag as concrete aggregate is reported to be competitive with gravel. Lytag is being used in construction of two large bridges and various industrial and commercial construction projects in the Netherlands (Faase et al., 1991).

3.4.4.3 Aggregate Production from Incinerator Ash. A production process is being developed to remove ferrous and nonferrous metals from incinerator ash, processing the ash to prepare aggregate for concrete. The typical range of ash composition is:

SiO_2	46 to 62%
Fe_2O_3	7.6 to 17%
Al_2O_3	5.5 to 10%
CaO	8.0 to 14%
Na_2O	3.6 to 7%
MgO	1.0 to 2%
SO_3	0.4 to 2%

The ash passes through a series of crushers, screens, and magnetic separators to remove metals. The ash is first crushed with a jaw crusher and then passed through roll crushers. Ferrous metals are removed by magnetic separators. The roll crushers flatten the softer nonferrous metal particles into platelets. Ash leaving the roll crushers is screened with a 0.9-mm (0.035-inch) sieve. The metal platelets are retained while the mineral matter passes through the screen. The mineral residues are further crushed to pass through a 0.01-in (0.3-mm) sieve. The residues are blended with clay, pelletized, and fired in a rotary kiln to produce smooth spherical aggregate. The resulting aggregate has undergone testing in concrete for up to 4.5 years (Wainwright and Robery, 1991).

3.5 Use Spent Abrasive as Asphalt

This section describes the use of spent ABM and similar wastes as a portion of the aggregate in asphaltic concrete. The value of ABM used as construction aggregate would be low. The average unit price for construction sand and gravel in 1993 was about \$3.60/ton (FOB at the mill) (Tepordei, 1993b). The cost for crushed stone ranges from about \$6.75/ton to \$8.42/ton. The cost for construction sand and gravel ranges from about \$6.73/ton to \$9.84/ton. These costs are current for late 1995 and apply to material delivered to a construction site in truckload quantities (ENR, 1995). The main economic advantage for this option is reduced disposal costs. Use of wastes in portland cement concrete is described separately (see Section 3.4) due to the different characteristics required for the two different types of aggregate.

3.5.1 Description of Recycling Option

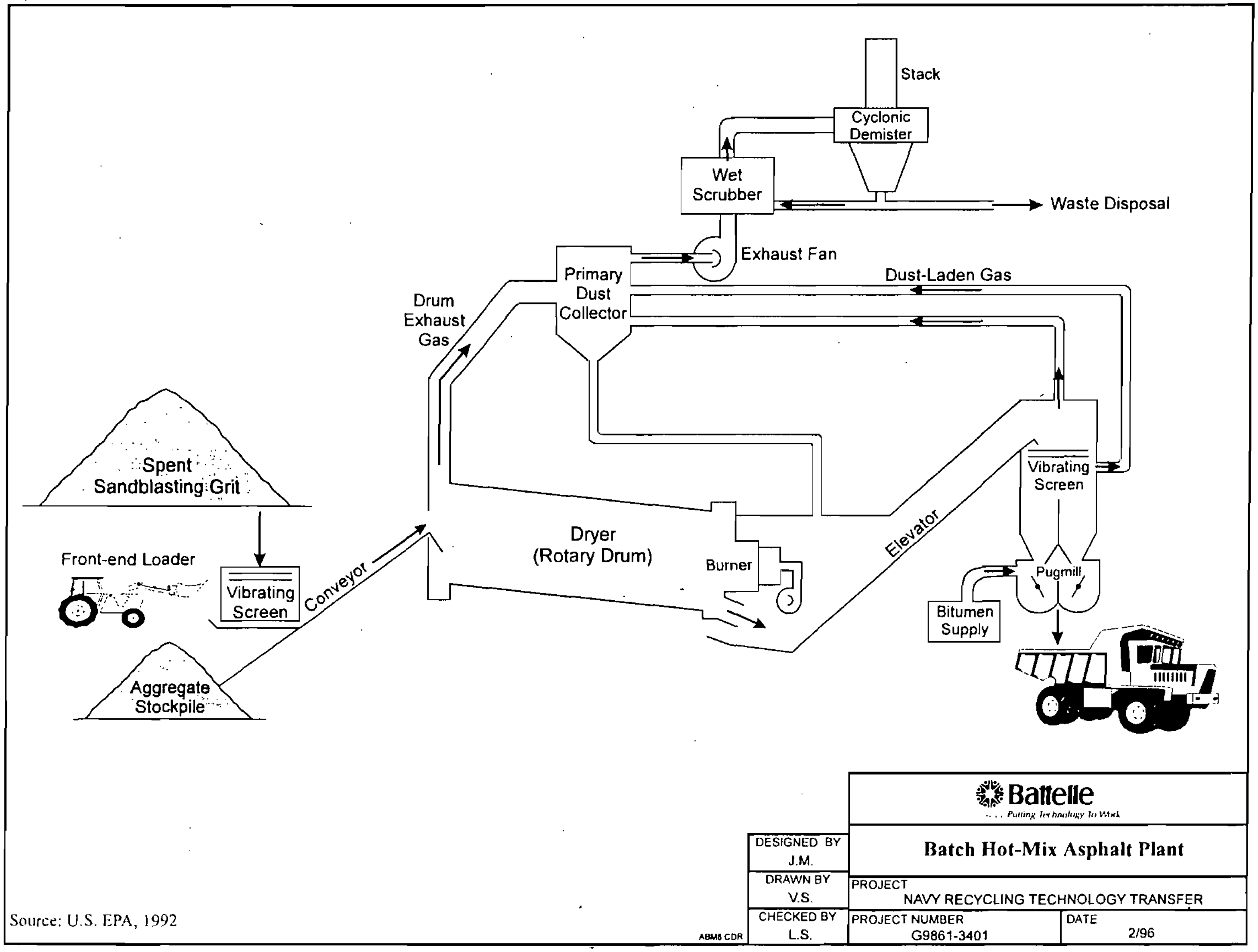
The recycling of wastes into asphaltic concrete is not a particularly new concept. A wide variety of materials have been successfully substituted for some portion of the normal graded aggregate without adverse effects on product quality. The hot mix process for asphalt production is illustrated in Figure 3-5. The most widespread example of waste used as aggregate in asphaltic concrete is reuse of reclaimed asphaltic concrete from previous paving projects. Old asphalt paving is crushed and substituted for a portion of the aggregate in either cold mix or hot mix asphaltic concrete. More than 12,000,000 tons (10,900,000 metric tons) of asphalt were recycled by 35 asphalt contractors in 1992 (ARRA, 1994). The corresponding savings were over \$600 million in landfill costs and over \$30 million for liquid asphalt and aggregate. In certain situations, the old pavement is recycled into cold or hot mix asphalt in place, thereby reducing paving costs and reducing truck traffic on the highways to transport the old aggregate back to the contractor's facility (ARRA, 1994).

Another example of waste recycling into asphalt is the recently developed concept of using glass cullet as an aggregate in asphalt. The resulting product has been termed “glassphalt” (Monroe, 1990). Glassphalt uses mixed color glass which has low value in the conventional glass recycling market. Glassphalt containing 10% glass was used in a base course lift for the first time on a project in New Jersey. Highway agencies in Connecticut, District of Columbia, New Jersey, and Virginia have been using glassphalt on a trial basis (Ahmed, 1993).

The ABM-to-asphalt recycling technology involves simply substituting the ABM for a portion of the fine-size aggregate in asphaltic concrete. As long as the metal concentrations in the spent ABM are not excessively high, the metal concentrations in the asphaltic concrete product will be very low, and any metals present will be physically and chemically immobilized in the asphalt binder. Typically, asphaltic concrete consists of 4.5 to 8% bitumen mixed with graded aggregate. The aggregate is made by mixing rock and sand to give particles ranging from fine sand to 1/2- to 1-in (13-mm to 25-mm) gravel. Depending on the mix design and the ultimate strength requirements of the product, the fine-size particle fraction may comprise 35 to 45% of the asphaltic concrete.

3.5.2 Advantages of Recycling Option

Application of spent ABM as aggregate can recycle large quantities of waste. Also, the use locations are widely distributed throughout the country so long shipping distances can be avoided in many cases.



Source: U.S. EPA, 1992

Figure 3-5. Illustration of the Hot-Mix Process for Asphalt Making.

Applicable wastes include a wide variety of geologic materials, pavement, construction materials, ceramics, or glasses that are either aggregates or can be crushed to form aggregates. Because reuse usually is in the public domain, the wastes should contain only low levels of relatively low-hazard contaminants. The technology for reusing nonhazardous soil and sand wastes for asphalt aggregate is mature and commercially available. Oil-contaminated soil has been used as asphalt aggregate in construction projects for many years (U.S. EPA, 1992, EPA/600/R-92/096).

Sharp angular particle shape is preferred for asphaltic concrete aggregate. Spent ABM typically would have more angular particles and should provide a good substitute for the sand portion of asphalt aggregate.

3.5.3 Limitations of Recycling Option

The asphalt recycling approach is viable only for certain types of aggregates. The aggregate must comply with both performance and environmental standards such as durability, stability, chemical resistance, biological resistance, permeability, and leachability (Testa and Patton, 1994). The principal limitations pertain to risk, regulatory considerations, or technical considerations pertaining to the integrity of the asphaltic concrete product. For example:

- ABM containing solvents or other particularly hazardous or toxic constituents should not be recycled in this manner.

- ABM with high metal contents (percent level or greater) may pose hazards either to workers at the asphalt plant due to dust exposure or to the public through the asphalt product because of metals leaching.

- The presence of sulfate or metallic iron is undesirable because of swelling upon oxidation. Reduced forms of trace metals may cause similar problems, which, however, may be avoidable by recycling the ABM into a base course layer where there is minimal contact with air.

- High concentrations of silt and smaller size particles are undesirable because they have poor wetting characteristics in the bitumen matrix and may generate dusts.

- Rounded aggregates do not give good vehicle traction characteristics when used in asphaltic concrete.

The chief chemist or engineer at the asphalt plant must ensure that the ABM is compatible with the production of a high-integrity asphaltic concrete.

Use of spent ABM as a low-value component of a product that is placed in direct contact with the land may be construed as "use constituting disposal" rather than a true recycling application. Regulatory agencies responsible for administration of federal and state solid and hazardous wastes should be contacted prior to proceeding with the recycling project. RCRA regulations discourage the land application of recycled hazardous materials (U.S. EPA, 1990c). In most cases, special wastes or state-regulated wastes may be recyclable, subject to state/local restrictions or policies. State and local restrictions often are controlled by local agencies such as water quality boards, air quality boards, and local planning commissions. Regulatory considerations are discussed in more detail in Section 4.5.

Use of the spent grit as aggregate provides chemical and physical immobilization of contaminants. However, the effectiveness of solidification/stabilization is dependent on the integrity of the asphaltic concrete rather than on fundamental changes in the mineral form of the matrix and contaminant.

3.5.4 Example Applications

3.5.4.1 Using Spent ABM as Aggregate in Asphaltic Concrete. The NFESC in Port Hueneme, California has been studying the recycling of spent ABM in the form of sandblasting grit into asphaltic concrete for commercial paving purposes. The sandblasting grit is used as a "blender sand" for a portion of the fine-grained aggregate that is used to produce the asphaltic concrete. This section briefly describes the case history for the ongoing "ABM-to-asphalt" recycling project in Hunters Point, California.

The spent ABM at Hunters Point is comprised of a 4,000-yd^3 (3,060-m^3) pile of Monterrey Beach sand contaminated with small amounts of paint chips. The spent ABM was generated in ship-cleaning operations conducted at Naval Station, Treasure Island, Hunters Point Annex by Triple AAA Shipcleaning during the 1970s and 1980s. Average copper, zinc, lead, and chromium concentrations are 1,800, 1,100, 200, and 100 mg/kg, respectively. Leachable metals concentrations using the California Waste Extraction Test (WET) methodology average 140, 150, 20, and 2.0 mg/L, respectively for copper, zinc, lead, and chromium. The WET test is California's version of the RCRA TCLP. The spent ABM at Hunters Point is considered hazardous by the state because of Soluble Limit Threshold Concentration (STLC) exceedances on the WET test for copper and lead, but is not an RCRA-listed hazardous waste because it passes the TCLP.

In the ABM-to-asphalt technology demonstration at Hunters Point, an ABM concentration of 5% by weight of the final asphaltic concrete is being used so the spent ABM comprises 5% of the asphaltic concrete replacing about 1/9 to 1/7 of the normal sand portion of the concrete. Higher ABM contents are possible; theoretically the entire fine fraction of the mix design could be comprised of ABM. However, at higher ABM concentrations, there is greater potential for lower product quality or elevated leachable metals concentrations in the product.

At Hunters Point the ABM is being recycled into hot mix asphalt for normal commercial paving applications, yielding high-strength asphaltic concrete for heavily used highways. ABM can be recycled into both a base course layer or any subsequent lifts applied to the base course. ABM also can be recycled into cold mix processes, which yield a lower grade product for road repair or lower traffic area applications.

The cost of an ABM-to-asphalt recycling project will depend on a number of factors, particularly:

- tippage rate charged by the asphalt plant
- distance between the generator and the asphalt plant, which affects transportation costs
- required amount of planning, regulatory interactions, reporting, and program management

and to a lesser extent:

- analytical fees for chemical and physical analyses of asphalt test cores to show compliance with any regulatory or institutional requirements

- ABM pretreatment such as screening and debris disposal

In the Hunters Point project, the tippage rate charged by the asphalt plant is $40/ton of ABM recycled. The overall unit cost about $140/ton, including significant costs for transportation to the asphalt plant, regulatory compliance, and analytical testing of core specimens produced in the laboratory prior to full-scale recycling. In general, the recycling unit cost decreases with increasing amounts of spent ABM recycled. The following ranges are typical for most projects:

Amount ABM (tons)	Estimated Costs of Recycling (per ton)
500 - 1,500	$125 - $175
1,500 - 3,000	$100 - $150
3,000 - 6,000	$ 50 - $100

Therefore, economically, the ABM-to-asphalt recycling approach is a win-win situation for both the asphalt plant and the ABM generator. Recycling costs the generator less per ton than the cost for disposal in a hazardous waste landfill and probably less than it would cost for on-site treatment and disposal, and the asphalt plant is paid for a raw material that it ordinarily would have to buy.

3.5.4.2 Using Soil as Aggregate in Asphaltic Concrete. A review of the literature found two examples of application of metal-contaminated soils as asphalt aggregate. American Reclamation Corporation asphalt was used to stabilize soil contaminated with fuel oil and lead at a closed steel wire manufacturing plant. The contaminants reportedly were immobilized by the asphalt treatment, allowing the material to be used to pave the site after remediation was completed.

Applied Environmental Services treated soil from a railcar brake shoe manufacturing plant containing 438 mg/kg lead and 336 mg/kg zinc. The soil was excavated and treated off site at a cold mix asphalt plant. Treatment was reported to have achieved acceptable immobilization of the metals. The treated waste was returned to the site for use as paving (Testa and Patton, 1992).

3.5.4.3 Using Steel Shot as Aggregate in Asphaltic Concrete. The incorporation of steel shot ABM from bridge-blasting operations has been the subject of an ongoing demonstration project in North Carolina (Medford, 1989, 1990, and 1992). Recent results suggest that the steel shot ABM is not compatible with the asphaltic concrete product and is leading to premature failure due to the oxidation and swelling of the steel particles (Medford, 1992, personal communication).

3.5.4.4 Using Spent Foundry Sand as Aggregate in Asphaltic Concrete. Lead-contaminated foundry sands from brass foundries in Pennsylvania are being recycled into asphalt (Boyd, 1992).

3.6 Use Spent Abrasive as a Construction Material

This section describes using spent ABM or similar wastes as replacements for construction materials. Minimal preprocessing may be done to remove debris or reduce metal leachability. If the waste has high organic content, high leachable metal content, low strength, a high proportion of fines, or other undesirable properties, more aggressive processing may be needed to produce a usable product (see Section 3.7).

Crushed stone, sand, and gravel fill a wide range of needs in the construction, chemical feedstock, and other industries. The quantities used are enormous. For example, the estimated crushed stone production in the United States during the second quarter of 1995 was 367,500,000 tons (333,600,000 metric tons). The estimated production of construction sand and gravel in the United States during the second quarter of 1995 was 265,100,000 tons (240,700,000 metric tons) (Tepordei, 1995). The average unit price for construction sand and gravel in 1993 was about \$3.60/ton (FOB at the mill) (Tepordei, 1993b). The cost for crushed stone ranges from about \$6.75/ton to \$8.42/ton. The cost for construction sand and gravel ranges from about \$6.73/ton to \$9.84/ton. These costs are current for late 1995 and apply to material delivered to a construction site in truckload quantities (ENR, 1995).

3.6.1 Description of Recycling Option

Sand and gravel are granular, unconsolidated agglomerations of rocks and minerals produced mainly by natural breakdown and abrasion of rocks (Bolen, 1993). The ASTM defines sand as naturally occurring unconsolidated or poorly consolidated rock particles that pass through a Number 4-mesh U.S. standard sieve and are retained on a Number 200-mesh U.S. standard sieve. Gravel is defined as naturally occurring unconsolidated or poorly consolidated rock particles that pass through a sieve with 3-in (7.62-cm)-square openings and are retained on a Number 4-mesh U.S. standard sieve. The construction industry generally accepts this differentiation of sand and gravel based on particle size.

Sand and gravel consist of a variety of rock and mineral types, so the composition varies. Silica is the major component of most commercial sand and gravel. Feldspar, mica, and iron oxides are common minor constituents. Specifications for sand and gravel used in roadbed and concrete construction usually state strict particle size gradation and shape requirements. Other requirements with regard to physical and chemical properties may be stated depending on the soil conditions, climate, and other locality-specific conditions. The National Aggregates Association has compiled 42 ASTM specifications and test methods for aggregates, concrete, and admixtures (Tepordei, 1993a).

The ASTM and the American Association of State Highway and Transportation Officials (AASHTO) are the main national organizations setting specifications on crushed stone for use in construction (Tepordei, 1993b). However, many specifications for construction aggregates are developed by states or localities based on their specific needs. Most common specifications control size grades, soundness, shape, abrasion resistance, porosity, chemical compatibility, and content of soft particles. Due to the skid resistance imparted to road surfaces when blast furnace or steel furnace slag is used as the aggregate, many state agencies specify slag aggregate for asphalt used for roads with high traffic volume (Solomon, 1993).

The American Railroad Engineering Association sets standards for railroad ballast. The general characteristics required of a good ballast material are strength, toughness, durability, stability, drainability, cleanability, workability, and resistance to deformation.

3.6.2 Advantages of Recycling Option

Application of spent ABM in general construction can recycle large quantities of waste. Also, the use locations are widely distributed throughout the country so long shipping distances can be avoided in many cases.

When the physical and chemical characteristics allow the waste to be reused directly in a construction application, the processing is simple and uses commercially available equipment. Figure 3-6 illustrates one way of using spent ABM for contained fill. There is a well-established precedent for recycling waste materials with characteristics similar to spent ABM in the construction industry. In 1994, an estimated 19 million metric tons of iron and steel slags, with an approximate value of $130,000,000, were recycled. About 80% of the recycled slags are used in construction applications such as road base, asphalt or cement aggregate, and fill. Other applications such as mineral wool manufacture, soil conditioning, and roofing account for the other 20% of slag use (Solomon, 1995b). Other ore-processing slags have been applied as drainage material in landfill construction and railroad road beds (U.S. EPA, 1990d, EPA/530-SW-90-070C). Spent foundry sand is another potential material for use in construction as road fill, aggregate, or daily landfill cover. About 6 million tons of spent foundry sand are produced annually by U.S. foundries, of which only 4.2% is put to beneficial reuse (Smith, 1992).

3.6.3 Limitations of Recycling Option

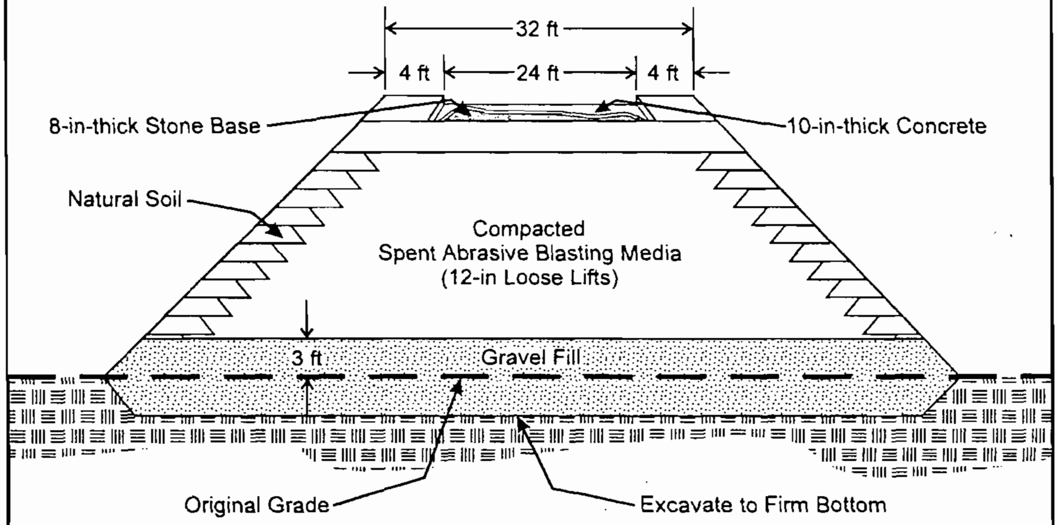
The principal requirements for the use of waste materials as aggregates or bulk materials are (1) acceptance by regulatory agencies, the customer, and the affected public; and (2) performance. Typically, the waste material must lend some useful function to the product and meet some leach-resistance criteria and specifications for physical properties (Wisconsin Department of Natural Resources, 1993). The end use should not be simply disposal in another form (termed "use constituting disposal" or "sham recycling"). Even if regulatory requirements and technical specifications are met, there may be reluctance on the part of the customer or the public to accept the use of those materials.

Wide use of waste materials for construction applications may pose the risk or perceived risk of exposing a large population to hazardous materials, generating occupational and public health concerns. The two principal exposure pathways are through inhalation of dusts or leaching of soluble metals from the aggregate into groundwater or surface water. Any recycling project using spent ABM in construction must have documented, quantitative evidence that no significant risk is being added to either the process or the product. Test results should demonstrate negligible incremental risk to the occupational workforce or to the public during processing of the material in its reuse environment. Potential liabilities may exist for the waste generator for real or perceived health effects resulting from the reuse.

The recycled material must equal or exceed the performance of the raw material it will replace. Product specifications for construction material include strength, size grading, chemical composition and purity, and chemical reactivity.

3.6.4 Example Applications

3.6.4.1 Using Ash in Construction Applications. Ash from a refuse-to-energy facility for processing of municipal waste is treated and used for landfill road construction. About 10 to 12% portland Type II cement is added to the ash. The treated ash is formed and cured to give a monolith which is crushed by equipment at the landfill. The resulting particulate is used as a subbase material for asphalt roadways at the landfill. The treated ash is accepted at no charge by the landfill and replaces recycled asphalt subbase that previously cost the landfill $2/ton (Korn and Huitric, 1992).



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Typical Cross Section Showing Use of Spent Abrasive Blasting Media as Fill

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Figure 3-6. Typical Cross Section Showing Use of Spent Abrasive Blasting Media as Fill.

3.6.4.2 Beneficial Reuse of Foundry Sand. Foundry sand has been used extensively in construction applications. More complex sand and binder systems and increased concern over potential chemical hazards have resulted in a decline of such use in recent years. The Wisconsin Department of Natural Resources is developing a program to encourage responsible beneficial reuse of foundry byproducts. In particular, the state is developing fact sheets for beneficial reuse of foundry sand in applications such as these (Wisconsin DNR, 1993):

- foundation subgrade fill
- concrete and asphalt fine aggregate
- landfill daily cover
- pavement subbase fill
- contained embankment fill

3.6.4.3 Soil Recycling Demonstration. The Toronto Harbor Commissioner's soil recycling process produces reusable fill material by treating soils using a three-step process to remove organic and inorganic contaminants to produce a reusable fill material. First, soil washing reduces the volume of material to be treated by concentrating the contaminants in a fine slurry. The second step removes metals from the slurry by acidification and chelation. In the third step, chemical hydrolysis and biodegradation destroy organic contaminants concentrated in the slurry. The technology is reported to produce clean soil for reuse as fill material. A Superfund Innovative Technology Evaluation Program Demonstration took place in April and May of 1992 (U.S. Environmental Protection Agency, 1993, EPA/540/AR-93/517).

3.7 Vitrify Spent Abrasive to Form Construction Material

This section describes high-temperature processing to convert spent ABM or other wastes with a high silica content to low-value construction materials. Vitrification will destroy organic contaminants, reduce leachability of metals, and make a product with high compressive strength and a controlled particle size distribution. Thus, vitrification can be used to convert wastes with undesirable chemical and physical properties into a useful product. Thermal processing to produce high-value ceramic products is discussed in Section 3.2.

3.7.1 Description of Recycling Option

Waste vitrification is a thermal treatment technology that oxidizes, melts, and transforms a broad spectrum of wastes into a glasslike or rocklike material. The average composition of the earth's crust is compared to the composition of several glass formulations in Table 3-3. The similarity of the compositions indicates that mineral processing slags and minerals, such as those used to manufacture ABM, would be expected to be good candidates for vitrification.

Vitrification is accomplished by introducing the waste into a melting kiln or container where the waste is heated to form a liquid melt. A typical overall mass balance for vitrification using a plasma arc heat source in a reducing environment is shown in Figure 3-7.

The melting energy is derived from the oxidation of materials in the feed and from external heating of the waste material. Electrical conduction through the molten waste and plasma arc heating are two common methods for heat input. Some systems use fossil fuel heating, which reduces energy costs but increases the volume of off-gas generated.

Table 3-3. Comparison of the Earth's Crust to Common Commercial Glasses

Oxide Material	Average Composition of the Earth's Crust (wt%)	Typical Composition of Soda-Lime Glass (wt%)	Typical Composition of Borosilicate Glass (wt%)
SiO_2	59.7	73.3	80.4
Al_2O_3	15.5	1.5	2.3
Fe_2O_3	7.2	0.1	0.0
CaO	5.1	9.8	0.0
Na_2O	3.8	14.2	3.8
MgO	3.5	0.3	0.0
K_2O	3.1	0.6	0.6
SO_3	0.1	0.2	0.0
Cl	0.1	0.0	0.0
B_2O_3	Trace	0.0	12.9

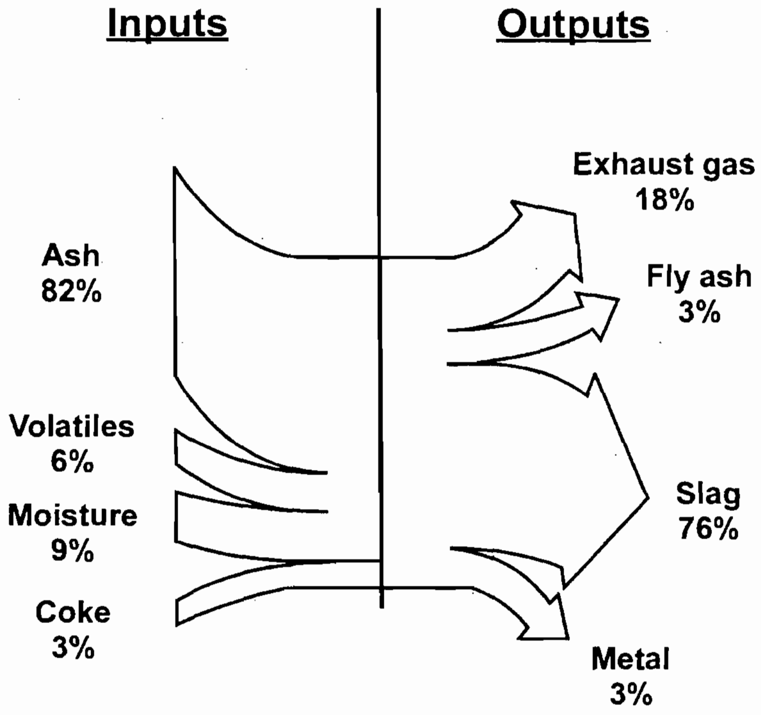
The discharged product usually provides high-volume reduction and a chemically durable material that typically passes the TCLP test as nonhazardous. The process typically collects particulates in the off-gas system and returns them to the melter feed to minimize secondary waste generation. For nonhazardous wastes, the discharged glass can be formed into useful construction materials, such as artificial aggregate, erosion-control boulders or slabs, or clean fill. Reuse of treated characteristic waste is possible (see Section 4.5.1 for a definition of hazardous characteristic). Testing will be required to demonstrate that the vitrification process removed the hazardous characteristic. However, it will be more difficult to identify markets of a material due to the previous waste code.

3.7.2 Advantages of Recycling Option

Vitrification of waste materials may be achieved over a broad range of earth and waste compositions and can immobilize many metal contaminants. The approximate solubility limit of a variety of common metal contaminants in glass is shown in Table 3-4 to indicate the general types and concentrations of metal contaminants that can be immobilized in a vitrified waste product. Examples of suitable wastes include sludge from wastewater treatment, electric arc furnace off-gas treatment residues, and baghouse dust (U.S. Air Force, 1990).

Vitrification has been adopted as the Best Demonstrated Available Technology (BDAT) for high-level radioactive wastes and for nonwastewater arsenic wastes. However, pretreatment usually is required to control arsenic volatilization during the vitrification process (U.S. EPA, 1990a, EPA/530/SW-90/059A).

The high-temperature vitrification process causes significant changes in the physical and chemical form of the matrix and the contaminants. Organic contaminants are oxidized to their mineral components. Metal contaminants are incorporated into a durable, leach-resistant mineral matrix. The discharged product is a chemically durable material that typically passes the TCLP test as nonhazardous. The process provides volume reduction (40% for soils to >99% for combustibles) (U.S. EPA, 1991, EPA/600/2-91/041).



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Material Balance for a Typical Plasma Arc Vitrification System

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Figure 3-7. Material Balance for a Typical Plasma Arc Vitrification System.

Table 3-4. Approximate Solubility Limit of Oxides of Metals in Silicate Glass

Element	Maximum Allowed Oxide Content (%)	Element	Maximum Allowed Oxide Content (%)
Ag	0.1	Mg	30
As	5	Mn	10
B	20	Mo	2
Ba	15	Ni	5
Be	10	Pb	30
Cd	1	Sb	2
Co	2	Se	1
Cr	2	Sn	5
Cs	25	Sr	15
Cu	5	U	20
Ga	5	Y	1
Hg	0	Zn	20

3.7.3 Limitations of Recycling Option

The vitrification process is capital and energy intensive. Processing is unlikely to break even for wastestreams when forming a low-value construction material. The main economic advantage is avoided disposal costs.

The construction material made by vitrification of spent ABM often will be placed in direct contact with the land. Even though significant chemical and physical changes occur during vitrification, use of vitrified wastes may be construed as "use constituting disposal" rather than a true recycling application. Regulatory agencies responsible for administration of federal and state solid and hazardous wastes should be contacted prior to proceeding with the recycling project. RCRA regulations discourage the land application of recycled hazardous materials (U.S. EPA, 1990c). In most cases special wastes or state-regulated wastes may be recyclable, subject to state or local restrictions/policies. State and local restrictions often are controlled by local agencies such as water quality boards, air quality boards, and local planning commissions. Regulatory considerations are discussed in more detail in Section 4.5.

Volatile metals such as arsenic, mercury, or beryllium are difficult to treat and can be present only at low concentrations. Wastes containing arsenic will require some combination of pretreatment, special processing conditions, and off-gas treatment systems to minimize arsenic volatilization. If reducing conditions can occur in the melt, cadmium, lead, and zinc can vaporize and enter the off-gas stream (Hollander et al., 1995).

3.7.4 Example Applications

3.7.4.1 Vitrification of Nonhazardous Sludge. World EnviroTech in New York, New York designs, builds, and operates thermal treatment systems to convert nonhazardous wastes such as sewage sludge to aggregate. The primary processing chamber operates at 2,400°F (1,300°C). Waste material reportedly is converted to an environmentally stable solid. The product can be either granulated (to a mainly vitreous form) or air-cooled (to a rocklike form) and is suitable for a wide range of uses as a replacement for sand and gravel. Example uses include preparing a subbase for roads, mixing in concrete as aggregate, or backfilling a pipe trench.

3.7.4.2 Waste Vitrification Process Options. Waste vitrification systems are under development or are available for hazardous and nonhazardous wastes from several vendors. Some examples of waste systems are summarized in Table 3-5.

Table 3-5. Examples of Some Waste Vitrification Process

Company/Process Name	Location	Process
Allis Mineral Systems/ Pyrokiln Encapsulation	20965 Crossroads Circle Waukesha, WI (414) 798-6265; fax (414) 798-6211	Fossil-fueled, direct-fired slagging rotary kiln(b)
Ausmelt	1331 17th Street, Suite M103 Denver, CO 80202 (303) 295-2216; fax (303) 295-7605	Fossil-fueled, direct-fired lance heater(c)
Babcock and Wilcox/ Cyclone Furnace	2200 Langhorne Drive Alliance, OH (216) 829-7394; fax (216) 829-7801	Fossil-fueled, direct-fired vortex furnace(a)(b)
Battelle/Terra-Vit	Battelle Boulevard, P.O. Box 999 Mail Stop P7-41 Richland, WA 99352 (509) 376-6576	Joule-heated melter(a)
Ecotechniek/Ecogrind	Het Kwadrant 1 Maarssen, 3606 The Netherlands (31-465) 577-00; fax (31-465) 544-72	Sintering in a rotary kiln(a)
EET Corporation/Microwaste Solidification Technology	129A Perimeter Park Road Knoxville, TN 37922 (615) 691-1223; fax (615) 691-2656	Microwave heating in drum(a)
Electro-Pyrolysis Inc./ Electro-Pyrolysis	996 Old Eagle School Road, Suite 1118 Wayne, PA 19087 (215) 687-9070; fax (215) 964-8570	Direct-current arc furnace(a)
EM&C Engineering Associates/ Vitriflux	1665 Scenic Avenue, Suite 104 Costa Mesa, CA 92626 (714) 957-6429; fax (714) 957-6414	Vitrification at low temperature using flux addition(a)
ENVITCO, Inc.	8400 West Central Avenue Sylvania, OH 43560 (419) 829-2728; fax (419) 537-1369	Small-batch, joule-heated melter(c)

Table 3-5. Examples of Some Waste Vitrification Process Vendors (Continued)

Company/Process Name	Location	Process
Ferro Corporation/ Waste Vitrifier	7500 East Pleasant Valley Road Independence, OH	Joule-heated melter(b)
Multiplex Environmental/ Xtaltite	4570 Westgrove Drive, Suite 255 Addison, TX 75248 (214) 733-3378; fax (214)733-0366	Combination of hydrometallurgical and pyrometallurgical processing to convert waste to a stable mineral form(a)
Penburthy Electromelt International, Inc.	631 South 96th Seattle, WA 98108 (206) 762-4244; fax (206) 763-9331	Joule-heated melter(c)
Plasma Technology Corporation/ Plasma Pyrolysis and Vitrification	8601 Six Forks Road, Suite 400 Raleigh, NC 27615 (919) 676-5304; fax (919) 676-5305	Plasma arc(c)
Retech/ Plasma Arc Centrifugal Treatment	100 Henry Station Road Ukiah, CA 95482 (707) 462-6522; fax (707) 462-4103	Plasma arc-heated rotating tub (centrifugal) melter(a)(b)
Stir-Melter/ STIR-MELTER Systems	Ampoint Industrial Park 995 Fourth Street Perrysburg, OH 43552 (419) 536-8828; fax (419) 536-8288	Joule-heated, stirred melter(a)
Vortec Corporation/ Combustion and Melting System	3770 Ridge Pike Collegeville, PA 19426 (610) 489-2255; fax (610) 489-3185	Fossil-fueled, direct-fired vortex furnace(a)(b)
Western Product Recovery Group, Inc./Coordinate Chemical Bonding and Adsorption	P.O. Box 79728 Houston, TX 77279 (713) 493-9321; fax (713) 493-9434	Sintering and partial slagging in a direct-fired rotary kiln(b)
Westinghouse Electric Corporation Science and Technology Center	1310 Beulah Road Pittsburgh, PA 15235 (412) 256-2235; fax (412) 256-1948	Plasma arc(c)

Sources:
(a) VISITT Version 4.0 (U.S. EPA, 1995, EPA/542-C-95/001).
(b) U.S. EPA, 1994, EPA/540/R-94/526.
(c) Vendor literature.

3.8 Processing in a Smelter

The metal content of spent ABM will not be sufficiently high to justify smelting to recover metals. The silica and calcium content may be useful as required slag-forming elements so that the spent ABM can be reused as flux in a pyrometallurgical process.

3.8.1 Description of Recycling Option

Pyrometallurgy is a broad term covering techniques for processing metal-bearing ores at elevated temperature. Processing at elevated temperature increases the rate of reaction and reduces the reactor volume per unit output. Elevated temperature often makes the reaction equilibrium more favorable. Pyrometallurgy, the oldest type of extractive metallurgy, dates back to the origins of recovering useful metals from ore. The earliest recorded use of pyrometallurgy was conversion of copper oxide ores to copper metal by heating with charcoal. This early type of pyrometallurgy was well established by 3,000 BC.

Pyrometallurgical processing to convert metal compounds to elemental metal usually requires a reducing agent, fluxing agents to facilitate melting and to slag off impurities, and a heat source. Figure 3-8 shows examples of oxidation and reduction smelting. The fluxing agents form a eutectic or other low-melting-point material due to the chemistry of the melt. An acceptable melting point is achieved by adding fluxing agents such as calcium oxide or by appropriate blending of the feedstocks. The most common fluxing agents in mineral smelting are silica and limestone. The spent ABM could be used to replace mineral raw materials as a source of silica. The spent ABM may contain trace metals that are recovered by the smelter, but the quantities would be incidental. The main recycling benefit from the ABM would be to provide silica.

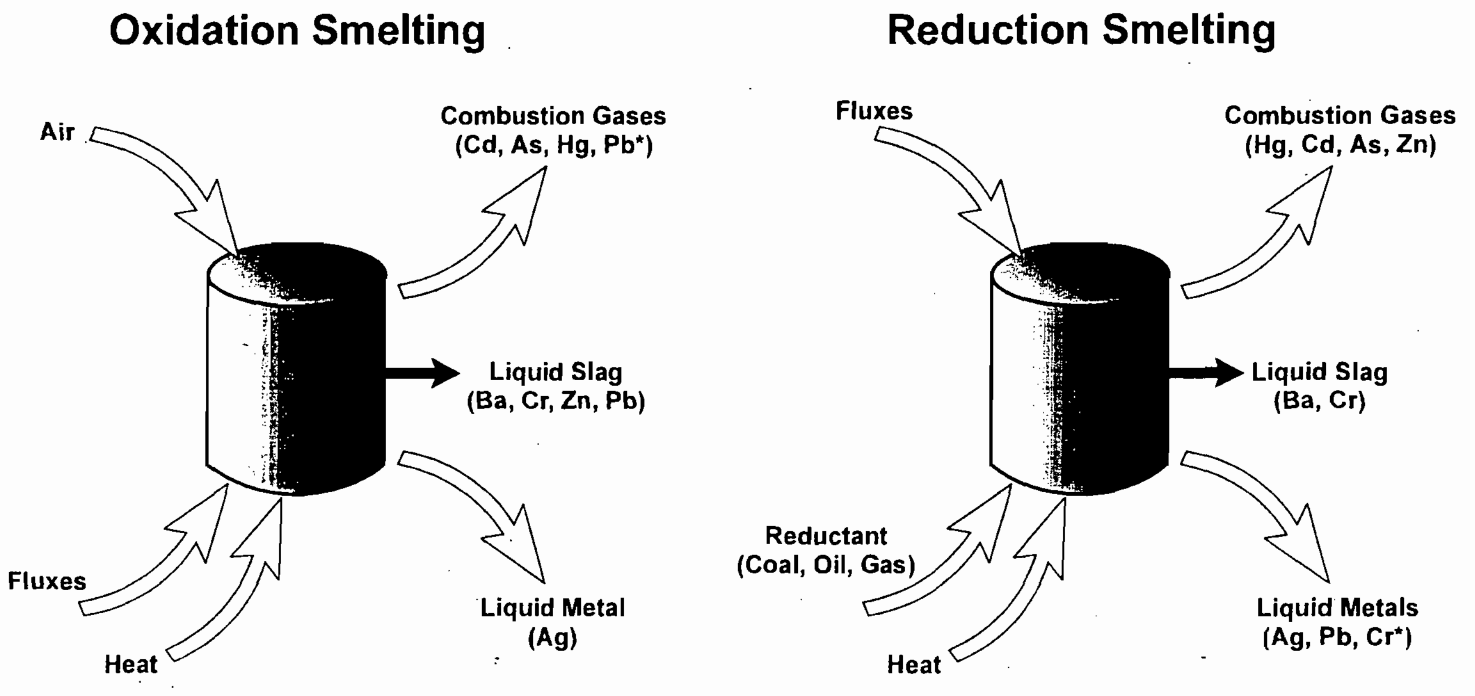
Separating the metal from the undesirable waste components typically is accomplished by physical action based on phase separations. As the metal salts react with the reducing agent to form metal or matte, the nonmetallic portions of the ore combine with the flux to form a slag. Volatile metals such as zinc and cadmium vaporize and are collected by condensation or oxidation from the off-gas, usually as oxides due to combustion of metal fume in the flue. Dense, nonvolatile metals can be separated from the less dense silicate slag by gravity-draining the metallics from the bottom of the reaction vessel. Slag oxides are tapped from a more elevated taphole.

3.8.2 Advantages of Recycling Option

Using spent ABM or other high-silica wastes in a smelter offsets the consumption of rock while producing a leach-resistant slag. The slag is similar to the product made by vitrification (see Sections 3.2 and 3.7). Using the waste in a smelter takes advantage of existing equipment to avoid the high capital and operating cost of a vitrification unit.

3.8.3 Limitation of Recycling Option

The slag chemistry in a smelting furnace must be closely controlled to produce a low-melting mix that scavenges impurities and helps to chemically reduce metal salts in the ore to elemental metal. Silicon and calcium compounds are desirable in helping to form a slag with the correct melting point. High-melting oxides such as alumina are undesirable. The smelter operators will be required to frequently sample and analyze the wastes to ensure they are compatible with the slag chemistry.



*If temperature is sufficiently high (1,400-1,600°C), Pb will volatilize as PbO.

*Chromium will distribute between metal and slag.

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Examples of Smelting Processes

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Figure 3-8. Examples of Smelting Processes.

3.8.4 Example Applications

3.8.4.1 Using Ash in Copper Smelting. Cyprus Miami Mining in Claypool, Arizona is a primary copper smelter used to process complex sulfide ores (LaChappelle and Dyas, 1993). The smelter produces copper as its main product with a small, but valuable, byproduct stream of gold and silver. Volatile metals such as lead, arsenic, and mercury are captured by acid scrubbing and sent to other facilities for recovery. The company is reported to be an exempt recycling facility with the capability of accepting D002 through D011 characteristic waste and F006 listed waste. The facility accepts selected metals; metal sludges or filter cakes; and incinerated ashes containing copper, silver, or gold. Processing ash from incineration of municipal wastewater treatment sludge provides silica as a flux and allows recovery of the trace quantities of gold and silver in the sludge. The plant also processes used foundry sand and lime residues from boiler cleaning. These materials provide fluxing agents and allow metal recovery.

3.8.4.2 Smelting Lead-Containing Wastes. The Center for Hazardous Materials Research and Exide/General Battery Corporation are demonstrating the use of secondary lead smelting to reclaim usable lead from waste materials containing between 1 and 50% lead. The characteristics of secondary lead smelters in the United States are summarized in Table 3-6. Waste containing 1 to 25% lead is treated in a reverberatory furnace to produce slag containing about 70% lead. The slag and other high-lead-content materials are fed to a blast furnace to produce lead metal products. Testing as part of the Superfund Innovative Technology Evaluation (SITE) Program has been performed on a variety of waste materials including battery cases, slags, lead dross, and lead paint chips. Materials from Superfund or other contaminated sites could be mixed with other higher grade lead material for smelting. The reported treatment cost ranges from $150/ton to $250/ton for Superfund materials (Timm and Elliott, 1993). The process has been used to treat about 1,350 tons (1,225 metric tons) of lead-bearing materials from the NL Industries Superfund site.

Table 3-6. United States Secondary Lead Smelters (November 1993) (Source: Smith et al., 1995)

Smelter Location	Year Built	Approximate Capacity MTPY(a)	Furnace Type(b)
Ponchatoula, LA	1987	8,000	BF-SRF
Boss, MO	1991	65,000	REV (Paste) SRF (Metal)
Lyon Station, PA	1964	54,000	REV-BF
Muncie, IN	1989	70,000	REV-BF
Reading, PA	1972	65,000	REV-BF
College Grove, TN	1953	10,000	BF
Eagan, MN	1948	55,000	REV-BF
Tampa, FL	1952	18,000	BF
Columbus, GA	1964	22,000	BF
Frisco, TX	1978	55,000	REV-BF
Los Angeles, CA	1981	90,000	REV-BF
Rossville, TN	1979	9,000	BF
City of Industry, CA	1950	110,000	REV
Indianapolis, IN	1972	110,000	REV-BF
Wallkill, NY	1972	70,000	REV
Troy, AL	1969	110,000	REV
Baton Rouge, LA	1960	70,000	REV-BF
Forest City, MO	1978	27,000	BF
Total secondary lead smelting capacity		1,023,000	

(a) As lead metal.

(b) BF = blast furnace; REV = reverberatory furnace; SRF = short rotary kiln.

4.0 EVALUATING RECYCLING OPTIONS FOR SPENT ABRASIVE

This section describes factors to consider when evaluating reuse and recycling options for spent ABM and other similar wastes.

4.1 Contaminant Characteristics

The types of contaminant present, their concentration, and their physical and chemical forms are major considerations in selection of a reuse or recycling option. Questions should be asked about the critical features of waste composition:

- Is the spent ABM suitable for cleaning and reuse?
- Will a mixture of metals in the waste complicate recycling?
- Will inorganic salts in the waste complicate recycling?
- Will organics in the waste complicate recycling?

The contaminant composition is determined by chemical and mineralogical analysis on a representative group of samples. The analysis should go beyond determining the concentration of the contaminants. The chemical form and speciation are important factors when considering recycling options. Matrix properties also are important (see Section 4.2).

Some fraction of the spent ABM will have the required particle size and shape to allow reuse for blasting if the impurities can be removed. Physical separation, thermal processing, or a combination of the two methods may be used to recover and restore the usable portion of the spent material.

A waste containing a limited number of contaminants generally is easier to recycle. Wastes containing a single type of metal contaminant are more likely to be suitable for higher-value uses. Segregating hazardous from nonhazardous wastes can be particularly helpful. Finding recycling options will be more difficult if the waste has a RCRA hazardous waste designation. It is often beneficial to separate spent ABM to be used for cleaning newer ships from spent ABM to be used for cleaning older ships. In 1977, the Consumer Product Safety Commission banned the use of lead-containing paints for residential use. Although there is no specific regulation banning the use of lead-containing paints for industrial coatings, lead primers have been nearly eliminated from use since the early 1980s (Leighton, 1995). Older coating materials containing lead can cause the spent ABM to be a RCRA-listed hazardous waste. If all spent ABM wastes were mixed, the volume of hazardous waste could be increased and recycling options decreased. However, plans for waste segregation should consider the desire of end users for a reliable supply of homogeneous material and the added cost of sampling and analyzing many different waste groupings (see Section 4.4.2).

Antifouling additives are a unique feature of marine coatings. The compounds used in antifouling paints for ships can introduce metal contaminants to the spent ABM. These antifouling paints serve a pest control function and must, therefore, be registered under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Copper-based antifouling coatings traditionally were favored but were largely replaced by organotin formulations that gave more reliable protection. Use of organotin antifouling coatings has been restricted worldwide, and the FIFRA registration of organotin coatings is under review by the U.S. EPA. With the increased regulatory scrutiny, the popularity of organotin antifouling coatings has been declining (Holder and Montemarano, 1995).

Inorganic salts can interfere with specific recycling options. For example, chlorides increase the volume of kiln dust waste from cement manufacturing and chlorides or sulfates produce acidic off-gas from thermal processes.

The presence of high concentrations of organic contaminants can complicate the recycling of spent ABM, but petroleum contaminants can be acceptable with some recycling options. Organic contaminants with properties similar to bitumen (e.g., the higher-molecular-weight hydrocarbons) are compatible with asphalt. Therefore, petroleum hydrocarbons may be tolerated, if the spent ABM is to be used for asphalt. Vitrification and cement-making require energy input; therefore, the waste can contain an organic contaminant if it burns to provide energy and does not add impurities or produce unacceptable off-gas.

4.2 Waste Characteristics

The waste matrix properties will affect the acceptability of the waste material for various recycling methods. For construction applications, the material matrix is the recycled product. The waste matrix affects the compatibility of the waste matrix with the intended end use. Review of waste matrix effects is aimed at answering these types of questions:

- Is the waste matrix compatible with the existing recycling processing techniques and equipment?
- Will the waste matrix increase or decrease contaminant mobility?
- Does the matrix have value as a bulk commodity?

The potential user of a recyclable waste will prefer a material with physical and chemical properties similar to those of the conventional raw material. In general, there will be a preference for a dry granular solid with a uniform concentration. The highest possible and most permanent leaching resistance is desirable and, of course, all regulatory leaching resistance requirements must be met.

Any recycling option will require simple pretreatment of the waste to upgrade, blend, or otherwise develop more uniform or desirable characteristics for the end user. At a minimum, the waste should be passed through a large mesh screen to remove trash and oversize material. Additional physical separations processing may also be useful. For example, crushing to reduce the size of large clumps followed by screening to remove both oversize debris and undersize dust will produce a more uniform particle-size material and may increase the value or range of applicable recycling options.

More complex separation processes are available to upgrade the spent ABM. Magnetic separation can remove ferromagnetic metals. Beneficiation processes involving water-assisted physical separation such as jigging, hydrocyclone separation, or tabling separate particles based on size, shape, and density. However, the added cost of the more complex beneficiation methods is more difficult to justify when dealing with wastes that are suitable only for lower-value uses.

It is important to note that conventional materials are not totally free of trace metal impurities. The metal content of the spent ABM may be within the range of composition of the conventional material it replaces. The trace element content of soils is shown in Table 4-1 to provide a general basis for comparison.

4.3 Site Characteristics

Site characteristics such as infrastructure capabilities and support service supplies may either favor or interfere with removal or handling of the waste material. Examination of site characteristics is directed at answering these types of questions:

- Is the material accessible for removal?

- Can the contaminated solid be moved efficiently by conventional bulk material handling equipment and techniques?

- Will the on-site and off-site infrastructure support transport of the waste materials?

- Are the required utility supplies and support services available?

Removal logistics are determined by access to the contaminated site for excavation, the ability to handle excavated material, space for placement of aboveground treatment equipment, and the road and rail system on and around the site. Recycling usually requires development of storage areas to allow for pretreatment of the waste (see Section 4.2), to accumulate sufficient volumes of uniform feed to satisfy user needs, and to stockpile material between projects. The surge storage will increase space requirements and may increase regulatory concerns.

Data needed to evaluate the removal logistics include maps of the site and surroundings. Important features to consider include the general arrangement of structures and infrastructure and the location of critical environments or sensitive receptors.

Table 4-1. Trace Element Content of Soils

Element	Common Range in Soil (mg/kg)	Average Concentration in Soil (mg/kg)
Ag	0.01 to 5	0.05
As	1 to 50	5
B	2 to 100	10
Ba	100 to 3,000	430
Be	0.1 to 40	6
Cd	0.01 to 0.7	0.06
Co	1 to 40	8
Cr	1 to 1,000	100
Cs	0.3 to 25	6
Cu	2 to 100	30
Ga	0.4 to 300	30
Hg	0.01 to 0.3	0.03
Mg	600 to 6,000	5,000
Mn	20 to 3,000	600
Mo	0.2 to 5	2
Ni	5 to 500	40
Pb	2 to 200	10
Sb	2 to 10	No data
Se	0.1 to 2	0.3
Sn	2 to 200	10
Sr	50 to 1,000	200
U	0.9 to 9	1
Y	25 to 250	50
Zn	10 to 300	50

Source: U.S. Environmental Protection Agency, 1983, SW-874.

4.4 Economic Factors

Economic factors including costs, market conditions, and time available for remediation play a major role in the identification and selection of recycling options.

4.4.1 Operating and Capital Costs

A reuse or recycling option is evaluated as a competitor among a group of options. To be acceptable, an option must effectively protect human health and the environment. In most cases, once effective options are identified, the one with the lowest implementation cost is selected. The economic analysis will need to consider the capital investment required to implement the candidate options and the overall cost of the recycling versus treatment and disposal. Questions typically considered as part of the economic evaluation include:

- Is there a profitable recycling option?
- Will consideration of life-cycle cost factors improve the competitive position of recycling?
- Do intangible factors favor recycling?
- Does recycling require a major investment of capital?

The value or cost of recycling spent ABM will be determined by competition with other raw materials in the marketplace. If a paying recycling market is identified for the spent ABM, treatment and disposal options should not be considered.

There usually will be a fee associated with recycling options for spent ABM and similar wastes. Recycling options will then need to be evaluated in competition with treatment and disposal alternatives, except where treatment and disposal are precluded by land ban requirements (e.g., wastes containing high concentrations of mercury or emission control dust or sludge from electric arc furnaces K061).

The economic analysis should include both direct costs and avoided expenses through the life cycle of the alternative considered. Intangible factors such as improved public image or the potential for liability should be considered. It may be appropriate to include some correction for costs that may occur but that cannot be quantified. For example, disposal options may result in liability for cleanup at a future date.

The relative capital costs can also influence a decision. Even if one option has a lower life-cycle cost, a higher total cost option with lower capital cost may be chosen due to limited availability of capital.

4.4.2 Recycling Market

The recycled spent ABM must compete effectively with conventional products filling the same needs. The competitive position of the contaminated material should be considered to address questions such as these:

- Will the recycled product equal or exceed the performance of competing products already in the market?

- Are adequate markets available within a reasonable shipping distance?

- Will the volume of material available for recycle justify the effort required to do the recycling?

Products formed from waste materials must meet or exceed the performance specifications of existing products. For example, ASTM C 825, "Specification for Precast Concrete Barrier," describes the required characteristics of formed concrete products given in the specification for New Jersey barriers.

The barrier specification combines requirements on materials, design, manufacture, and physical performance. The materials used (cement, aggregates, air-entrainment additives, and steel reinforcement) must meet applicable ASTM specifications. The design factors specified are concrete strength and air content, dimensions, reinforcement placement, finish, lifting devices, and anchorage points. Requirements for the manufacturing steps of mixing, curing, and forming are given. Test methods and required performance are given for compressive strength and dimensional tolerance.

The form of the barrier specification illustrates one hurdle for waste-derived products. For many waste-derived products, the materials and method of manufacture are totally different from those used in making the existing product. The customer may be unwilling to accept the new manufacturing methods even when the measured physical and chemical properties are equal or superior. The customer is concerned that the quality of the product is affected in part by features or interactions too complex to be measured by physical properties alone, so the quality of the raw materials and the production process must be specified and controlled. As a result, a waste-derived product often must undergo a lengthy demonstration to prove performance in real-world applications.

The location of the site and the volume of spent ABM can influence the economic viability of recycling. The shipping, handling, and storage costs can be a significant portion of the total cost, particularly with low-unit-value aggregate or construction materials. A waste source located near the end user will reduce shipping costs.

Industrial users prefer a steady supply of consistent materials. The desire for a homogeneous feedstock often is not consistent with the realities of waste production. Both the matrix composition and the contaminant levels in wastestreams can be highly variable. Also, as discussed in Section 4.1, waste segregation can help reduce the volume of hazardous wastes produced but will increase the number of waste types. Waste segregation efforts must consider a tradeoff between reducing the volume of hazardous wastes versus the increased complexity introduced by having many waste types. When wastes are segregated in small batches, each batch must be characterized, increasing sampling and analysis costs and increasing the challenges in marketing several smaller volumes of wastes.

Preprocessing the waste to improve homogeneity is a possible approach to improving market acceptance. However, additional processing increases the cost to implement the option and the complexity of the equipment needed on site.

4.4.3 Time Available for Remediation

Evaluation of reuse and recycling options should consider the amount of time required to mobilize, operate, and demobilize the selected option in relation to the time actually available to perform the work. Consideration of the timing of the options is directed at answering these types of questions:

- Can the cleanup be completed in a time frame consistent with health, safety, and environmental protection?

- Can the cleanup be completed in a time frame consistent with the end use requirements?

The time available for remediation is controlled primarily by the need to protect human safety and health and the environment. If a toxic contaminant is present, the contaminant concentration is high, or the contaminant is mobile and near a critical ecosystem, the remediation must proceed quickly. Time available may be controlled by the value or intended end use for the site. It is undesirable to keep a high-value site out of productive use for a long period.

Identification of recycling options, definition of applicable specifications, testing to determine their suitability, and negotiating contracts to do the recycling can require more time than conventional treatment technology. If the contaminant presents an imminent danger due to hazard level, mobility, or other factors, rapid remediation is needed. The need for rapid remediation of an imminent hazard favors treatment.

The importance of the length of remediation time may be lessened if the time constraint is driven by economic or end use requirements. Depending on the site logistics and the site use, it may be possible to continue routine site operations while material is removed (and, if appropriate, while it is processed on site) for recycling. However, the need for rapid remediation still generally increases the favorability of treatment technologies.

4.5 Regulatory Considerations

Regulatory constraints describe the overall regulatory climate at the site based on federal, state, and local regulations. Typically the recycled material fills only a small portion of the user's feed material requirements. Should the regulatory requirements or liability concerns be large, the user typically has a competitive source of virgin material to replace the recycled material. As a result, regulatory issues can present a significant challenge to recycling of materials with a RCRA waste code or coming from a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) site. Examination of regulatory standards is directed at answering such questions as these:

- What contaminant control levels are required?
- Are the materials controlled by RCRA hazardous characteristics or listings?
- Are the materials controlled by state or local hazardous or industrial waste regulations?
- Can a valid reuse, reclamation, or recycling process be applied to exempt RCRA waste?

Regulatory considerations often are the most important factors influencing the viability of a particular recycling option. Therefore, before plans for recycling are pursued in depth, it is important to determine the federal, state, and local regulations that may be applied to a particular site, waste material, and/or recycling option.

Regulations pertaining to recycling vary widely from state to state; in addition, the prevailing attitude on the part of the regulator towards recycling will vary based on a number of factors, such as prior track record, perceived risk, and other factors. It is not possible here to define or predict the compliance issues that may be encountered on a project-by-project basis. The remainder of this section summarizes U.S. EPA and some examples of state regulations that pertain to the recycling of spent ABM. The discussion of state regulations and policy pertains primarily to California, Oregon, and Washington but may provide some generic perspective on the types of compliance issues that may be encountered in other states as well.

4.5.1 Federal Regulations — RCRA

One of the first steps in identifying the regulatory requirements is to determine if the spent ABM is considered a hazardous waste under RCRA. This law and the regulations issued pursuant to the law place stringent requirements on the storage, treatment, and disposal of hazardous waste. Under RCRA, a waste may be considered hazardous if it is either specifically listed (e.g., certain spent solvents from certain processes or specific chemicals) or it may be hazardous by characteristic (i.e., it is ignitable, reactive, corrosive, or "toxic" based on the TCLP). For spent ABM, it is most often the metals from the paints (e.g., lead) that cause the waste to fail the TCLP and thus be considered a RCRA hazardous waste.

Because of extensive regulatory tracking, reporting, testing, and in some cases, permitting requirements, and because of concerns for future liability, many companies are not willing to accept RCRA hazardous wastes as substitutes for their normal raw materials. Therefore, it is important to know if the waste is RCRA hazardous and to discuss any proposed reuse/recycling with the potential recycler before proceeding. In addition, the U.S. EPA or their delegated regulatory agency has authority over recycling of RCRA hazardous wastes and it is critical to determine whether the recycling option will be allowed by the regulatory agency before engaging in the process.

The regulation of recycling RCRA hazardous waste is a complex and evolving area. The U.S. EPA is considering revising the existing regulations to make legitimate recycling easier; however, these revisions are not yet in place. The regulation of recycling is still quite complex and is often determined on a case-by-case basis. An overview of the existing recycling regulations and policies is discussed below.

Rules issued by U.S. EPA on January 4, 1985 (50 FR 614) acknowledged the need to encourage safe recycling of hazardous wastes — particularly when recycling clearly reduces potential harm — while at the same time assuring the abatement of pollution and the prevention of harm to human health and the environment.

For a secondary material to be regulated under RCRA Subtitle C, a substance must first meet the definition of a "solid waste." Section 1004(27) of RCRA defines solid waste as:

> any garbage, refuse, sludge, ... and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations and from community activities.

A central element of this definition is that wastes are "discarded." In 1985, the U.S. EPA revised the definition of solid waste to further clarify when a secondary material that will be recycled is considered a solid waste. Under the regulatory definition of solid waste, found in 40 CFR 261.2(a-f), a secondary material is defined as a solid waste if:

- it is abandoned
- it is recycled in certain ways, or
- it has been defined as "inherently waste like."

The term "secondary material" refers to spent materials, sludges, byproducts, commercial chemical products, and scrap metals. "Spent material" is defined as a material that has been used, which as a result of contamination can no longer serve the purpose for which it was produced without further processing. When any of the five types of secondary materials are "recycled in certain ways," they may or may not be defined as solid wastes. The U.S. EPA has made distinctions between recycling that is regulated as waste management and recycling that is exempt from regulation, depending on the type of secondary material and the manner in which it is being managed.

With respect to the second item, "recycled in certain ways," secondary materials are solid wastes, and thus are subject to regulation, when they are recycled in the following four ways:

- used in a manner constituting disposal (i.e., applied to the land or used to produce a product that is placed on the land) [note that use of hazardous waste in asphalt and concrete generally is considered use constituting disposal.]
- burned for energy recovery (including use to produce a fuel)
- reclaimed (processed to recover a usable product or component or regenerated), or
- accumulated speculatively (material stored with less than 75% recycled within 1 calendar year).

The regulations state that when any of the secondary materials identified above is recycled in any of the four ways indicated, it is defined as a solid waste, with four primary exceptions:

- characteristic sludges being reclaimed
- characteristic byproducts being reclaimed
- commercial chemical products being reclaimed, or
- commercial chemical products being speculatively accumulated.

Characteristic sludges and byproducts used in any of the remaining three ways (i.e., placed on the land, burned for energy recovery, or accumulated too long before recycling) are solid wastes. Commercial chemical products that are placed on the land or burned for energy recovery also are solid wastes, unless that is their ordinary use.

In addition to the exclusions discussed above, the U.S. EPA recognized other situations that closely resemble production processes and, therefore, are excluded from regulation under the RCRA program. Materials are not solid wastes when they are legitimately recycled by being:

- used or reused as an ingredient in an industrial process to make a product, provided the materials are not first reclaimed
- used or reused as effective substitutes for commercial products provided they have not been reclaimed, or
- returned to the original process from which they were generated without first being reclaimed (material must be used as a substitute for raw material feedstock).

These materials are not considered solid waste.

Although the direct reuse provisions exempt certain materials from being solid wastes, there are limits to these exemptions. Materials that are used/reused as ingredients or substitutes for commercial products, but are also placed on the ground or incorporated into products placed on the ground (i.e., that are used in a manner constituting disposal) remain solid wastes. Also, if a material is used or reused by being burned for energy recovery or used to produce a fuel, it remains a solid waste. Finally, if a material is speculatively accumulated or is "inherently waste like," the material remains a solid waste regardless of the manner in which it is recycled.

The burden of proof that a particular material is not a solid waste and is, therefore, exempt from regulation lies with the person making the claim. This person must be able to demonstrate that there is a market for the material and that the specific use/reuse meets the condition of the exclusion. Closed-loop recycling processes also are excluded from regulation (40 CFR 261.4).

In addition, three case-by-case variances can be granted by the Regional EPA Administrator to exclude a material from classification as a "solid waste," the following two of which involve recycling:

- A material is reclaimed and then reused as a feedstock within the original primary production process in which the material was generated if the reclamation operation is an essential part of the production process, or

- A material has been reclaimed but must be reclaimed further before recovery is complete if, after initial reclamation, the resulting material is commodity-like.

The U.S. EPA has also established a policy identifying criteria that may indicate sham recycling that is actually a surrogate for hazardous waste treatment or disposal. If a person uses a secondary material as is (in a production process), that person must be able to show that the secondary material is as effective as the raw material it is replacing. Also, if the material does not contribute any necessary or significant element to a product of the production process, the recycling may be a sham. Other indicators of sham recycling are use of a secondary material in excess of the amount necessary for a particular process and the handling of a secondary material without regard to economic loss. The burden of proof for the legitimacy of a claimed regulatory exemption rests solely on the recycler.

For secondary materials subject to regulation as a solid waste and potentially as a hazardous waste, specific standards exist for some types of hazardous waste reuse or reclamation activities. Generators and transporters of recyclable materials (hazardous wastes that will be recycled) generally are subject to 40 CFR Parts 262 (generator requirements) and 263 (transporter requirements) of Subtitle C, as well as notification requirements of Section 3010 of RCRA. Additionally, recycling facilities that store recyclable materials prior to recycling are subject to notification requirements and Subtitle C hazardous waste storage requirements. However, in general, the recycling process itself currently is exempt from regulation under Subtitle C. Recycling facilities that do not store recyclable materials before recycling are subject only to Subtitle C notification and manifest requirements.

Some particular recyclable materials are not subject to the full generator, transport, and storage requirements of Subtitle C, but are only subject to the limited provisions of Part 266 (again, the actual recycling process is not regulated; only the storage prior to recycling is subject to full Subtitle C regulation). Recyclable materials regulated under Part 266 include:

- hazardous waste burned for energy recovery
- precious metal reclamation
- spent lead-acid batteries
- recyclable materials used in a manner constituting disposal.

4.5.2 State and Local Regulations

State and local requirements can vary widely. Therefore, it is important to determine what the requirements are for a specific location. For spent ABM that is not RCRA hazardous, the following regulatory agencies potentially could have cognizance:

- state air board or air quality management district
- state water board
- state environmental protection agency (or department of environmental protection)
- county department of public health (or similar agency, if applicable)
- city department of public health (or similar agency, if applicable).

The names of these organizations may vary widely from region to region, and the above list is not necessarily complete. A list of addresses and phone numbers of state environmental regulatory agencies, and a list of U.S. EPA information hotlines and other sources of regulatory information pertaining to recycling are provided in Appendix B.

Some states have established requirements that are more stringent than those of the federal government for determining what waste is considered hazardous. Thus, spent ABM that is not hazardous under RCRA potentially could be considered hazardous by a particular state and must be handled and disposed of according to the state or local requirements. For example, California requires a slightly different testing procedures for determining toxic metals content and leachability. Also, the state has established lower concentrations for toxic metals and includes several additional metals such as copper that are not regulated under RCRA.

4.5.2.1 Summary of California EPA Policy Regarding "Use in a Manner Constituting Disposal." California is one of a handful of states that have promulgated policy pertaining to recycling hazardous wastes into construction materials and specifying acceptance criteria for the types of wastes or byproducts that may be recycled. On August 18, 1995, the California EPA, Department of Toxic Substances Control (DTSC), Alternative Technology Division in Sacramento issued a management memo dated August 1995 for "The Use of Recyclable Materials in Asphalt Concrete and Concrete (Use Constituting Disposal or UCD)" (Appendix C). The purpose of this policy is to encourage the recycling of suitable wastes into construction materials and to establish conditions to assure that the recycling occurs safely and can be monitored as necessary to prevent abuses. Several of these conditions, which are described more fully in Appendix C, are as follows:

- The policy applies only to non-RCRA (California-only) hazardous wastes.

- For wastes failing the California WET test, the contaminant in the resulting construction material needs to be "chemically-bound." The effect of contaminant dilution by other ingredients in the construction materials needs to be accounted for by increasing the measured leachable concentration by the dilution factor so that the component of immobilization due to chemical binding can be assessed. The WET soluble metal content of the asphalt-treated ABM must adhere to STLC standards after accounting for the effect of dilution.

- Recyclable materials should add no significant hazard to public health or the environment, either in the recycling process or in the final product.

- The recyclable materials must be used beneficially; that is, the material must meet accepted performance standards such as Caltrans (California Department of Transportation) specifications and must be made for commercial use.

Clearly, compliance with these criteria will involve some testing and evaluation. Demonstrating compliance with the metals leaching criteria will require laboratory or field treatability tests to evaluate the extent of metals immobilization due to asphaltic binder ingredients. Compliance with the criteria pertaining to hazards posed by the recycling process or product may require the performance of a quantitative risk assessment.

4.5.2.2 California Hazardous Waste Management Compliance Issues. The regulations summarized above specify when a hazardous byproduct is recyclable. Once that recyclability is demonstrated, for category 2 and 3 wastes, it will still be necessary to manage that recycling project in compliance with applicable state, local, and/or U.S. EPA waste management regulations.

As in the previous sections, it is not possible to define these regulations and policies for every region, as they will vary significantly from region to region. However, it is instructive to indicate the types of compliance issues that may exist, using California as an example.

In California, hazardous waste control requirements are set forth in the California Health and Safety Code, Division 20, Chapter 6.5, Section 25100 et seq. and regulations have been adopted to implement this section of the statutory code. Recyclable materials are subject to these requirements unless a variance is issued by the California DTSC or unless the material is excluded or exempted from classification as a waste under Section 25143.2(b), (c), or (d) or California's hazardous waste management regulations (adopted pursuant to Sections 25150 and 25151).

Materials exempted or excluded under Section 25143.2, subdivisions (b) or (d), must be managed in accordance with the requirements for management of a recyclable material specified in 25143.9. Under 25143.9(a), if a material is held in a container or tank, the container or tank must be labeled, marked, and placarded in accordance with DTSC hazardous waste labeling, marking, and placarding requirements applicable to generators, except that the container or tank would be labeled or marked clearly with the words "Excluded Recyclable Material" instead of the words "Hazardous Waste," and manifest document numbers would not be applicable.

Under 25143.9(b), the owner or operator of the business location where the material is located must have a business plan that meets the California requirements given in Section 25504, including but not limited to, emergency response plans and procedures, as described in subdivision (b) of Section 25504, which specifically address the material meet the DTSC's emergency response and contingency requirements that are applicable to generators of hazardous waste.

Section 25143.9(c) requires that the recyclable material be stored and handled in accordance with all local ordinances and codes governing the storage and handling of the hazardous material, including but not limited to, fire codes. If a local jurisdiction does not have an ordinance or code requiring secondary containment for hazardous material storage areas, then the material must be stored in tanks, waste piles, or containers meeting the DTSC's interim status regulations establishing design standards applicable to tanks, waste piles, or containers storing hazardous waste. Finally, under Section 25143.9(d), there are additional requirements if the material is being exported to a foreign country.

Although recyclable materials are not required to comply with the same regulations applied to hazardous waste generators, there is a statutory provision that affects the length of time that recyclable materials can be stored. Under Section 25413.2(e), materials that are accumulated speculatively do not qualify for the exemptions under Section 25143.2. Because California has not specified a definition of speculative accumulation, the definition established by the U.S. EPA in 40 CFR 261.1(c)(8) applies. Under this definition, a recyclable material is not accumulated speculatively if the person accumulating it can show that the material is potentially recyclable and has a feasible means of being recycled; and that during the calendar year (commencing on January 1), the amount of material that is recycled or transferred to a different site for recycling equals at least 75% by weight or volume of the amount of that material accumulated at the beginning of the period.

Persons recycling more than 100 kilograms per month of recyclable material are required to provide reports to the local health officer or other local public officer authorized to implement the statute (see Section 25143.10). The following information is required to be provided in writing every 2 years:

- the name, site address, mailing address, and telephone number of the owner or operator of any facility that recycles the material
- the name and address of the generator of the recyclable material
- documentation that the requirements of any exemptions or exclusions pursuant to Section 25143.2 are met including, but not limited to, all of the following:
  - where a person who recycles the material is not the same person who generated the recyclable material, documentation that there is a known market for disposition of the recyclable material and any products manufactured from the recyclable material.
  - where the basis for the exclusion is that the recyclable material is used or reused to make a product or as a safe and effective substitute for a commercial product, a general description of the material and products, identification of the constituents or group of constituents, and their approximate concentrations, which would render the material or product hazardous under the regulation adopted pursuant to Sections 25140 and 25141, if it were a waste, and the means by which the material is beneficially used.

This information must be provided in the format developed by the California Conference of Directors of Environmental Health in consultation with the DTSC. Also, if the person recycling the material is not the same person who generated the recyclable material, then the person who recycles the material is required to provide the generator with a copy of the information listed above.

If the exclusion of the recyclable material is questioned and the regulatory authority brings action against owner or operator using the recyclable material, the burden of proof that the exclusion is valid lies with the owner or operator, not with the agency. The owner or operator would be required to provide information on the management of the material and to maintain adequate records to demonstrate that there is a market for disposition of the material (Section 25143.2, subdivision (f)).

4.5.2.3 Spent ABM Reuse in Washington and Oregon. The states of Washington and Oregon each have state regulations that potentially could favor recycling of state-only hazardous waste because of restrictions on landfilling such materials. A brief summary of these regulations is discussed below.

Washington's Dangerous Waste Guidelines (Washington Administrative Code [WAC] Chapter 173-303) have adopted TCLP testing parameters that are identical to the federal regulations specified under RCRA. However, Washington Department of Ecology Technical Information Memorandum (TIM)

86-1 specifies additional analytical testing requirements for foundry slag and baghouse wastes from the sandblasting industry. TIM 86-1 specifies three additional metals: copper, nickel, and zinc. This memorandum stipulates that if the cumulative concentrations of these three metals in their soluble form exceeds 5 parts per million (ppm), then additional criteria under aquatic toxicity testing must be reviewed prior to disposal through a municipal facility. These criteria may not apply if the materials are recycled or used in additional industrial processes. It is not clear how this would apply to spent ABM; however, recycling potentially could be more favorable if the presence of these metals caused disposal costs to be greater.

The Oregon Hazardous Waste Guidelines (Oregon Administrative Rules (OAR) Chapter 340) also have adopted the federal TCLP criteria for heavy metals. However, the Oregon Department of Environmental Quality has recently promulgated legislation for the management of ABM from ship repair activities. This segment of legislation specifically targets the ship repair industry and the use of antifouling paints. Under this regulation, spent antifouling residues may be considered pesticides. Because antifouling paints are potential pesticides, and sandblast grit waste containing such is subject to Oregon's Aquatic Toxicity Test (OAR 340-101-033). If the sandblast grit fails the original TCLP parameters, the material is then classified as a federally regulated hazardous waste and an aquatic toxicity test is not necessary; it must be managed as a hazardous waste. If the waste passes the TCLP test and fails the aquatic toxicity test, it is classified as an Oregon State-Only dangerous waste and must be managed as a hazardous waste. Upon further review of this legislation, this rule is applicable to materials primarily managed and disposed through municipal landfill facilities and does not include those wastes managed through a legitimate recycling or reuse program. The Department of Environmental Quality does allow disposal of spent grit that fails the aquatic toxicity test if the solid waste landfill meets design criteria specified in 40 CFR 258.40.

5.0 SUMMARY AND CONCLUSIONS

Section 2 describes physical and chemical aspects of new and spent ABM, Section 3 discusses some specific approaches to recycling spent ABM, and Section 4 describes factors to consider when reviewing and selecting recycling options. These sections outline some guideposts to possible markets for your spent ABM or similar wastes and indicate factors to consider when searching for recycling options. The analysis is a complex task which must be done for a specific waste material.

Due to the lack of a clear definition of what constitutes valid recycling, the user needs to be particularly careful when identifying options for hazardous material recycling. The ultimate interpretation rests with the federal and local regulators.

Once the potential markets are identified, some basis must be found for establishing specifications for materials. Reliable materials commerce requires some acceptable standards describing the composition, quality, and properties of recycled materials. The specifications may be based on the material origin, composition, end use performance, or other characteristics. Potential end users may avoid recycled material if they are uncertain about the impurity levels or how well the quality of the material will be controlled.

In general, developing a specification will require negotiation between the supplier and user. Some guidance is available in the form of ASTM or other specifications that include or can be applied to recycled materials. The U.S. EPA, under the provisions of RCRA, is encouraging government agencies to allow use of recycled materials. However, most existing specifications are written to ignore or possibly even preclude recycled materials. Creative use of existing specification may be needed to reach a definition of material composition and properties that is acceptable to the buyer and seller.

Material characterization for recycling requires a somewhat different outlook and approach than is typical for waste treatment studies. Waste characterization for waste treatment and disposal usually focuses mainly on the amounts of contaminant present. The mineral form of the contaminant and the composition and form of the matrix are considered only in light of how they may affect the performance of treatment or disposal options. Recycling requires thinking of the entire body of waste material as a product. As a result, its total composition, chemical speciation, and physical form need to be established early in the characterization process.

Waste materials, particularly those from CERCLA sites, usually have highly variable compositions. End users prefer a reliable stream of materials with predictable composition. The waste supplier may, therefore, need to provide pretreatment to homogenize and sample the material to prepare a product that is acceptable for the user.

In the face of competition for traditional raw materials sources, the waste generator or supplier often needs to take an active role to seek out uses for the waste material. Recycling can succeed only if there are markets for the waste material. In general, users of recycled materials are in a buyer's market. A large new source of waste materials available for recycling can saturate end use markets. These elements can help in finding a home for waste materials:

- established and effective specifications
- creative efforts to identify possible uses

- providing a reliable supply of consistent material
- programs to improve public awareness of recycling potential.

These seem daunting tasks that lie beyond the scope of normal waste processing and disposal. However, significant benefits can be achieved in reduced liability and possibly reduced cost if the waste material is recycled rather than sent for disposal.

The individual waste generator can contribute, but efforts are needed from a variety of groups to help expand recycling of industrial wastes. The task is not impossible. Europe has installed an infrastructure for recycling a variety of industrial wastes. Technologies and systems are growing in the United States to support recycling.

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APPENDIX A

ABRASIVE BLASTING MEDIA QUALIFIED FOR USE ON U.S. NAVY SHIPS

QUALIFICATIONS CERTIFIED
MAY 1990

QPL-22262-18
20 June 1995
SUPERSEDING
QPL-22262-17
21 May 1993

QUALIFIED PRODUCTS LIST

OF

FSC 5350

PRODUCTS QUALIFIED UNDER MILITARY SPECIFICATION

MIL-A-22262

ABRASIVE BLASTING MEDIA SHIP HULL BLAST CLEANING

This list has been prepared for use by or for the Government in the acquisition of products covered by the subject specification and such listing of a product is not intended to and does not connote indorsement of the product by the Department of Defense. All products listed herein have been qualified under the requirements for the product as specified in the latest effective issue of the applicable specification. This list is subject to change without notice; revision or amendment of this list will be issued as necessary. The listing of a product does not release the contractor from compliance with the specification requirements.

THE ACTIVITY RESPONSIBLE FOR THIS QUALIFIED PRODUCTS LIST IS THE NAVAL SEA SYSTEMS COMMAND, SEA 03R42, 2531 JEFFERSON DAVIS HWY, ARLINGTON, VA 22242-5160.

GOVERNMENT DESIGNATION	MANUFACTURER'S DESIGNATION	TEST OR QUALIFICATION REFERENCE	MANUFACTURER'S NAME AND ADDRESS
	BARTON 1640 GARNET	NAVSHIPYD, MARE 9631, Ser 134.6/62 and NEHC Rpt. 6266, Ser 34Bdbm 06015	Barton Mines Corp. P.O. Box 400 North Creek, NY 12853 Plant: Hudson River Plant Route 28 North Creek, NY 12853
	STARBLAST XL	NAVSHIPYD, MARE 9631, Ser 134.6/79 and NEHC Rpt. 6260, Ser 34Bnhp/2014	E.I. du Pont de Nemours & Co., Inc. Chestnut Run Plaza Building 709 Wilmington, DE 19880-0709 Plant: Florida Plant Route 230 Starke, FL 32091

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GOVERNMENT DESIGNATION	MANUFACTURER'S DESIGNATION	TEST OR QUALIFICATION REFERENCE	MANUFACTURER'S NAME AND ADDRESS
	Emerald Creek Garnet	NAVSHIPYD, MARE 9631, Ser 134.6/ 158 and NEHC Rpt. 6270, Ser 342/0548	Emerald Creek Garnet P.O. Box 190 Fernwood, ID 83830 Plant: Route 4 Emerald Creek Road Fernwood, ID 83830
	Black Diamond	NAVSHIPYD, MARE 9631, Ser 134.6/ 151 and NEHC Rpt. 4121, Ser 34Bvs/ 02176	Foster Dixiana Corp. P.O. Box 2005 Columbia, SC 29202 Plant: 5360 Bainbridge Blvd. Chesapeake, VA 23320
	Black Diamond (CX-8)	NAVSHIPYD, MARE 9631, Ser 134.6/ 56 and NEHC Rpt 4123, Ser 34Dndb/ 01007	Foster Dixiana Corp. P.O. Box 2005 Columbia, SC 29202 Plant: Hardeeville Ind. Park - Hwy. 321 Hardeeville, SC 29927
	ROM 30x60 Garnet Abrasive GMA 30X60 GMA 60 mesh GMA 80 mesh	NAVSHIPYD, MARE 9631, Ser 134.6/ 178 and NEHC Rpt. 6270, Ser 34Bns 06336	Garnet Millers Assoc. Pty. Ltd. (GMA), c/o Barton Mines Corp., Suite 190 1658 Cole Blvd. Golden, CO 80401 Plant: Gould Road Geraldton, WA 6530 Australia
	CAMEL BLACK	NAVSHIPYD, MARE 9631, Ser 134.6/95 and NECH Rpt. 6270 Ser 34B/4697	Genstar Stone Products Company Executive Plaza IV Hunt Valley, MD 21031-1091 Plant: 10300 Pulaski Highway White Marsh, MD 21162

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GOVERNMENT DESIGNATION	MANUFACTURER'S DESIGNATION	TEST OR QUALIFICATION REFERENCE	MANUFACTURER'S NAME AND ADDRESS
	GREEN DIAMOND	NAVSHIPYD, MARE 9631, Ser 134.6/ 61 and NEHC Rpt. 6270, Ser 34Baj/ 06016	Glenbrook Nickel Co. 5094 Glenbrook Loop Rd P.O. Box 85 Riddle, OR 97469 Plant: 6th & E Street Riddle, OR 97469
	Kleen Blast	NAVSHIPYD, MARE ISLAND Rpt. 9631 Ser 134.6/34 & NEHC Rpt. 6270 Ser 42p/08213	Kleen Blast Abrasives 2400 Old Crow Canyon Road, #AZ San Ramon, CA 94583 Plant: Pacific Abrasive and Supply West Carson Rd. Grand Forks, B.C. Canada VOH 1-HO
	Sharpshot M-60 Sharpshot F-80	NAVSHIPYD, MARE ISLAND Rpt. 9631 Ser 134.6/67 & NEHC Rpt. 6266 Ser 422mb/12025	Minerals Research & Recovery of Arizona, Inc. 4565 South Palo Verde Suite #203 Tucson, AZ 85714 Plant: Highway 85 Ajo, AZ 85321
	Ferro-Blast/ Best Grit 73	NAVSHIPYD, MARE Rpts. 9631, Ser 134.6/25 & 9631, Ser 134.6/169 and NEHC Rpt. 4121, Ser 34Bm/12187	RDM Multi-Enterprises, Inc. P.O. Box 179 Anaconda, MT 59711 Plant: 1/2 Mile East of Anaconda on Montana Highway #1 Anaconda, MT 59711

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GOVERNMENT DESIGNATION	MANUFACTURER'S DESIGNATION	TEST OR QUALIFICATION REFERENCE	MANUFACTURER'S NAME AND ADDRESS
	Black Beauty 1240 2040	NAVSHIPYD, MARE 9631, Ser 134.6/181 and NEHC Rpt. 6720, Ser 422hc/03299	Reed Minerals Div. Harsco Corporation 8149 Kennedy Avenue Highland, IN 46322 Plant: State Road 176 Drakesboro, KY 42337
	Black Beauty 1040 1243 2043	NAVSHIPYD, MARE Rpts. 9631, Ser 134.6/202 & Ser 134.6/ 224 & NEHC Rpt. 6720, Ser 34Bvs/11513	Reed Minerals Div. Harsco Corporation 8149 Kennedy Avenue Highland, IN 46322 Plant: River Rd. at Merrimack Power Station Concord (Bow), NH 03302
	Stan-Blast	NAVSHIPYD, MARE 9631, Ser 134.6/48 and NEHC Rpt. 6270, Ser 422c/08253	Stan-Blast Abrasives Company, Inc. 2525 South Shore Blvd. Suite 301 League City, TX 77573 Plant: 5712 Port Industrial Galveston, TX 77552
	Stan-Blast	NAVSHIPYD, MARE 9631, Ser 134.6/132 and NEHC Rpt. 6270, Ser 422c/08253	Stan-Blast Abrasives Company, Inc. 2525 South Shore Blvd. Suite 301 League City, TX 77573 Plant: 3300 River Road Harvey, LA 70059
	Black Blast	NAVSHIPYD, MARE 9631, Ser 134.6/11 and NEHC Rpt. 4121, Ser 34Bns/11017	Virginia Materials P.O. Box 7400 Norfolk, VA 23509 Plant: 3306 Peterson Street Norfolk, VA 23509

APPENDIX B

LISTING OF REGULATORY INFORMATION SOURCES

HAZARDOUS WASTE CONTACTS

ALABAMA
Alabama Dept of Environmental Management
Land Division
1751 Federal Drive
Montgomery, AL 36130
334-271-7730

ALASKA
Dept. of Environmental Conservation
410 Willoughby Avenue, Suite 105
Juneau, AK 99801-1795
Program Manager: 907-465-5150
Northern Regional Office (Fairbanks): 907-451-2360
South-Central Regional Office (Juneau): 907-563-6529
Southeast Regional Office (Juneau): 907-465-5350

ARIZONA
Arizona Dept. of Environmental Quality
Waste Programs Bureau
3033 North Central Avenue
Phoenix, AZ 85012
602-207-2300

ARKANSAS
Dept. of Pollution Control and Ecology
Hazardous Waste Division
P.O. Box 8913
8001 National Drive
Little Rock, AR 72219-8913
501-562-7444

CALIFORNIA
California EPA
Dept. of Toxic Substances Control
400 P Street, 4th Floor
P.O. Box 806
Sacramento, CA 95812-0806
916-322-0504

California EPA
State Water Resources Control Board
Water Resources Control Board
P.O. Box 100
Sacramento, CA 95812-0100
916-657-2390

COLORADO
Public and Environment Dept.
Hazardous Materials and Waste Management Division
4300 Cherry Creek Drive South
Denver, CO 80222
303-692-3300

CONNECTICUT
Dept. of Environmental Protection
Waste Management Bureau
Waste Engineering and Enforcement Division
79 Elm Street
Hartford, CT 06106
203-424-3023

Connecticut Resource
Recovery Authority
179 Allyn Street, Suite 603
Professional Building
Hartford, CT 06103
203-549-6390

DELAWARE
Dept. of Natural Resources and Environmental Control
Division of Air and Waste Management
Hazardous Waste Office
89 King's Highway
P.0. Box 1041
Dover, DE 19903
302-739-3689

DISTRICT OF COLUMBIA
Dept. of Consumer and Regulatory Affairs
Environmental Regulation Administration
Pesticides and Hazardous Waste Management Branch
2100 Martin Luther King Avenue, SE, Suite 203
Washington, DC 20020
202-645-6617

FLORIDA
Environmental Protection Dept.
Waste Management Division
Solid and Hazardous Waste Bureau
3900 Commonwealth Boulevard
Tallahassee, FL 32399
904-488-0300

GEORGIA
Georgia Dept. of Natural Resources
Environmental Protection Division
Hazardous Waste Management Branch
Floyd Towers East, Suite 1154
205 Butler Street, SE
Atlanta, GA 30334
404-656-7802

HAWAII
Dept. of Health
Solid and Hazardous Waste Branch
5 Waterfront Plaza, Suite 250
919 Ala Moana Boulevard
Honolulu, HI 96813
808-586-4225

IDAHO
Dept of Health and Welfare
Division of Environmental Quality
280 North 8th Street
Boise, ID 83720
208-334-5840

ILLINOIS

Energy and Natural Resources Dept.
Solid Waste and Renewable Resources Division
325 West Adams Street, Room 300
Springfield, IL 62704
217-785-2800

INDIANA
Dept. of Environmental Management
Office of Solid and Hazardous Waste
100 North Senate Avenue
Indianapolis, IN 46206
317-232-3210

IOWA
Dept. of Natural Resources
Waste Management Assistance Division
Wallace State Office Building
900 East Grand
DesMoines, IA 50319
515-281-8975

KANSAS
Dept. of Health and Environment
Bureau of Waste Management
Forbes Field, Building 740
Topeka, KS 66620
913-296-1612

KENTUCKY
Natural Resources and Environmental Protection Cabinet
Division of Waste Management
18 Reilly Road
Frankfort, KY 40601
502-564-4245

LOUISIANA
Dept. of Environmental Quality
Solid and Hazardous Waste Division
11720 Airline Highway
Baton Rouge, LA 70817
504-765-0249

MAINE
Dept. of Environmental Protection
Bureau of Hazardous Materials and Solid Waste Control
State House Station #17
Augusta, ME 04333
207-289-2651

MARYLAND
Environment Dept.
Waste Management Administration
2500 Broening Highway
Baltimore, MD 21201
410-631-3304

MASSACHUSETTS
Dept. of Environmental Protection
Hazardous Waste Division
One Winter Street, 5th Floor
Boston, MA 02108
617-292-5853

MICHIGAN
Michigan Dept. of Natural Resources
Waste Management Division
P.O. Box 30241
Lansing, MI 48909
517-373-2730

MINNESOTA
Pollution Control Agency
Hazardous Waste Division
520 Lafayette Road North
St. Paul, MN 55155
612-297-8502

MISSISSIPPI
Dept. of Environmental Quality
Division of Solid and Hazardous Waste Management
P.O. Box 10385
Jackson, MS 39289
601-961-5047

MISSOURI
Dept. of Natural Resources
Waste Management Program
P.O. Box 176
Jefferson City, MO 65102
314-751-3176
Missouri Natural Resources Hotline: 800-334-6946

MONTANA
Dept. of Health and Environmental Sciences
Waste Management Division
Cogswell Building, Room B 201
Helena, MT 59620
406-444-1430

NEBRASKA
Environmental Quality Dept.
P.O. Box 98922
Lincoln, NE 68509
402-471-2186

NEVADA
Conservation and Natural Resources Dept.
Division of Environmental Protection
Waste Management Program
123 West Nye
Carson City, NV 89710
702-687-4670

NEW HAMPSHIRE
Dept. of Environmental Services
Waste Management Division
Health and Welfare Building
6 Hazen Drive
Concord, NH 03301
603-271-3406

NEW JERSEY
Dept. of Environmental Protection and Energy
Solid Waste Management
401 East State Street, CN-423
Trenton, NJ 08625
609-530-8591

NEW MEXICO
Environmental Improvement Division
Hazardous Waste Bureau
P.O. Box 26110
Santa Fe, NM 87502
505-827-2775

NEW YORK
Dept. of Environmental Conservation
Division of Hazardous Substances Regulation
50 Wolf Road, Room 229
Albany, NY 12233
518-457-6934
SQG Hotline: 800-462-6553

NORTH CAROLINA
Dept. of Environmental, Health, and Natural Resources
Hazardous Waste Section
P.O. Box 27687
Raleigh, NC 27611
919-715-4140

NORTH DAKOTA
Dept. of Health
Consolidated Laboratories
Division of Waste Management
P.O. Box 5520
1200 Missouri Avenue, Room 302
Bismark, ND 58502
701-328-5166

OHIO
Ohio EPA
Division of Hazardous Waste
P.O. Box 1049
Columbus, OH 43216
614-644-2917

OKLAHOMA
Environmental Quality Dept.
Waste Management Division
1000 NE Tenth Street
Oklahoma City, OK 73117
405-271-7041

OREGON
Dept. of Environmental Quality
Hazardous Waste Division
811 SW. Sixth Avenue
Portland, OR 97204
503-229-6585

PENNSYLVANIA
Dept. of Environmental Resources
Bureau of Waste Management
Director's Office
P.O. Box 2063
Harrisburg, PA 17105
717-787-9870

RHODE ISLAND
Dept. of Environmental Management
Division of Air and Hazardous Materials
291 Promenade Street
Providence, RI 02908
401-277-4700

SOUTH CAROLINA
Dept. of Health and Environmental Control
Bureau of Solid and Hazardous Waste Management
2600 Bull Street
Columbia, SC 29201
803-734-5202

SOUTH DAKOTA
Dept. of Environment and Natural Resources
Office of Waste Management
500 East Capital Avenue
Pierre, SD 57501
605-773-3351

TENNESSEE
Environment and Conservation Dept.
Solid Waste Management Division
401 Church Street, 21st Floor
Nashville, TN 37248
615-532-0780

TEXAS
Natural Resource Conservation Commission
Industrial and Hazardous Waste Division
P.O. Box 13087
Capital Station
Austin, TX 78711
512-239-2324

UTAH
Dept. of Environmental Quality
Division of Solid and Hazardous Waste
P.O. Box 144810
Salt Lake City, UT 84114
801-538-6170

VERMONT
Natural Resources Agency
Environmental Conservation Dept.
Hazardous Material Division
103 South Main Street
Waterbury, VT 05676
802-241-3888

VIRGINIA
Natural Resources Office
Environment Quality Dept.
629 East Main Street
Richmond, VA 23219
804-762-4020
Hazardous Waste Hotline: 800-552-2075

WASHINGTON
Dept. of Ecology
Solid and Hazardous Waste Program
P.O. Box 47600, Row 6, Building 4
Olympia, WA 98504
360-407-6103

WEST VIRGINIA
Environmental Protection Bureau
Waste Management Division
1356 Hansford Street
Charleston, WV 25301
304-558-5929

WISCONSIN
Dept. of Natural Resources
Solid and Hazardous Waste Management
P.O. Box 7921
Madison, WI 53707
608-266-1327

WYOMING
Dept. of Environmental Quality
Solid Waste Management Division
Herschler Building
122 West 25th Street
Cheyenne, WY 82002
307-777-7752

ADDITIONAL SOURCES OF INFORMATION

1. *Phone & Hotline Information*

- RCRA/Superfund Hotline
  1-800-424-9346 (in Washington, DC 260-3000)
- EPA Small Business Ombudsman Hotline
  1-800-368-5888 (in Washington, DC 557-1938)
- National Response Center
  1-800-494-8802 (in Washington, DC 260-2675)
- Transportation of Hazardous Materials
  202-366-4488
- Toxic Substance Control Act (TSCA) Assistance Service
  202-554-1404
- Center for Hazardous Materials Research (CHMR) Hotline
  1-800-334-2467

2. EPA Documents

- EPA/530-SW-86-019, September 1986, *Understanding the Small Quantity Generator, Hazardous Waste Generator.*
- EPA/530-SW-037, November 1986, *Solving the Hazardous Waste Problem — EPA's RCRA Program.*

3. ***Journal of Protective Coatings & Linings*** (available from Technology Publishing Co., 2300 Wharton St., Suite 310, Pittsburgh, PA 15203 [800-837-8303])

4. Other Publications

- *Bridge Paint Removal, Containment & Disposal*, Synthesis Report 20-05/20-09, 1992. Transportation Research Board, 2101 Constitution Ave., Washington, DC 20418
- *Removal of Lead-Based Bridge Paints*, NCHRP Report 265, December 1983, Transportation Research Board.
- *Industrial Lead Paint Removal Handbook*, SSPC 91-18, November 1991. Available from SSPC, 4400 Fifth Ave., Pittsburgh, PA 15213.

APPENDIX C

THE USE OF RECYCLABLE MATERIALS IN ASPHALT CONCRETE AND CONCRETE USE CONSTITUTING DISPOSAL OR UCD

HAZARDOUS WASTE MANAGEMENT PROGRAM

MANAGEMENT MEMO

MANAGEMENT MEMO #: EO-95-010-MM

TITLE: USE CONSTITUTING DISPOSAL

AFFECTED PROGRAMS: Hazardous Waste Management Program
Site Mitigation Program

ISSUE:

The Department of Toxic Substances Control (DTSC) is now developing regulations to address the "use constituting disposal" restriction as it pertains to recyclable materials that are non-RCRA hazardous wastes in section 25143.2(e)(2) of the Health and Safety Code (HSC). A "non-RCRA" waste is hazardous waste that is regulated in California but is not a Resource Conservation and Recovery Act (RCRA) waste. A RCRA hazardous waste is any waste identified as a hazardous waste in Part 261, Subchapter I, Chapter 1 of Title 40 of the Code of Federal Regulations (40 CFR). The "use constituting disposal" restriction affects the eligibility of recyclable materials for the exclusions and exemptions provided under HSC section 25143.2. The purpose of this management memo is to provide interim guidance on how to interpret "use constituting disposal," and therefore determine if a waste is subject to regulation pursuant to HSC section 25143.2(e)(2), until the regulations are adopted.

BACKGROUND:

HSC section 25143.2 addresses exclusions and exemptions for recyclable materials that are managed in a specified manner. Note that a recyclable material is defined as a hazardous waste that is capable of being recycled.[1] HSC section 25143.2 also lists conditions under which the recyclable materials must be fully regulated as hazardous wastes, regardless of the exclusions from classification as a waste and the exemptions from facility permitting requirements granted in this section. One such condition is when the materials are "used in a manner constituting disposal." This restriction is addressed separately for RCRA wastes and non-RCRA wastes.

Under California law, there is no definition for "use constituting disposal." The U.S. Environmental Protection Agency (U.S. EPA) has defined "use constituting disposal" to mean placing recyclable materials or products derived from recyclable

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[1] Ref. HSC section 25120.5.

materials on the land.[2] Under federal regulations, recyclable materials that are used in a manner constituting disposal are subject to regulation as solid wastes. At the same time, the U.S. EPA does not currently regulate products containing recyclable materials that are placed on the land if the recyclable materials have undergone a chemical reaction in producing the product so as to be physically inseparable from the product and the product meets the applicable treatment standards (or applicable prohibition levels where no treatment standards have been established) in subpart D, part 268, 40 CFR.

Since 1987, the DTSC has applied a set of criteria to recyclable materials placed on the land in determining whether or not such materials are "used in a manner constituting disposal." If these criteria are met, the recyclable materials are not regulated pursuant to HSC section 25143.2(e)(2) and may be eligible for the exclusions and exemptions under HSC section 25143.2 (b), (c) or (d). **The DTSC's criteria apply only to non-RCRA wastes.** The DTSC is currently writing regulations to address the issue of recyclable materials that are placed on the land ("use constituting disposal"). This management memo clarifies the criteria applied by the DTSC pending adoption of these regulations.

ACTION:

The following, **which applies only to non-RCRA wastes**, is the DTSC's present interpretation of the "use constituting disposal" restriction, i.e., of which recyclable materials are subject to regulation, in HSC section 25143.2(e)(2). This interpretation applies only until regulations addressing recyclable materials used in a manner constituting disposal or placed on the land are adopted.

A recyclable material that is placed on the land or used to produce a product which is placed on the land is regulated pursuant to HSC section 25143.2(e)(2) unless all applicable criteria listed below are met.

1. This criterion applies to situations where the recyclable material is used as an ingredient in the manufacture of a product. Hazardous constituents in the recyclable material whose concentrations are greater than or equal to the

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[2] Ref. 50 Federal Register 618, January 4, 1985, and 40 CFR 266.20.

regulatory Soluble Threshold Limit Concentrations (STLCs)[3] shall have chemically reacted or become physically bound so as not to leach from the product containing the recyclable material. Specifically, the hazardous constituents shall not leach out in concentrations that would exceed the applicable STLC, once the effect of dilution by other ingredients (as explained below) has been taken into account.

In order to meet this requirement, the following procedures must be used to evaluate the recyclable material and the product:

(a) Sampling and analysis:

(1) Sampling shall be conducted according to the sampling methods described in Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, 3rd edition, 1986, or one of the sampling methods listed in Appendix I, Chapter 11, Division 4.5, Title 22, California Code of Regulations (22 CCR); and

(2) Analysis shall be conducted according to the Waste Extraction Test (WET), Appendix II, Chapter 11, Division 4.5, 22 CCR, or an alternative test method approved pursuant to 22 CCR section 66260.21

(b) In order to demonstrate that the hazardous constituents in the recyclable material are bound in the product so that they would not exceed the applicable STLC, even when eliminating the effect of dilution by other ingredients, the following calculations must be used.

The concentration of the hazardous constituents in the final product, as determined by the WET, must be multiplied by the dilution factor inherent in combining the recyclable material with other materials. The dilution factor is calculated by dividing the weight of the final product made with the recyclable material by the weight of the recyclable material used in the product, or

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[3] As set forth in sections 66261.24(a)(2)(A) and (a)(2)(B), Division 4.5, Title 22 of the California Code of Regulations (22 CCR).

$$\frac{\text{weight of final product}}{\text{weight of recyclable material}} = \text{dilution factor}$$

If the ingredients in the product that are not recyclable materials contain the same hazardous constituents present in the recyclable material, the hazardous constituents in the ingredients that are not recyclable materials may be subtracted from the concentration of hazardous constituents in the final product, adjusted for dilution.

The final calculation of the hazardous constituents present in the product, as determined by taking into account the effects of dilution and, where applicable, the effects of hazardous constituents in ingredients that are not recyclable materials, must be less than the applicable STLC.

The following is an example of how these calculations can be done.

A ton of spent sandblast grit, which is hazardous due to a mean soluble lead concentration of 12 mg/L, is combined with nineteen tons of other aggregate and asphalt to produce twenty tons of asphaltic concrete. The dilution factor is thus 20 (twenty tons of final product, including the recyclable material, divided by the original one ton of recyclable material). The asphaltic concrete is then subjected to the WET and yields mean results for lead of 0.05 mg/l. This number is then multiplied by the dilution factor, 20, for a result of 1.00 mg/l. The aggregate that is not a recyclable material was tested with the WET and found to have a concentration of 0.05 mg/l lead. This concentration can be subtracted from 1 mg/l to give you 0.95 mg/l. This final calculation does not exceed the STLC for lead of 5 mg/l and therefore meets the criterion.

2. A recyclable material used as a substitute for a commercial product or a product containing a recyclable material shall not contain constituents that cause the product to exhibit hazardous characteristics pursuant to Chapter 11, Division 4.5, CCR 22, other than those constituents that are also found in the same or greater concentrations in a comparable commercial product. The only exception to this requirement is if the person claiming an exclusion obtains

the DTSC's written concurrence prior to using the recyclable material that:

(a) the concentrations of hazardous constituents greater than those present in a comparable commercial product improve the quality of the product made from the recyclable material and do not increase the hazards to public health or the environment of that product; or

(b) if no comparable commercial product exists, the hazardous constituents in the recyclable material that cause the product to exhibit a characteristic of a hazardous waste are beneficial to the product and do not cause the product to pose a threat to public health or the environment.

3. The recyclable material must be used beneficially, as demonstrated by both of the following conditions:

(a) Prior to use, the recyclable material and the product containing that material must each be certified by a qualified independent engineer registered in the state of California[4] to meet the applicable standards or specifications for the intended use of the recyclable material or product of the American Society for Testing and Materials (ASTM), the American Association of State Highway and Transportation Officials (AASHTO), the American National Standards Institute (ANSI), the Uniform Building Code (UBC), or the standards of a government agency having jurisdiction over the construction applications of that recyclable material or product. A nationally recognized industry standard, other than those mentioned, may be used with the prior written approval of the DTSC.

(b) There shall be no indications of sham recycling, including, but not limited to, use of the recyclable material or a product containing a recyclable material in excess of what is necessary to accomplish its function, handling of the recyclable material in a manner inconsistent with the economic value of the

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[4] By "qualified independent engineer", we mean an engineer whose registration (e.g., civil, mechanical, structural, etc.) is appropriate for the product she/he is certifying and who is not an employee of the person claiming an exclusion or exemption pursuant to HSC 25143.2.

material, or insufficient use of the recyclable material to accomplish its function.

Non-RCRA hazardous wastes managed according to the applicable criteria above will not be regulated pursuant to HSC 25143.2(e) and may therefore qualify for the exclusions and exemptions in HSC section 25143.2 if the requirements of a specific exclusion or exemption are met and none of the other provisions of subdivision (e) apply.

Examples of recyclable materials used in products placed on the land are spent sandblast grit, contaminated soils, foundry sands, ash, and demolition wastes, which may be used, among other things, as asphalt treated road base, landfill cover material, or aggregate in Portland cement concrete or an asphaltic concrete.

Use of recyclable materials as fertilizer, soil amendment, agricultural mineral, or an auxiliary soil and plant substance, with or without combination with other materials, is not covered by this management memo and is regulated separately.[5] Used oil is also not covered by this management memo.[6]

This management memo will stay in effect until the promulgation of regulations regarding management requirements for recyclable materials that are placed on the land, i.e., used in a manner constituting disposal, or until it is replaced by a subsequent management memo or DTSC policy.

DISTRIBUTION:

Cal/EPA Access Bulletin Board System
Hazardous Waste Management Program Policy Mailing List

ATTACHMENTS: None

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[5] Ref. Article 8, Chapter 16, 22 CCR.

[6] Ref. Article 13, Chapter 6.5, Division 20 of the Health and Safety Code.

CONTACT:

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State Regulatory Program Division
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8/18/95
Date

Ted N. Rauh
Deputy Director

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INTERNATIONAL WEATHER
NATIONAL WEATHER
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Tampa, Fla.

HISTORICAL WEATHER DATA

Average Temperature

	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
°F	**72.4**	59.9	61.5	66.6	71.3	77.4	81.3	82.4	82.4	80.9	74.8	67.5	62.2
°C	**22**	15	16	19	21	25	27	28	28	27	23	19	16

Years Charted: 30

Source: National Weather Service, San Francisco

Results based on data collected from 1961 - 1990

Average High Temperature

	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
°F	**81.6**	69.8	71.4	76.6	81.7	87.2	89.5	90.2	90.2	89	84.3	77.7	72.1
°C	**27**	21	21	24	27	30	31	32	32	31	29	25	22

Years Charted: 30

Source: National Weather Service, San Francisco

Results based on data collected from 1961 - 1990

Average Low Temperature

	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
°F	**63**	50	51.6	56.5	60.8	67.5	72.9	74.5	74.5	72.8	65.2	57.2	52.3
°C	**17**	10	10	13	16	19	22	23	23	22	18	14	11

Years Charted: 30

Source: National Weather Service, San Francisco

Results based on data collected from 1961 - 1990

Average Wind Speed

	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
mph	**8.3**	8.6	9.2	9.4	9.2	8.7	7.9	7.1	6.9	7.7	8.4	8.4	8.4
km/h	**13**	13	14	15	14	13	12	11	11	12	13	13	13

Years Charted: 47 **Source:** National Weather Service, San Francisco

Results based on data collected through 1993

Average Days of Precipitation

	Total	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Days	**106**	7	7	7	5	6	12	16	17	13	7	5	6

Years Charted: 47 **Source:** National Weather Service, San Francisco

Results based on data collected through 1993

Days With Sunshine

	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
%	**66**	63	66	71	75	75	67	62	61	61	65	64	62

Years Charted: 46 **Source:** National Weather Service, San Francisco

Results based on data collected through 1993

Mean Number of Cloudy Days

	Total	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Days	**121**	12	10	10	8	8	10	12	11	11	9	9	11

Years Charted: 47 **Source:** National Weather Service, San Francisco

Results based on data collected through 1993

Mean Number of Partly Cloudy Days

	Total	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Days	**143**	10	9	10	11	12	14	16	17	14	10	9	10

Years Charted: 47 **Source:** National Weather Service, San Francisco

Results based on data collected through 1993

Highest Recorded Temperature

	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
°F	99	86	88	91	93	98	99	97	98	96	94	90	86
°C	37	30	31	32	33	36	37	36	36	35	34	32	30

Years Charted: 47 **Source:** National Weather Service, San Francisco

Results based on data collected through 1993

Lowest Recorded Temperature

	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
°F	18	21	24	29	40	49	53	63	67	57	40	23	18
°C	-7	-6	-4	-1	4	9	11	17	19	13	4	-5	-7

Years Charted: 47 **Source:** National Weather Service, San Francisco

Results based on data collected through 1993

Mean Number of Days Below 32°F/0°C

	Total	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Days	3	2	1	---	0	0	0	0	0	0	0	---	1

Years Charted: 30 **Source:** National Weather Service, San Francisco

Results based on data collected through 1993

Average Precipitation

	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
in.	43.92	1.99	3.08	3.01	1.15	3.1	5.48	6.58	7.61	5.98	2.02	1.77	2.15
mm	1115	50	78	76	29	78	139	167	193	151	51	44	54

Years Charted: 30 **Source:** National Weather Service, San Francisco

Results based on data collected from 1961 - 1990

Average Snowfall

	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
in.	0	0	0	0	0	0	0	0	0	0	0	0	0
mm	0	0	0	0	0	0	0	0	0	0	0	0	0

Years Charted: 47 **Source:** National Weather Service, San Francisco

Results based on data collected through 1993

Mean Number of Clear Days

	Total	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Days	**102**	9	9	11	11	11	6	3	3	5	12	12	10

Years Charted: 47 **Source:** National Weather Service, San Francisco
Results based on data collected through 1993

Average Morning Relative Humidity

	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
%	**88**	87	86	87	87	86	87	87	90	91	89	88	87

Years Charted: 30 **Source:** National Weather Service, San Francisco
Results based on data collected through 1993

Average Afternoon Relative Humidity

	Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
%	**58**	59	56	55	51	52	60	63	64	61	57	57	59

Years Charted: 30 **Source:** National Weather Service, San Francisco
Results based on data collected through 1993

Questions? Comments? Suggestions? E-mail weather@weatherpost.com.

INSTRUCTIONS
FORM 2.8 STORAGE PILE WORKSHEET

This form is **REQUIRED** if a facility is reporting emissions from one or more open storage piles that are on the facility site.

Due to an APCP policy change in March 1998, the methodology for calculating storage pile emissions has been modified. There are now two different categories of emissions from storage piles: **(1) activity and (2) wind erosion**. The activity portion of storage pile emissions submittals includes the vehicle activity and load in/load out components and are calculated in the same manner as in previous EIQs. The wind erosion component is now calculated using pile area **(acres)** instead of **tons** stored as the throughput.

The rationale for the separation of these two categories is the physical difference in the nature of emissions from storage piles. Load in/load out and vehicle activity emissions are generated by human activity around the pile and can be represented by tons stored in the pile. However, wind erosion emissions can occur without disturbance of the pile and only occur during specific meteorological conditions.

With the use of the revised methodology, two different Source Classification Codes (SCC) are required. For quarry and associated industry storage piles, use SSC No. 3-05-020-07, Stone Quarrying, Open Storage (lb/ton) with activity emissions and use SCC No. 3-05-025-07, Sand/Gravel Storage Piles (lb/acre) with wind erosion emissions. **This will require the use of two emission point information forms (Form 2.0) for each different type of storage pile but point number should be the same.** Assign an activity SCC associated with a pound per ton emission factor to one Form 2.0 and a wind erosion SCC associated with a pound per acre emission factor to the other.

If you want to continue using SCC No. 3-05-020-07 with the default PM_{10} emission factor of 0.12 lb/ton for all storage pile emissions, complete all the information for Block 1, STORAGE PILE INFORMATION. If you are not using SCC emission factors, fill out this document completely.

Use Form 2.8 to derive two emission factors for each storage pile, using various criteria inputs. When calculating the PM_{10} emission factor for a storage pile, the following instructions apply.

Use a separate Form 2.8 for each storage pile emission point identified on Form 1.1, Process Flow Diagram and Form 1.2, Summary of Emission Points.

You may group and report separate storage piles as one point if they meet certain conditions: a) the physical characteristics of the pile and the surrounding environment are so similar that, if you calculate separate emission factors, the results would be the same; or b) the physical characteristics of the piles and the characteristics of the surrounding environment are so different that if you calculated emission factors for each pile, the results would not be equal. In this case, the reported emission factor will be the weighted average of the emission factor for each pile.

STATE OF MISSOURI
DEPARTMENT OF NATURAL RESOURCES
AIR POLLUTION CONTROL PROGRAM
205 JEFFERSON STREET, P.O. BOX 176
JEFFERSON CITY, MISSOURI 65102

EMISSIONS INVENTORY QUESTIONNAIRE (EIQ)

FORM 2.8 STORAGE PILE WORKSHEET

SHADED AREAS FOR OFFICE USE ONLY

FACILITY NAME	FIPS COUNTY NO.	PLANT NO.	YEAR OF DATA

[1] STORAGE PILE INFORMATION

POINT NO.	AIRS ID-PT	SCC	SEG NO.	TYPE OF MATERIAL STORED Coal slag / Spent ABD

MOISTURE CONTENT (%) 0.4 (DEFAULT = .07%)

AREA OF STORAGE PILE (ACRES) 0.03 per pile

SILT CONTENT 10 (DEFAULT = 1.6%)

STORAGE DURATION (DAYS)

ANNUAL AMOUNT STORED (TONS)

MAXIMUM HOURLY AMOUNT STORED ~~[illegible]~~ 550 TPH

RAW MATERIAL LOADING METHOD (CHECK ONE)

- ☐ BARGE
- ☐ RAIL
- ☐ TRUCK
- ☐ CONVEYOR
- ☐ OTHER (SPECIFY)

RAW MATERIAL UNLOADING METHOD (CHECK ONE)

- ☐ BARGE
- ☐ RAIL
- ☐ TRUCK
- ☐ CONVEYOR
- ☐ OTHER (SPECIFY)

[2] OTHER FACTORS AFFECTING EMISSION RATES

MEAN WIND SPEED (MPH) 8.3 (DEFAULT = 10 MPH)

% OF TIME WIND > 12 MPH 32% (DEFAULT = 32%)

DRY DAYS PER YEAR 260 (DEFAULT = 260 DAYS)

VEHICLE ACTIVITY FACTOR 1 (DEFAULT = 1.0)

[3] STORAGE PILE EMISSION FACTOR CALCULATIONS

[3-A-1] LOAD IN-LOAD OUT COMPONENT =

.00224 X ({MEAN WIND SPEED} / 5)^1.3 / ({MOISTURE CONTENT (%)} / 2)^1.4

LOAD IN-LOAD OUT COMPONENT ~~0.0421~~ 0.0412

[3-A-2] VEHICLE ACTIVITY COMPONENT =

0.05 X ({SILT CONTENT (%)} / 1.5) X ({DRY DAYS PER YEAR} / 235) X {VEHICLE ACTIVITY FACTOR}
0.05 x (10/1.5) x ((260/235) x 1)

VEHICLE ACTIVITY COMPONENT 0.369

[3-B] WIND EROSION COMPONENT =

0.85 X ({SILT CONTENT (%)} / 1.5) X ({STORAGE DURATION (DAYS)}
X ({DRY DAYS PER YEAR} / 235) X ({% OF TIME WIND > 12MPH} / 15) LB/ACRE

WIND EROSION COMPONENT 0.53 lb/acre per day

[4] STORAGE PILE PM10 EMISSION FACTOR

ACTIVITY PM10 EMISSION FACTOR =
{[3-A-1] LOAD IN-LOAD OUT COMPONENT} ÷ {[3-A-2] VEHICLE ACTIVITY COMPONENT}

[4-A] ACTIVITY PM10 EMISSION FACTOR 0.41 ~~[illegible]~~ $\frac{\text{lb PM10}}{\text{ton}}$ LB PM10/TON

[4B] WIND EROSION PM10 EMISSION FACTOR LB PM10/ACRE

PLEASE NOTE

IF YOU USE A SOURCE CLASSIFICATION CODE (SCC) NUMBER AND EMISSION FACTOR FROM THE LIST IN THE INSTRUCTIONS FOR THIS FORM, MAKE SURE TO COMPLETE BLOCK 1, STORAGE PILE INFORMATION FOR EACH STORAGE PILE.

DUPLICATE THIS FORM AS NEEDED.

Activity Emission Factor Example: Suppose a facility has three distinct storage piles with annual throughputs of 100,000, 200,000 and 500,000 tons, respectively. Also assume the respective calculated PM_{10} activity emission factors are .18, .135 and .165 lbs/ton of material stored.

100,000 tons x .18 lbs/ton	= 18,000 lbs.
200,000 tons x .135 lbs/ton	= 27,000 lbs.
<u>500,000</u> tons x .165 lbs/ton	= <u>82,500</u> lbs.
800,000 tons	127,500 lbs.

127,500 lbs. PM_{10}) 800,000 tons = .1594 lbs. PM_{10} /ton.

You would enter this weighted average result of .1594 on Form 2.0 for the activity portion as the emission factor for the point.

Complete Facility Name, County Number, Plant Number and Year of Data.
See Form 1.0 instructions, page 1.0-1.

1) STORAGE PILE INFORMATION

Point Number: This number is the unique identification number for each specific storage pile. This identification number must match the point number entered on Form 1.1, Process Flow Diagram; Form 1.2, Summary of Emission Points; and Form 2.0, Emission Point Information.

NOTE: Again, using the revised approach, there will be two Form 2.0 completed but the same point number will be used for each storage pile or group (one for activity and one for wind erosion).

SCC Number for Activity: List the SCC in tons that identifies the type of storage material for activity emissions.

SCC Number for Wind Erosion: List the SCC in **acres** that identifies the type of storage material for wind erosion emissions.

Type of Material Stored: Enter the type of material in the open storage pile for this emission point. Examples of some common storage pile materials include gravel, fines, pea gravel, crushed stone dust, crushed cinder, etc.

Moisture Content of Stored Material: Enter the moisture content of the storage pile if known. For examples, refer to Table 13.2.4-1 or Table 2.1.2-2 at the end of this instruction set. You may use a default value of 0.7% for the moisture content of the storage pile if no other information is available.

Use the moisture content percentage, not the decimal equivalent, when calculating the Load In-Load Out Factor in Section 3-A. Example: If the default value of 0.7% is selected, enter as .7 in the formula.

Area of Storage Piles: Estimate the number of acres of land that is under this specific storage pile.

Silt Content: Enter the Silt Content of the storage pile if known. Calculate the Silt Content by measuring the proportion of dry aggregate material that passes a 200 mesh screen, using ASTM-C-136 method. The Silt Content for some common materials stored in open storage piles are listed in Table 13.2.4-1 and Table 2.1.2-2. You may use a default value of 1.6% may be used for the storage pile if no other information is available.

Use the Silt Content percentage, not the decimal equivalent, when calculating the Wind Erosion and Activity Factors in Section 3-B and 3-C.
Example: If the default value of 1.6% is selected, enter as 1.6 in the formula.

Storage Duration: Enter the average number of days per year that aggregate material remains in the storage pile. Table 2.1.2-2 lists some estimates on the storage duration for various types of storage material.

Annual Amount Stored: Enter the total amount of all aggregate material produced and subsequently stored in the storage pile during the year. Enter tons of material stored per year.

Maximum Hourly Amount Stored: List the largest quantity of aggregate stored at any time during the last calendar year. Enter the maximum number of tons of material stored.

Raw Material Loading Method: Check the box that best corresponds to the main method of loading or removing material from the storage pile.

Raw Material Unloading Method: Check the box that best corresponds to the main method of unloading or adding material to the storage pile.

2) OTHER FACTORS AFFECTING EMISSION RATES

Mean Wind Speed: The statistical mean of all wind speeds at a height 10 centimeters above the storage piles, regardless of the wind direction. You may use a default value of 10 miles per hour for the Mean Wind Speed figure.

Percent of Time the Wind Velocity is Greater than 12 MPH:
The percent of time that the unobstructed wind velocity exceeds 12 miles per hour at the mean pile height. You may use a default value of 32%.

Dry Days Per Year: The number of days that at least 0.01 inches of rain did not fall. You may use a default value of 260 days.

Vehicle Activity Factor: Use the following table to select the correct value for VAF (Vehicle Activity Factor) for this storage pile. You may use a default value of 1.0.

MATERIAL	VAF VALUE
Coal	0.08
Coke	0.25
Gravel	0.25
Iron Ore	0.06
Limestone	0.25
Sand (Fines)	1.00
Slag	1.00
Top Soil (Overburden)	0.25
All Others	1.00

3) STORAGE PILE EMISSION FACTOR CALCULATIONS

A.1 LOAD IN-LOAD OUT FACTOR

The Load In-Load Out factor is a calculated number that represents the amount of PM_{10} emissions that will result from the Load In-Load Out process. Use this formula to calculate the factor:

Load In-Load Out Factor =
0.00224 x (Mean Wind Speed) 5)^1.3) [Moisture Content (%)) 2]^1.4 lb/ton
(The Values 1.3 and 1.4 are exponents).

Perform the calculation for the Load In-Load Out Factor and enter the results in Block 3-A.1 of this form.

A.2 VEHICLE ACTIVITY FACTOR

The Activity Factor is a calculated number that represents the amount of PM_{10} released into the atmosphere due to vehicular traffic around the storage pile. Use this formula to calculate the factor:

Activity Factor =
0.05 x [Silt Content (%)) 1.5] x (Dry Days per Year) 235)
x (Vehicle Activity Factor) lb/ton

Perform the calculation for the Activity Factor and enter the results in Block 3-A.2 of this form

B. WIND EROSION PORTION FACTOR

The Wind Erosion Factor is a calculated number that represents the amount of PM_{10} released into the atmosphere from this storage pile due to wind erosion. Use this formula to calculate the factor:

Wind Erosion Factor =
0.85 x [Silt Content (%)) 1.5] x Storage Duration (Days)
x (Dry Days per Year) 235) x [(% of Time Wind > 12 MPH)) 15] lb/acre

Perform the calculation for the Wind Erosion Factor and enter the results in Block 3-B of this form.

4) COMBINED ANNUAL STORAGE PILE PM_{10} EMISSION FACTORS

(A) Add the Load In-Load Out Factor (3-A.1), and Vehicle Activity Factor (3-A.2) together and enter the result in Block 4-A of this form. When using this worksheet, always express the units as pounds of PM_{10} emitted per ton of aggregate stored in piles.

(B) Enter the result of the calculation in Block 3-B. When using this worksheet, always express wind erosion units in pounds of PM_{10} per acre of storage.

ENTER THE FOLLOWING ON FORM 2.0, EMISSION POINT INFORMATION FOR THE ACTIVITY PORTION OF STORAGE PILE EMISSIONS:

Block 1 - Enter the SCC. If you use the default SCC, enter **3-05-020-07 (lb/ton).**

Block 7 - Enter the combined Activity PM_{10} Emission Factor (Block 4-A) for this storage pile in the appropriate box.

ENTER THE FOLLOWING ON A SEPARATE FORM 2.0, EMISSION POINT INFORMATION FOR THE WIND EROSION PORTION OF STORAGE PILE EMISSIONS:

Block 1 - Enter the SCC. If you use the default SCC, enter **3-05-025-07 (lb/acre).**

Block 7 - Enter the Wind Erosion PM_{10} Emission Factor (Block 4-B) for this storage pile in the appropriate box.

[illegible]rginia Materials and Supplies, I[illegible]
3306 Peterson Street~Norfolk, VA 23509
Phone (757) 855-0155~ Fax (757) 857-5631
Email jb@sandblaster.com

Material Safety Data Sheet
(Complies with 29 CFR 1910.1200)

Section I - General

Virginia Materials & Supplies, Inc. (VMS)
T/A Virginia Materials
3306 Peterson Street
Norfolk, VA 23509
EMERGENCY TELEPHONE NUMBERS:
(757) 855-0155
(800) 793-0094

Product Name: "Black Blast" Abrasives

CAS Number: 68476-96-0
Particles not otherwise **regulated**
Common Name: Slag, Coal
Date: May 1995

SECTION II - Ingredients

Slag, Coal 99% - 100%

		OSHA *PEL	ACGIH *TLV
Nuisance Dust			
Total Dust	:	15	10
Respirable Dust	:	5	5

*Values Expressed as mg/M3

SECTION III - Physical Data

Physical Form:	Solid (angular granules)	**Boiling Temperature:**	N/A	**Melting Point:**	Greater than 2300 F
Vapor Pressure/Density:	N/A	**Evaporation Rate:**	N/A	**Specific Gravity:**	2.7 g/cc (typical)
Water Solubility:	Negligible	**Color:**	Black	**Odor:**	None

SECTION IV - Fire and Explosion Data

Product is nonflammable and nonexplosive.

SECTION V - Reactivity Data

P[illegible]uct is stable under normal conditions of use, storage and transportation.

SECTION VI - Health Hazard Data

Low health risk by inhalation. Treat as a nuisance dust. Typical free silica less than 0.1%. This material is not a recognized carcinogen or cocarcinogen. Human toxic response has not been demonstrated for any route of entry. Mechanical irritation may occur to eyes, skin or respiratory tract. Pre-existing health conditions may be aggravated.
Carcinogenicity: NTP - no; IARC Monographs - no; OSHA Regulated - no.

FIRST AID:

In case of:

1. Eye contact - Immediately flush eyes thoroughly with water or an opthalmic saline solution.
2. Skin contact - Wash skin with soap and water if irritation occurs.
3. Inhalation - Remove affected person(s) to fresh air source.
4. Oral Intake - Rinse mouth with water.

IF SYMPTOMS PERSIST CONTACT PHYSICIAN OR OTHER MEDICAL PERSONNEL.

SECTION VII - Spill, Leak and Disposal Procedures

No special procedures required for clean-up. Wetting with water will reduce airborne dust. Uncontaminated product does not exceed Toxicity Characteristic Leaching Procedure (TCLP) limits and may be disposed of as an inert material in an appropriate solid waste landfill according to applicable Federal, State and Local regulations.

SECTION VIII - Control Measures

Use appropriate NIOSH certified respiratory protection when exposure limits may be exceeded. Maintain sufficient ventilation to allow visual contact with work surfaces. Appropriate abrasive blaster's protective equipment is required, which may also include gloves, hood with protective lens, safety glasses and hearing protection.

SECTION IX - Special Precautions

Keep product dry and free of all contamination to assure free flow. Use an appropriate safety screen over fill hatch of blasting pot. Respirable dust may be generated during pressure abrasive cleaning operations.

NOTE

[illegible]pinions expressed herein are those of qualified experts within Virginia Materials & Supplies, Inc. (VMS). VMS believes that the information contained herein is current and accurate for the normal and intended use of this product as of the date of the Material Safety Data Sheet. Since the use of this information and of those opinions or the conditions of use of the product are not within the control of Virginia Materials & Supplies Inc., it is the user's obligation to determine and observe the conditions of safe use and disposal of the product by their operations.

Revised 08/2/99 Supercedes 5/12/99

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
AGGREGATE SYSTEM
FINE AGGREGATE CODE FORM

SOURCE IDENTIFICATION

PROJECT NO. ____ PAY ITEM NO. ____ MATERIAL NO. ____

SAMPLE NO. 1 LAB NO. 1 TESTED BY PDPG DATE SAMPLED 02/22/01

SAMPLED BY FRANK M. IATE TESTED 02/23/01 SOURCE NO. (MINE/TERMINAL) ____ MINE NO. ____

MATERIAL IDENTIFICATION

MATERIAL CODE ____ MATERIAL TYPE ____ SAMPLE TYPE ____ SAMPLED FROM ____

PROCESS ____

NFORMATION ____

TEST RESULTS

FM ____ TARGET FM ____ PASS 200 10.26 APPARENT 2.815

____ TYPE GV ____ MOISTURE CONTENT 0.4% ABSORP. 0.4%

RB ____ MOD L.A. ____ SPGR(DRYBULK) 2.786 MOD GRAD ____

BULK(SSD) 2.796 DES MIX ____

ASPHALT / CONCRETE PLANT NO. ____

REMARKS NFCT MATERIAL

SAMPLE WT. 411.5 gms/lbs -DRY WT. 381.4 = loss 30.1 + PAN WT. 12.1

WEIGHT (WT.)

%-200=[(Origional Dry Wt. -Dry Wt. After Washing)+Minus 200 Mateial From Dry Sieving] x 100/origional Dry Wt.

Gradation 411.5

SIE	SIEVE SIZE	ACCUM WT		% WEIGHT	% RETAINED		% PASSING	REMARKS
1	3/8"-9.5mm	0.0		0.0%	0.0%		100.0%	
2	No.4-4.75mm	2.6		0.6%	0.6%		99.4%	
3	No.10-2.00mm	5.7		1.4%	1.4%		98.6%	
4	N0.40-425um	179.1		43.5%	43.5%		56.5%	
5	N0.80-180um	296.9		72.2%	72.2%		27.8%	
6	NO.100-150M	320.2		77.8%	77.8%		22.2%	
7	NO.200-75MN	368.40		89.5%	89.5%		10.5%	
TOTAL WEIGHT		380.50						

TYPICAL CHEMICAL ANALYSIS
BLACK SAND - BOILER SLAG

Bulk Materials International Company Inc.

silicon dioxide SiO_2	43.2%
aluminum oxide Al_2O_3	18.5%
iron oxide Fe_2O_3	27%
magnesium oxide MgO	2%
calcium oxide CaO	7%
sulfur trioxide SO_3	3%

DHRS # 82315

DHRS E-82179

**Southeastern Environmental
Laboratories, Inc.
80 Industrial Loop North, Building 5
Orange Park, FL 32073
(904) 269-6176**

CQAP # 880633G

Conrad Yelvington
460 Bay Point Way N.
Jacksonville, Florida 32259

Sampled By:	Client
Client Job/PO No.:	H/S – TITUSVILLE
Project Name:	Sandblasting Abrasive
Submission Number:	9900160
Reported Date:	11/17/99

Description **Sample ID**

Sandblasting Abrasive

Sample Date: 11/10/99

Parameter	**Result**	**Units**	**Method**	**Analyst Initials**	**Date/Time**
Arsenic	U 0.25	mg/l	1311/6010	VP	11/17/99
Barium	0.13	mg/l	1311/6010	VP	11/17/99
Cadmium	U 0.10	mg/l	1311/6010	VP	11/17/99
Chromium	U 0.10	mg/l	1311/6010	VP	11/17/99
Lead	U 0.10	mg/l	1311/6010	VP	11/17/99
Mercury	U 0.005	mg/l	1311/7471	VP	11/17/99
Selenium	U 0.25	mg/l	1311/6010	VP	11/17/99
Silver	U 0.20	mg/l	1311/272.1	VP	11/17/99

5 Day Turn Around

Approved By: ______________________

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
AGGREGATE SYSTEM
FINE AGGREGATE CODE FORM

SOURCE IDENTIFICATION

PROJECT NO. ______
PAY ITEM NO. ______
MATERIAL NO. ______
SAMPLE NO. 2
LAB NO. 2
TESTED BY PDPG
DATE SAMPLED 02/22/01
SAMPLED BY FRANK M.
ATE TESTED 02/23/01
SOURCE NO. (MINE/TERMINAL)
MINE NO.

MATERIAL IDENTIFICATION

MATERIAL CODE
MATERIAL TYPE
SAMPLE TYPE
SAMPLED FROM
PROCESS
NFORMATION ______

TEST RESULTS

FM ______
TARGET FM ______
PASS 200 9.26
APPARENT ______
______
TYPE GV ______
MOISTURE CONTENT 0.3%
ABSORP. ______
CARB ______
MOD L.A. ______
SPGR(DRYBULK) ______
MOD GRAD ______
BULK(SSD) ______
DES MIX ______
ASPHALT / CONCRETE PLANT NO. ______

REMARKS NFCT MATERIAL

SAMPLE WT. 444.8 gms/lbs -DRY WT. 417.4 = loss 27.4 + PAN WT. 13.8
WEIGHT (WT.)

%-200=[(Origional Dry Wt. -Dry Wt. After Washing)+Minus 200 Mateial From Dry Sieving] x 100/origional Dry Wt.

Gradation 444.8

[illegible]	SIEVE SIZE	ACCUM WT.		% WEIGHT	% RETAINED		% PASSING	REMARKS
1	3/8"-9.5mm	0.0		0.0%	0.0%		100.0%	
2	No.4-4.75mm	2.5		0.6%	0.6%		99.4%	
3	No.10-2.00mm	4.7		1.1%	1.1%		98.9%	
4	N0.40-425um	199.6		44.9%	44.9%		55.1%	
5	N0.80-180um	327.0		73.5%	73.5%		26.5%	
6	NO.100-150M	351.6		79.0%	79.0%		21.0%	
7	NO.200-75MM	401.80		90.3%	90.3%		9.7%	
TOTAL WEIGHT		415.60						

DHRS E-82179

Southeastern Environmental
Laboratories, Inc.
80 Industrial Loop North, Building 5
Orange Park, FL 32073
(904) 269-6176

CQAP # 880633G

Conrad Yelvington
460 Bay Point Way N.
Jacksonville, Florida 32259

Sampled By:	Client
Client Job/PO No.:	
Project Name:	NFCT
Submission Number:	10006422
Reported Date:	2/23/01

Description **Sample ID**

Gross

Sample Date: 2/21/01

Parameter	Result	Units	Method	Date/Time
Arsenic	U 0.100	mg/kg	6010	2/22/01
Barium	796	mg/kg	6010	2/22/01
Cadmium	U 0.030	mg/kg	6010	2/22/01
Chromium	115	mg/kg	6010	2/22/01
Copper	599	mg/kg	6010	2/22/01
Iron	256	mg/l	6010	2/23/01
Lead	16.3	mg/kg	6010	2/22/01
Mercury	0.091	mg/kg	7470	2/23/01
Nickel	33.5	mg/kg	6010	2/22/01
Selenium	U 0.200	mg/kg	6010	2/22/01
Silver	U 0.030	mg/kg	6010	2/22/01
Zinc	112	mg/kg	6010	2/22/01

DHRS E-82179

Southeastern Environmental
Laboratories, Inc.
80 Industrial Loop North, Building 5
Orange Park, FL 32073
(904) 269-6176

CQAP # 880633G

Conrad Yelvington
460 Bay Point Way N.
Jacksonville, Florida 32259

Post-it® Fax Note 7671	Date 2-26 # of pages ▶ 3
To Frank Milton	From Wanda
Co./Dept.	Co.
Phone #	Phone #
Fax #	Fax #

Sampled By: Client
Client Job/PO No.:
Project Name: NFCT
Submission Number: 10006422
Reported Date: 2/23/01

Description **Sample ID**

Fines (-200)

Sample Date: 2/21/01

Parameter	Result	Units	Method	Date/Time
Arsenic	U 0.100	mg/kg	6010	2/22/01
Barium	696	mg/kg	6010	2/22/01
Cadmium	U 0.030	mg/kg	6010	2/22/01
Chromium	124	mg/kg	6010	2/22/01
Copper	793	mg/kg	6010	2/22/01
Iron	268	mg/l	6010	2/23/01
Lead	229	mg/kg	6010	2/22/01
Mercury	0.634	mg/kg	7470	2/23/01
Nickel	35.9	mg/kg	6010	2/22/01
Selenium	U 0.200	mg/kg	6010	2/22/01
Silver	U 0.030	mg/kg	6010	2/22/01
Zinc	126	mg/kg	6010	2/22/01

Southeastern Environmental
Laboratories, Inc.
80 Industrial Loop North, Building 5
Orange Park, FL 32073
(904) 269-6176

DHRS E-82179

CQAP # 880633G

Conrad Yelvington
460 Bay Point Way N.
Jacksonville, Florida 32259

Sampled By: Client
Client Job/PO No.:
Project Name: NFCT
Submission Number: 10006422
Reported Date: 2/23/01

Description **Sample ID**

SPLP

Sample Date: 2/21/01

Parameter	Result	Units	Method	Date/Time
Arsenic	U 0.100	mg/l	1312/6010	2/22/01
Barium	0.420	mg/l	1312/6010	2/22/01
Cadmium	U 0.030	mg/l	1312/6010	2/22/01
Chromium	U 0.050	mg/l	1312/6010	2/22/01
Lead	U 0.100	mg/l	1312/6010	2/22/01
Mercury	U 0.005	mg/l	1312/7470	2/23/01
Selenium	U 0.200	mg/l	1312/6010	2/22/01
Silver	U 0.030	mg/l	1312/6010	2/22/01
Copper	3.27	mg/l	1312/6010	2/22/01
Iron	5.76	mg/l	1312/6010	2/23/01
Nickel	0.027	mg/l	1312/6010	2/22/01
Zinc	7.28	mg/l	1312/6010	2/22/01

Approved By: Radford Murphy

RINKER Environmental Services, INC.

COMPQAP #950491
HRS #E86536

Materials Analysis Report

REPORT DATE	2/19/98
SAMPLE DATE	2/4/98
SAMPLE SOURCE	[redacted]
REFERENCE	46
R.E.S. ID NUMBER	8920
SAMPLE TYPE	Black Sand

PARAMETER	RESULT	UNITS	METHOD	D. LIMITS	ANALYSIS DATE	ANAL. INITIAL
Arsenic	0.6	mg/kg	7060	0.5	2/9/98	PEP
Barium	379	mg/kg	7080	0.9	2/10/98	PEP
Cadmium	0.05	mg/kg	7131	0.02	2/6/98	PEP
Chromium	35.4	mg/kg	7191	0.8	2/10/98	PEP
Mercury	BDL	mg/kg	7471A	1.0	2/5/98	PEP
Lead	7.0	mg/kg	7420	0.1	2/11/98	PEP
Selenium	0.5	mg/kg	7740	0.4	2/9/98	PEP
Silver	BDL	mg/kg	7761	0.1	2/6/98	PEP
Copper	14.5	mg/kg	7210	1.0	2/11/98	JSP
Zinc	43.0	mg/kg	7950	1.0	2/11/98	JSP

Juan A. Gonzalez

Juan Gonzalez
QA/QC Manager

RINKER Environmental Services, INC.

COMPQAP #950491
HRS #E86536

Materials Analysis Report

REPORT DATE	2/19/98
SAMPLE DATE	2/4/98
SAMPLE SOURCE	[redacted]
REFERENCE	48
R.E.S. ID NUMBER	8921
SAMPLE TYPE	Black Sand

PARAMETER	RESULT	UNITS	METHOD	D. LIMITS	ANALYSIS DATE	ANAL INITIAL
Arsenic	1.1	mg/kg	7060	0.5	2/9/98	PEP
Barium	580	mg/kg	7080	0.9	2/10/98	PEP
Cadmium	0.12	mg/kg	7131	0.02	2/6/98	PEP
Chromium	49.7	mg/kg	7191	0.8	2/10/98	PEP
Mercury	BDL	mg/kg	7471A	1.0	2/5/98	PEP
Lead	29.5	mg/kg	7420	0.1	2/11/98	PEP
Selenium	BDL	mg/kg	7740	0.4	2/9/98	PEP
Silver	BDL	mg/kg	7761	0.1	2/6/96	PEP
Copper	2850	mg/kg	7210	1.0	2/11/98	JSP
Zinc	865	mg/kg	7950	1.0	2/11/98	JSP

Juan A. Gonzalez

Juan Gonzalez
QA/QC Manager

RINKER Environmental Services, INC.

COMPQAP #950491
HRS #E86536

Materials Analysis Report

REPORT DATE	2/19/98
SAMPLE DATE	2/4/98
SAMPLE SOURCE	[redacted]
REFERENCE	48
R.E.S. ID NUMBER	8922
SAMPLE TYPE	Black Sand

PARAMETER	RESULT	UNITS	METHOD	D. LIMITS	ANALYSIS DATE	ANAL. INITIAL
Arsenic	1.3	mg/kg	7060	0.5	2/9/98	PEP
Barium	170	mg/kg	7080	0.9	2/10/98	PEP
Cadmium	0.03	mg/kg	7131	0.02	2/6/98	PEP
Chromium	32.8	mg/kg	7191	0.8	2/10/98	PEP
Mercury	BDL	mg/kg	7471A	1.0	2/5/98	PEP
Lead	7.5	mg/kg	7420	0.1	2/11/98	PEP
Selenium	BDL	mg/kg	7740	0.4	2/9/98	PEP
Silver	BDL	mg/kg	7761	0.1	2/6/98	PEP
Copper	39.1	mg/kg	7210	1.0	2/11/98	JSP
Zinc	76.5	mg/kg	7950	1.0	2/11/98	JSP

Juan A. Gonzalez

Juan Gonzalez
QA/QC Manager

RINKER Environmental Services, INC.

COMPQAP #950491
HRS #E86536

Materials Analysis Report

REPORT DATE	2/19/98
SAMPLE DATE	2/4/98
SAMPLE SOURCE	[redacted]
REFERENCE	79
R.E.S. ID NUMBER	8923
SAMPLE TYPE	Black Sand

PARAMETER	RESULT	UNITS	METHOD	D. LIMITS	ANALYSIS DATE	ANAL INITIAL
Arsenic	BDL	mg/kg	7060	0.5	2/9/98	PEP
Barium	1030	mg/kg	7080	0.9	2/10/98	PEP
Cadmium	0.06	mg/kg	7131	0.02	2/6/98	PEP
Chromium	49.2	mg/kg	7191	0.8	2/10/98	PEP
Mercury	BDL	mg/kg	7471A	1.0	2/5/98	PEP
Lead	13.0	mg/kg	7420	0.1	2/11/98	PEP
Selenium	BDL	mg/kg	7740	0.4	2/9/98	PEP
Silver	BDL	mg/kg	7761	0.1	2/6/98	PEP
Copper	45.0	mg/kg	7210	1.0	2/11/98	JSP
Zinc	21.2	mg/kg	7950	1.0	2/11/98	JSP

Juan A. Gonzalez

Juan Gonzalez
QA/QC Manager

RINKER Environmental Services, INC.

COMPQAP #950491
HRS #E86536

Materials Analysis Report

REPORT DATE	2/19/98
SAMPLE DATE	2/4/98
SAMPLE SOURCE	[redacted]
REFERENCE	38
R.E.S. ID NUMBER	8924
SAMPLE TYPE	Black Sand

PARAMETER	RESULT	UNITS	METHOD	D. LIMITS	ANALYSIS DATE	ANAL. INITIAL
Arsenic	BDL	mg/kg	7060	0.5	2/9/98	PEP
Barium	215	mg/kg	7080	0.9	2/10/98	PEP
Cadmium	0.02	mg/kg	7131	0.02	2/6/98	PEP
Chromium	24.0	mg/kg	7191	0.8	2/10/98	PEP
Mercury	BDL	mg/kg	7471A	1.0	2/5/98	PEP
Lead	6.0	mg/kg	7420	0.1	2/11/98	PEP
Selenium	BDL	mg/kg	7740	0.4	2/9/98	PEP
Silver	BDL	mg/kg	7761	0.1	2/6/98	PEP
Copper	68.0	mg/kg	7210	1.0	2/11/98	JSP
Zinc	18.8	mg/kg	7950	1.0	2/11/98	JSP

Juan A. Gonzalez

Juan Gonzalez
QA/QC Manager

Advanced Environmental Laboratories, Inc.

Aanlytical Report

Client:	Gulf Marine Repair.	**Report No.:**	J001042
Project No.:	32937	**Date Sampled:**	Unknown
Matrix:	TCLP Extract	**Date Submitted:**	5/9/00
		Date Reported:	5/11/00
		Page No.:	2 of 2

[redacted]

Units: mg/L

Aanlyte	**Method**	**MRL**	**TCLP Limits**	**Lab Code:** **Date Aanlyzed**	J001042-1 **Sand Blast**	J001108-1-mb **Method Blank**
Arsenic	6010B	0.050	5.0	5/10/00	U	U
Barium	6010B	0.25	100	5/10/00	0.568	U
Cadmium	6010B	0.025	1.0	5/10/00	U	U
Chromium	6010B	0.05	5.0	5/10/00	U	U
Lead	6010B	0.050	5.0	5/10/00	U	U
Selenium	6010B	0.05	1.0	5/10/00	U	U
Silver	6010B	0.05	5.0	5/10/00	U	U
Mercury	7470A	0.0020	0.20	5/10/00	U	U

GALE
EUSTACE

Not detected above the MRL
MRL. Method Reporting Limit

SCHNEIDER LABORATORIES

INCORPORATED

2512 W. Cary Street • Richmond, Virginia • 23220-5117
804-353-6778 • 800-785-LABS (5227) • (FAX) 804-353-6928
Excellence in Service and Technology
AIHA 8938, ELLAP 8808, NVLAP 1160, NYELAP 11413, CAELAP 2078

LABORATORY ANALYSIS REPORT

EPA SW846 Method 1311 (Toxicity Characteristic Leachate Procedure)

ACCOUNT:	1649-99-23	**DATE COLLECTED:**	7/27/99
CLIENT:	Worth Contracting	**DATE RECEIVED:**	7/29/99
ADDRESS:	2112 Jernigan Rd Jacksonville, Fl. 32207	**DATE ANALYZED:**	8/2/99
		DATE REPORTED:	8/2/99
P.O.#:			
PROJECT NAME	Washington Terrace	**SAMPLE TYPE:**	TCLP
PROJECT NO.:	239		
JOB LOCATION:	St. Pete, Fl.		
CLIENT SAMPLE NO.:	23810		
SLI SAMPLE NO.:	1904319		

METAL NAME:	ACTUAL CONC.	UNITS	**ANALYSIS METHOD**	**REGULATORY LIMIT(ppm)**
Arsenic (As)	<0.04	ppm	EPA 6010	5.0
Barium (Ba)	1.19	ppm	EPA 6010	100.0
Cadmium (Cd)	<0.02	ppm	EPA 6010	1.0
Chromium (Cr)	0.05	ppm	EPA 6010	5.0
Lead (Pb)	<0.20	ppm	EPA 7420	5.0
Mercury (Hg)	<0.005	ppm	EPA 7470	0.2
Selenium (Se)	<0.05	ppm	EPA 6010	1.0
Silver (Ag)	<0.02	ppm	EPA 6010	5.0

SAMPLE TYPE: Blast Waste
SAMPLE pH: 8.35
ANALYST: CAROLYN C. RING

REVIEWED BY Matthew D. Asbury, ANALYST

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*Quality Control Data available upon request. *For true values, assume 2 significant figures. Sample concentrations below the Minimum Reporting Limit are indicated with a "less than" (<) sign. Note on measurement units: mg/L = ppm (parts per million). All testing is done in strict accordance with Schneider Laboratories, Inc. protocol.*

Screen or mesh size

In the language of the sandblaster the size of the blasting grit is referred to as the mesh or screen size. The screen number is the number of equal size holes in a 1" square screen. The larger the number, the more holes and therefore the smaller each hole is. The lower the number the coarser the media. Please note that the screen material takes up space so a #4, which has 4 holes per square inch is not 1/4" in size. It is actually about 3/16" or 1/16" less then 1/4".

The size of a particle of blasting grit is the number given to the smallest screen it will pass through. In other words if something passes through a #30 screen but stops at the #25 screen it is known as a #30.

In blasting you want to have a mix of sizes to give the best cleaning and profile so you normally see sizes like 20/40. This means that most of what is in the mix is a #30 with part of it finer, up to a #40 and some of it coarser, down to a #20.

The terms fine, medium or coarse or the numbers 0, 00, 000 or 2, 3 or 4 given out by some manufacturers are not what you want to use to compare sizes between two companies. One companies fine can be someone else's medium.

For your information:

- Regular ground coffee is approximately a 16/40 mesh.
- Sugar is about a 50/80 mesh.
- Table salt around a 30/80 mesh.
- Fine ground black pepper is a 30/50 mesh.

The following is a friendly comparison chart of National Bureau of Standards (NBS) screen sizes used in the blasting industry

Screen Number	Size in MM	Size in Inches	Nearest Fraction*
4	4.75	.187	3/16"
5	4.00	.157	5/32"
6	3.35	.132	1/8"
7	2.80	.111	
8	2.36	.0937	3/32"
10	2.00	.0787	5/64"
12	1.70	.0661	
14	1.40	.0555	
16	1.18	.0469	3/64"
18	1	.0394	

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12	1.70	.0661	
14	1.40	.0555	
16	1.18	.0469	3/64"
18	1	.0394	

20	.85	.0331	
25	.71	.0278	1/32"
30	.60	.0234	
35	.50	.0197	
40	.425	.0165	
45	.355	.0139	1/64"
50	.300	.0117	
80	.180	.0070	
100	.150	.0053	
120	.125	.0049	
200	.075	.0029	
325	.045	.0017	

*Close to, but not exact in every case!

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Got a question - sales@sandblaster.com is the address for answers.

Revised: October 05, 2000.

Examples of cleaning rates of some common abrasives:

Abrasive	Consumption	Production Rate	Comments
Silica Sand 16/40 mesh	2.6 lbs/sq/ft	4.75 sq/ft/min	1.5 mil profile Dusty
Coal Slag 12/40 mesh	3.2 lbs/sq/ft	3.83 sq/ft/min	2.5 - 3 mil profile Medium dust and embeddment
Steel Grit #40	5.5 lbs/sq/ft	3.06 sq/ft/min	2.5 mil profile No dust, but high embeddment
Garnet #36	3.6 lbs/sq/ft	3.55 sq/ft/min	1.5 mil profile Medium dust and embeddment
Aluminum Oxide #36	3.1 lbs/sq/ft	4.58 sq/ft/min	1.5 mil profile Very little dust
Staurolite 50/100 mesh	3.1 lbs/sq/ft	4.85 sq/ft/min	.5 mil profile medium dust
Copper Slag 16/40 mesh	3.1 lbs/sq/ft	4.36 sq/ft/min	2 mil profile Medium dust and embeddment
Brown Blast 16/50 mesh	1.5 lbs/sq/ft	3.0 sq/ft/min	3 mil profile Medium dust and embeddment
Glass Grit 8/40 mesh	2.8 lbs/sq/ft	3.33 sq/ft/min	4 mil profile Medium dust and embeddment
Crystalgrit 20/70 mesh	1.5 lbs/sq/ft	5.97 sq/ft/min	3 - 4 mil profile Very low dust and embeddment

The above numbers were derived from tests by Virginia Materials and others including SSPC. All testing was done with a #6 (3/8") nozzle at 100 PSI and blasting to a SSPC 10 (near white finish) on new steel with mil scale only.

Many, many, many factors contribute to the consumption and production rates of abrasive blasting and your results may be very different from the above. This is only for comparison purposes to show the **typical differences** between materials.

Beneficial Reuse Program

Handling spent abrasives with common sense and the environment in mind!

It has come to our attention in recent years that disposing of the spent abrasive is frequently almost as costly as actually buying the grit. In order to help customers with this problem, Virginia Materials has come up with a solution that not only helps our customers but also helps to preserve the environment.

Instead of disposing of the spent grit in landfills, as is customary, Virginia Materials accepts spent grit from our customers. After collecting and screening the grit to ensure the removal of all oversize trash we ship it to a portland cement manufacturer as a feed stock. The cement company superheats this raw material to a molten state (2600° F) along with other materials and uses it to make clinker, which is then ground up and used to produce portland cement. Thus, our customers no longer need to take up precious landfill space with tons of waste grit which can be better used to make a useful end product, which will probably itself be recycled, as concrete is almost infinitely recyclable these days. This also reduces the use of our natural resources by cutting into the use of precious minerals that would have been used.

Another benefit of this beneficial reuse plan is that the waste grit is safely disposed of in a manner whereby it will never become a problem and be traced back to the generator, as can happen with land filling. Such as could be the case in a "Superfund Site" with liability to everyone who disposed of something in it - hazardous or not! This plan is heartily endorsed by the Department of Environmental Quality Waste Division authorities and by all customers who have taken advantage of it. Virginia Materials is fully licensed by the State of Virginia as a material recovery facility.

To view our full program download this Adobe Acrobat file - Beneficial Reuse Program

Home | Information | What's New | Products

Revised: October 05, 2000.

Virginia Materials
3306 Peterson Street, Norfolk, VA 23509-2415
Phone: 757-855-0155, FAX: 757-857-5631

BENEFICIAL REUSE AND DISPOSAL OF SPENT ABRASIVES PROGRAM

TOMORROW'S FUTURE STARTS TODAY!

Background

Virginia Material's program for the removal of spent abrasives has been developed to meet the increased need to recycle waste products rather than dumping those materials in landfills. The use of spent abrasives in the portland cement manufacturing process converts a waste material into a useful product, thus removing the potential risk that landfilled abrasive wastes may have should they become a future problem. By using your spent abrasive as a raw material in a new product it "*Breaks the chain of custody*!"

On October 28, 1997; Virginia Materials was issued the first and so far the only permit for a Materials Recovery Facility in the Commonwealth of Virginia which serves as a spent blast grit reprocessing facility at its location - 3306 Peterson Street, Norfolk, Virginia. To date more the 150,000 tons have been recycled which otherwise would have been destined to be placed into landfills. Of course at the same time this eliminates depletion of our natural resources and minerals that would have been used otherwise.

Working with the Department of Environmental Quality and our cement industry consultant, Bulk Materials we have developed standards to enable us to meet the relevant regulatory requirements as well as kiln requirements by sampling: testing and classifying spent abrasive blasting materials. Materials meeting the criteria for acceptance by us are now processed and transported by rail to cement plants. In general, the only spent abrasives that will be unacceptable for shipping will be those containing more than 5 parts per million (PPM) of lead when tested by the TCLP leachate extraction procedure or otherwise considered hazardous.

The procedures and fee for removal and disposal will depend on the volume and location of the spent abrasive. Our customer's responsibility will be to provide assistance with sampling and testing of the waste material prior to moving and classification then to provide facilities and labor for loading of accepted material into dump trailers, or trucks, dumpsters, rail cars, barges, or VM bins prior to shipment to Norfolk.

Virginia Materials offers this spent abrasive disposal service to provide a cost-effective method of reprocessing a waste material to provide a new, useful product and reduce the amount of material being placed in landfills. Please contact Ben Burns at VM if we can be of assistance to you with this program.

Your Responsibilities

The Commonwealth of Virginia Department of Environmental Quality Division of Waste Operations Guidance Document No. 97-2001 sets the standard for the handling, storage and disposal of spent sandblasting abrasives for the Commonwealth of Virginia. Other states will have similar rules and regulations and should be read and understood by those concerned.

The items of most importance to the facility where the sandblasting is taking place are contained in section III and section IV and paraphrased here:

> ***From Section III***
>
> *"Appropriate Container" as pertains to spent and/or discarded sandblast grit falls into two categories; long term (i.e., longer than 90 days) and short term (i.e., less than or equal to 90 days):*
>
> - *for long term storage, means an enclosed building, tank, or impermeable pad with curbs and drains. Containers which are not covered must be capable of collecting and controlling, in addition to the material contained, the water volume resulting from a 24-hour, 25 year storm event. Also, containers for long term storage must have outlets or drains for proper removal of collected liquids to a sanitary sewer or holding tank for ultimate disposal at an approved publicly-owned treatment works (POTW) or other permitted wastewater treatment facility;,*
> - *for short term storage, means dumpsters or roll off containers which are covered with a tarp, or an enclosed building, or if material is piled on the ground (i.e., a waste pile), a berm around such pile, with the pile covered with a tarp. These containers must be designed to minimize run-on and run-off.*
>
> ***From Section IV***
>
> 1. *Spent sandblast grit from sandblasting operations that is being generated on a site shall be stored or in appropriate containers for no more than 90 days. No spent sandblast grit may be brought from off-site. Best management practices for the sandblasting operations shall be implemented so that the spent sandblast material is not discharged to state waters.*

As you can see from the above it is required that the sandblasting facility to remove all spent abrasives with in the defined "short term" period of 90 days.

Don't take a chance, Virginia Materials has the necessary facilities for storage and processing of your spent abrasives.

How it Works

CHANGING WASTE INTO A USEFUL PRODUCT

All of the spent sandblast abrasives accepted by our licensed Material Recovery Facility at Virginia Materials are presently processed and transported to a cement kiln manufacturer. There they are used as a raw material "feed stock" and are mixed with other raw materials to produce Portland Cement. This mix of materials is processed and burned in a kiln with a 3,400°F temperature achieving a material temperature of 2,800°F. The spent sandblast abrasives are chemically changed and recycled to create a "risk-free" environmentally safe product called a clinker which is cooled and ground into portland cement.

LEAD BASED COATING REMOVAL

Are you faced with removing lead-based paints? Blastox has become the recognized leader for the removal of lead based and other heavy metals paints. When properly utilized, sandblasting abrasives pre-blended with Blastox will not mask hazardous lead waste. A potentially lead contaminated hazardous waste will become non-hazardous waste and can be placed in our Beneficial Reuse Program.

Virginia Materials is an authorized blender of Blastox and will accept the used material into our Beneficial Reuse Program.

PROGRAM MANAGER

Mr. Benjamin Burns has been appointed our "Beneficial Reuse Program" Manager. Ben has been coordinating Virginia Materials efforts and oversees the program since its inception. Ben is a graduate of Old Dominion University with a strong work ethic and gets the job done right the first time.

Ben Burns along with all the Virginia Materials staff is ready to help you with "Beneficial Reuse" including transportation, TCLP procedures, and with any other questions or concerns that may arise. Call Ben anytime!

Beneficial Reuse Participants

We are proud to highlight a few of our fine customers who have taken the initiative on their own to start recycling voluntarily. Thus helping themselves and the environment.

- Alco Welding
- Bay Mechanical
- Consolidated Launcher
- Holmes Brothers
- Lockly Mfg.
- Metro Machine
- Moon Engineering
- Norshipco
- Reliable Trash
- Superior Disposal
- Vanwin Coatings
- Ampro
- Colonnas Shipyard
- Hico
- Huntsman Chemical
- Marine Hydraulics
- Mid Atlantic Coatings
- Norfolk Naval Shipyard
- Oilfield Pipe & Supply
- Riggins
- Technico
- Virginia Machine
- North Carolina DOT

Service Fees

Our charge to you for processing and transportation to the portland cement manufacturer is $23.90/Ton FOB Virginia Materials.

In certain situations, based upon large volume, it is possible to develop a reduced service fee. Upon your request we will be happy to design a program to meet you specific goals.

Please note that we must have a TCLP report on the material to assure that it is non-hazardous before shipment and handling.

Transportation

There are a number of ways for you to get the spent abrasive material to us that we can arrange for you. The least expensive is generally via dump trailer or truck; however, roll off containers may be used.

We also offer customers who use our steel bins to take delivery of new abrasive the option to return the spent material in the same bins, at no additional cost then what you would normally pay for return of the empty bins.

The use of bulk bags or super sacks is another permissible method to return spent abrasives back to us. This can work well when the new abrasives are purchased in the super sacks and you, the user refill it for transportation via truck, rail or boat if tonnages warrant it.

For large volume disposal needs in excess of 80 tons and it the distance is considerable, Virginia Materials may be able to arrange for the use of open top hopper rail cars.

FLORIDA

Department of
Environmental Protection

Marjory Stoneman Douglas Building
3900 Commonwealth Boulevard
Tallahassee, Florida 32399-3000

Jeb Bush
Governor

David B. Struhs
Secretary

January 30, 2001

CERTIFIED MAIL RETURN RECEIPT REQUESTED

Mr. William C. Thomas, III
Vice President of Industrial Development & Operations
Conrad Yelvington Distributors, Inc.
Post Office Box 1686
Daytona Beach, Florida 32115

Re: Amended Application for an Air Construction Permit
Powerscreen Sand and Gravel Classifier: Draft Permit No.: 7770473-001-AC

Dear Mr. Thomas:

We received the original application for an air construction permit for a Powerscreen Chieftain 510 on April 19, 2000. The initial application indicated that the screener was to be employed as a relocatable facility at any on the applicant's aggregate storage and processing yards for screening and classifying sand and rock aggregates, at various storage yards owned or operated by Conrad Yelvington Distributors, Inc.(CYDI), throughout the state. This application was processed to a draft Air Construction Permit that was issued on August 11, 2000. In the final days of processing the application we discovered, during a telephone call, that the CYDI intended to use this screener for processing spent abrasive blasting media (ABM). This intended use was not indicated in the application. The spent ABM has the potential of containing toxic heavy metals and toxic chemical residues from paints. Rather than delay or deny the draft permit at that time, we included a paragraph prohibiting the processing of ABM or other hazardous material.

CYDI has never published the public notice that was included in the "Intent to Issue" package for 7770473-001-AC. Rather, CYDI sought to amend the application, and urge the Department to modify the draft Air Construction Permit. Assurances were to be provided that the spent abrasive material was not hazardous, that the proposed processing of ABM would not violate state or federal air pollution standards, that the ABM would not constitute a health hazard, to provide testing criteria for acceptable material, and a management plan for dust and unacceptable spent ABM material.

We agreed to allow you 60 days to amend the application (without additional fees).

Your letter transmitting Stephanie Brooks' undated letter and laboratory reports followed on October 2, 2000. We accepted these documents as an "amendment" to the application. Ms. Brooks made some emission calculations based on TCLP test results and AP 42 emission factors. These calculations were unacceptable because TCLP is not an appropriate laboratory test for determining potential air emissions. I deemed this amendment to the application insufficient and wrote a "Completeness Review and Request for Additional Information", which was mailed on October 16, 2000. I also provided technical reference material that I obtained from the Department's Division of Waste and from an EPA internet search site.

The certified mail return receipt card shows that you received the notice of completeness review and request for additional information on October 23, 2000.

More than 90 days have past since you received our completeness letter. The application has been in house 280 days, including our agreed extensions.

The Powerscreen Chieftain 510 is not permitted to operate at this time. The documents issued on August 11, 2000, do not authorize assembly, testing or operation of the facility. They only reflect the Department's intent to issue an Air Construction Permit, following (and conditioned upon) the publication of a public notice and resolution of any issues arising therefrom. The procedure for obtaining an Air Operation Permit requires the existence of a valid Air Construction Permit, a separate application and fee for the Air Operating Permit, as well as completion of compliance testing.

Rule 62-4.055(1) Florida Administrative Code provides:

> (1) Within thirty days after receipt of an application for a permit and the correct processing fee the Department shall review the application and shall request submittal of additional information the Department is authorized by law to request. The applicant shall have ninety days after the Department mails a timely request for additional information to submit that information to the Department. If an applicant requires more than ninety days in which to respond to a request for additional information, the applicant may notify the Department in writing of the circumstances, at which time the application shall be held in active status for one additional period of up to ninety days. Additional extensions shall be granted for good cause shown by the applicant. A showing that the applicant is making a diligent effort to obtain the requested additional information shall constitute good cause. Failure of an applicant to provide the timely requested information by the applicable deadline shall result in denial of the application.

Since we have had no response to our letter of October 16, 2000, requesting additional information, nor have we had any request for an extension to the 90 day response time, the Department will allow you thirty days from the receipt of this letter to provide all the information requested in the October 16 letter, or to indicate good cause why this time should be extended. Otherwise, the requested permit will be denied.

If you have any questions, please call me at (850) 921-9522.

Sincerely,

W. Leffler

William Leffler, P.E.
Permitting Engineer

Cc:
Stephanie S. Brooks, P.E., Brooks and Associates, Inc.
Clair Fancy, BAR
Bruce Mitchell, BAR
Jerry Campbell, Hillsborough County Environmental Protection Commission
Richard B. Tedder, Division of Waste Management