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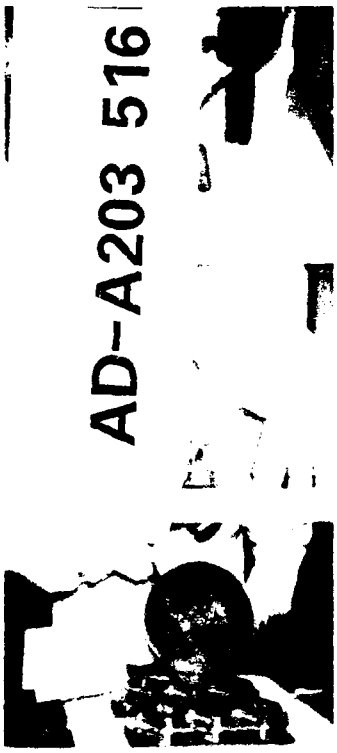

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AN EVALUATION OF STABILIZATION/ SOLIDIFICATION OF FLUIDIZED BED INCINERATOR ASH (K048 AND K051)

by

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Environmental Laboratory

DEPARTMENT OF THE ARMY
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This report presents the results of testing preformed on a stabilized/solidified (S/S) incinerator ash. This study was conducted in support of the US Environmental Protection Agency, Best Demonstrated Available Technology program. The ash samples evaluated in the study were residuals resulting from the incineration of a mixture of dissolved air-flotation float (K048), API separator oily sludge (K051), and a biological sludge. Three S/S processes were evaluated in this study. They included: (1) a cement process; (2) a kiln dust process; and (3) a lime/fly ash process. Physical and leaching characteristics of the S/S waste ash materials were evaluated. Physical characteristics were evaluated using the unconfined compressive-strength test. The waste-leaching characteristics were evaluated using the toxicity characteristic leaching procedure. Physical test results

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Ash	Demonstrated technology	
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showed that S/S ash developed 28-day strengths ranging from 200 to 1,000 psi. Results of the chemical leach tests suggested that the effectiveness of a S/S process is contaminant specific. This study indicated that all three S/S processes were effective for aluminum, arsenic, selenium, sodium, and vanadium. These S/S processes were least effective for barium, chromium, and iron.

PREFACE

This report was prepared for the US Environmental Protection Agency (USEPA), Risk Reduction Engineering Laboratory, by the US Army Engineer Waterways Experiment Station (WES). This project, conducted as part of the USEPA program to develop treatment standards for wastes subject to land-ban disposal restrictions, was funded under Interagency Agreement DW96930146-01-5.

The work was performed during the period February to August 1987 by Mr. R. Mark Bricka, Ms. Teresa Holmes, and Mr. M. John Cullinane of the Water Supply and Waste Treatment Group (WSWTG), Environmental Engineering Division (EED), Environmental Laboratory (EL), WES. Chemical analyses were performed by PEI Associates, Inc., Cincinnati, OH. Cement, lime, fly ash, and kiln dust analyses were performed by the Materials and Concrete Analysis Group, Concrete Technology Division, Structures Laboratory (SL). The work was conducted at WES under the direct supervision of Mr. Norman R. Francingues, Chief, WSWTG; and the general supervision of Dr. Raymond L. Montgomery, Chief, EED; and Dr. John Harrison, Chief, EL. Project officers for the USEPA were Messrs. Paul de Percin and Carlton Wiles. Mr. Bobby Odom, assigned to the Information Technology Laboratory under the Intergovernmental Personnel Act, edited the report.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
degrees (angle)	0.01745329	radians
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
feet	0.3048	metres
gallons (US liquid)	3.785412	cubic decimetres
inches	25.4	millimetres
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
quarts (US liquid)	0.9463529	cubic decimetres
square inches	6.4516	square centimetres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

AN EVALUATION OF STABILIZATION/SOLIDIFICATION OF FLUIDIZED BED INCINERATOR ASH (K048 AND K051)

PART I: INTRODUCTION

Background

1. Amendments to the Resource Conservation and Recovery Act (RCRA), enacted through the Hazardous and Solid Waste Amendments of 1984 (HSWA), impose substantial new responsibilities on handlers of hazardous waste. In particular, these amendments prohibit the continued land disposal of untreated hazardous wastes beyond specified dates, "unless the Administrator determines that the prohibition...is not required in order to protect human health and the environment for as long as the wastes remain hazardous..." (RCRA sections 3004(d)(1), (e)(1), (g)(5), 42 USC 6924(d)(1), (e)(1), and (g)(5)).

2. Waste treated in accordance with treatment standards set by the US Environmental Protection Agency (USEPA) under section 3004(m) of RCRA is not subject to the prohibitions and may be land disposed. The statute requires USEPA to set "levels or methods of treatment, if any, which substantially diminish the toxicity of the waste or substantially reduce the likelihood of migration of hazardous constituents from the waste so that short-term and long-term threats to human health and the environment are minimized..." (RCRA section 3004(m)(1), and 42 USC 6924(m)91).

3. Congress has also prohibited the storage of any hazardous waste that is subject to the prohibition on land disposal unless "such storage is solely for the purpose of the accumulation of such quantities of hazardous waste as are necessary to facilitate proper recovery, treatment or disposal..." (RCRA section 3004(j), 42 USC 6294(j)).

4. Congress has provided a statutory exemption from the land disposal restrictions for the treatment of wastes in a surface impoundment, provided that the impoundments meet minimum technological requirements (with limited exceptions) and that treatment residues that do not meet the treatment standard(s) are removed within 1 year of the entry of the waste into the impoundment (RCRA section 3005(j)(11)(A)(B), 42 USC 6925(j)(11)(A)(B)).

5. To expedite the development of treatment standards, various deadlines have been established for agency action. Further land disposal of a

particular group of hazardous wastes is prohibited at certain deadlines if the USEPA has not set treatment standards under RCRA section 3004(m) for such wastes or determined, based on a case-specific petition, that there will be no migration of hazardous constituents from the units for as long as the wastes remain hazardous. Additional deadlines result in conditional restrictions on land disposal to take effect if treatment standards have not been promulgated or if a petition has not been granted.

6. Treatment standards will be established based on Best Demonstrated Available Technology (BDAT) and developed in accordance with RCRA section 3004(m). USEPA (1986a) defines a technology as best, demonstrated, and available as follows:

a. Best--if several technologies are available for treating the same (or similar) waste(s), the waste treatment method which reduces the concentration and/or the migration of contaminants most effectively is considered best.

b. Demonstrated--for a waste-treatment technology to be considered demonstrated, a full scale facility must be known to be in operation for treating the waste.

c. Available--for a waste-treatment technology to be considered available, it must: (1) not present a greater total risk than land disposal; (2) be able to be purchased or licensed from the proprietor if a technology is a proprietary or patented process; and (3) provide substantial treatment.

7. Stabilization/solidification (S/S) is one technology that meets the demonstrated and available criteria (USEPA 1986c). S/S of hazardous wastes has been proposed as a treatment method for substantially reducing the likelihood of contaminant migration. EPA has initiated studies to evaluate S/S technology as a BDAT and to develop data to support the establishment of treatment standards.

Stabilization/Solidification

8. S/S is a process that involves the mixing of a hazardous waste with a binder material to enhance the physical and chemical properties of the waste and to chemically bind any free liquid (USEPA 1986c). Typically, the binder is a cement, pozzolan, or thermoplastic. Proprietary additives may also be added. In most cases, the S/S process is changed to accommodate specific wastes. Since it is not possible to discuss completely all possible modifications to a S/S process, discussions of most S/S processes have to be

related directly to generic process types. The performance observed for a specific S/S system may vary widely from its generic type, but the general characteristics of a process and its products are usually similar. Comprehensive general discussions of waste S/S processes are given in Malone and Jones (1979); Malone, Jones, and Larson (1980); Iadevaia and Kitchens (1980); and USEPA (1986b).

9. Waste S/S systems that have potential BDAT applications include:

   a. Lime/fly ash pozzolanic processes.

   b. Pozzolan-portland cement systems.

   c. Vitrification.

10. Lime/fly ash pozzolanic processes use a finely divided, noncrystalline silica in fly ash and the calcium in lime to produce low-strength cementation. The waste containment is produced by entrapping the waste in the pozzolan concrete matrix (microencapsulation). Metals are also converted to less soluble forms which further inhibit leaching.

11. Pozzolan-portland systems use portland cement and fly ash or other pozzolan materials to produce a type of waste/concrete composite. Contaminant migration is reduced by microencapsulation of the contaminants in the concrete matrix. The addition of soluble silicates to pozzolan-portland systems may accelerate hardening. As with lime/fly ash pozolonic systems, metals are also converted to less soluble forms in the pozzolan-portland systems.

12. Vitrification is a process whereby hazardous wastes are converted into a glassy substance utilizing very high temperatures. The process is carried out by inserting electrodes into a waste mass and passing a high current of electricity through the mass. The high temperature produces a melt, and as the melt cools, contaminants are trapped in the melt. The melt, when cooled, forms a stable noncrystalline solid which resembles obsidian, a very strong glass.

Waste of Interest

13. The waste utilized in this evaluation is a fluidized bed incinerator ash (FBdI-Ash). The FBdI-Ash waste was produced by incinerating, American Petroleum Institute (API) separator sludge (K051), dissolved air-flotation float (DAF, K048), and biological sludge. These wastes are described in more detail below.

14. The surface skimming from a dissolved air flotation (DAF) unit (commonly referred to as "DAF float") is listed waste K048. DAF processes are used by petroleum refineries for separating suspended and colloidal materials, including suspended solids and insoluble oily wastes, from process wastewater. The DAF unit separates oily wastes and suspended solids from water by introducing many tiny air bubbles into the water. These bubbles attach themselves to oil droplets and suspended solids that are dispersed through the waste stream. The resultant oil/air bubble complexes rise through the wastewater and collect on the water's surface where they can be removed by surface skimming devices.

15. API separators are used in petroleum refining operations to remove floating oil and suspended solids from the wastewater. In an API separator, oily water enters one end of a rectangular channel, flows through the length of the channel, and discharges at the other end. A sufficient residence time is provided to allow oil droplets to float and coalesce at the surface of the wastewater. An oil skimmer is provided near the end of the separator to collect the floating oil. Floating oil is advanced toward the skimmer by an oil and sludge moving device. These devices consist of a series of moving flights which span the width of the separator. As the flights move over the surface of the separator, floating oil is advanced toward the skimmer. The flights return to the inlet of the separator on the bottom of the channel. Solids which have settled out of the water are thus scraped along the channel bottom to a sludge-collecting hopper. The API separator sludge (K051) is pumped directly to the fluidized bed incinerator.

Purpose and Scope

16. The specific objectives of this study were to determine if S/S techniques can be applied to a FBdI-Ash (K048 and K051) and to characterize the effect of S/S on the ash. The physical and chemical properties of the S/S FBdI-Ash were evaluated in order to determine if S/S techniques will substantially reduce the amount of hazardous contaminants in the leachate and improve the physical handling properties of the ash. These data were collected as input to the USEPA's program to develop BDAT treatment standards for wastes generated by the petroleum refining industry which are subject to land-disposal restrictions.

17. Three binder systems (cement, kiln dust, and lime/fly ash) were used to stabilize/solidify the FBdI-Ash. The S/S FBdI-Ash materials were cured, and the physical and chemical properties of the S/S FBdI-Ash were determined. The unconfined compressive strength test (UCS) was used to measure the physical strength, and the Toxicity Characteristic Leaching Procedure (TCLP) was used to measure the chemical leachability of the contaminants from the S/S FBdI-Ash.

18. This report only presents the methods and test results from the S/S of the waste material. This report is not intended to, nor does it, make any attempt to make a determination as to whether S/S is a BDAT for K048 and K051. This determination will be made by the EPA in accordance with their regulatory procedures.

Organization of Report

19. This report is divided into four basic parts:

a. Part I briefly describes the background which explains the need for this study and introduces the concept of S/S.

b. Part II describes the methods used for sampling, treatment, and testing of the waste materials.

c. Part III describes the results of physical and contaminant mobility testing of the S/S FBdI-Ash.

d. Part IV presents conclusions based on the results of testing.

PART II: MATERIALS AND METHODS

General Approach to the Investigation

20. This investigation was conducted in four primary phases as summarized below:

a. Phase I: Sample Collection. Samples were collected and shipped to WES by the USEPA contractor.

b. Phase II: Preparation of Test Specimens. Test specimens of S/S waste were prepared. Preparation of the test specimens included an initial screening test (IST) to determine the appropriate water/binder/waste ratios for detailed evaluation.

c. Phase III: Physical and Contaminant-Release Testing. Physical characteristics were evaluated using the UCS test. Based on the results of the physical testing, the contaminant-release properties of BDAT-listed metal constituents were evaluated using the TCLP.

d. Phase IV: Data Analysis. Data from US Army Engineer Waterways Experiment Station (WES) and USEPA contractors were consolidated and evaluated.

Sample Collection

21. The FBdI-Ash utilized in this study was generated at the Amoco refinery in Whiting, IN. Ash samples were collected by a USEPA contractor on 15 January 1987. Samples of the raw ash were sent to Radian Corporation, Austin, TX, for total composition and TCLP analysis on the raw waste.

22. On 20 January 1987, the Water Supply and Waste Treatment Group (WSWTG) of WES received, under chain-of-custody, the FBdI-Ash samples. The samples were collected by the Radian Corporation and shipped to the WSWTG. The samples were received in three boxes containing a total of ten 1-gal* cans. An inventory listing of the FBdI-Ash samples is provided in Table 1.

23. In order to assess the variability of the sampling and treatment processes, the FBdI-Ash was divided into three subsamples and treated separately. Each subsample was prepared by randomly combining 3-1/3 cans of the FBdI-Ash and thoroughly mixing. Two 1-qt portions of each subsample were

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.

collected for the initial screening procedures. All samples were stored at 4° C until they were needed for testing.

Preparation of the Test Specimens

General description of the S/S processes

24. Three solidification processes were used to stabilize/solidify the FBdI-Ash and are differentiated by the type of binder material used in the process. The three processed included: portland cement, kiln dust, and lime/fly ash. A compositional and chemical analysis of binders used in this study is presented in Tables 2 and 3.

25. The S/S process involves the addition of water and binder material to the waste followed by mixing and a curing period. A schematic flowchart of the S/S processing is shown as Figure 1.

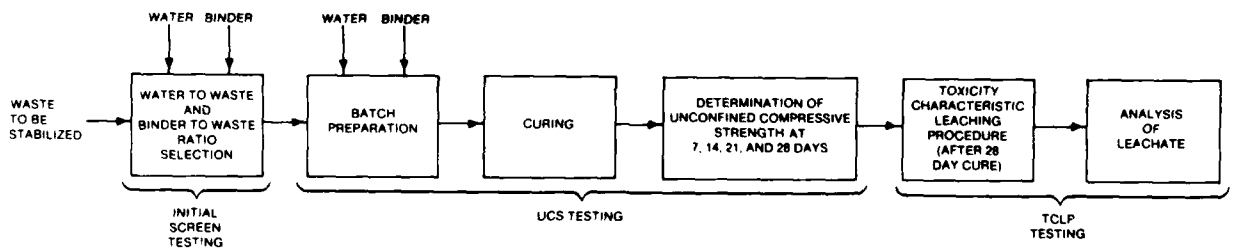

Figure 1. Schematic flowchart for stabilization processing

Initial screening test

26. The approach to the initial screening test was two-fold: first, to determine the appropriate water to binder/FBdI-Ash ratio for each S/S process; and second, to narrow the range of binder to FBdI-Ash ratios used for detailed evaluation. The FBdI-Ash was a very dry, fine material, and it was necessary to add water to the FBdI-Ash for S/S to be effective. The initial waste/binder screening test involved mixing binder, water, and FBdI-Ash in a K455S Hobart mixer at three water-to-ash weight ratios: 0.2; 0.5; and 0.7. These ratios were chosen on a basis of previous experience of the testing personnel. The matrix of test specimens prepared during the initial screening test is shown in Table 4.

27. Determination of the optimal water to binder/FBdI-Ash ratio was based on the results of the Cone Index Test (CI) performed on the initial screening test samples after they had cured for 48 hr. The CI measures the resistance of a material to the penetration of a 30-deg right circular cone. The method specified in TM 5-530 was followed (Headquarters, Department of the Army 1971). The CI value is reported as force per unit surface area (pounds per square inch) of the cone base required to push the cone through a test material at a rate of 72 in./min. Two cones are available for this test: the standard WES cone having an area of 0.5 sq in.; and the airfield penetrometer having a base area of 0.2 sq in. It was convenient to use the standard WES cone on material with a CI less than 100 psi and to use the airfield penetrometer on materials with a CI greater than 100 psi. The maximum CI value that can be measured by the airfield penetrometer is 750 psi; therefore, materials having CI values greater than 750 psi are reported simply as >750 psi.

28. The results of the initial screening test define the optimal water to binder/FBdI-Ash ratio and produce data which aid in the selection of the binder/FBdI-Ash ratios for detailed evaluation. The test specimens generated during the initial screening test were not used for further evaluation.

Preparation of specimens for detailed evaluation

29. The three subsamples were S/S using the three binders (cement, kiln dust, and lime/fly ash). A total of four binder/FBdI-Ash ratios for the cement and kiln dust binders and nine binder/FBdI-Ash ratios for the lime/fly ash binder were evaluated. The binder/FBdI-Ash ratios was selected on the basis of results of the initial screening test.

30. Table 5 summarizes the matrix of test specimens prepared for detailed evaluation. Each time a stabilization process was applied, a batch of material was generated. As shown, 12 batches of solidified waste were prepared for the cement and kiln dust solidification processes, and 27 batches were prepared for the lime/fly ash solidification processes. These batches were differentiated by the alphanumeric codes shown in Table 5.

31. Solidified specimens were prepared by mixing water/binder with FBdI-Ash in a Hobart K455S mixer. The water/binder/FBdI-Ash slurry was poured into 2 by 2 in. brass molds. To aid in removing test specimens from the molds, a light coat of grease was applied to the molds. Specimens prepared in the greased molds were used in the UCS testing. Specimens used for the TCLP

test were prepared in ungreased molds. Immediately after the binder/water/FBdI-Ash mixtures were placed in the molds, they were vibrated on a Sentron model VP61D1 vibration table to remove voids. At the high lime ratio (0.6), the binder/water/FBdI-Ash mixture was very viscous, and vibration was an ineffective method for removing voids. These specimens were compacted in the 2- by 2-in. molds using a compaction hammer with a 5.74-lb weight, a 1.8- by 1.0-in. brass head, and a 12-in. drop. Compaction was accomplished by placing two layers of the binder/water/FBdI-Ash mixture in the molds and dropping the weight five times per layer.

32. The molded, S/S materials were cured in the molds at 23° C and 98-percent relative humidity for a minimum of 24 hr. Specimens which were removed from the molds when they developed sufficient strength to be free standing were cured under the same temperature and relative humidity conditions until further testing.

Physical and Contaminant Release Testing

Unconfined compressive strength

33. UCS was used to define and characterize the effects of the S/S process on the physical characteristics of the waste. The UCS of the S/S FBdI-Ash was determined using ASTM method C 109-86 (ASTM 1986). The only deviation from this method was vibration or compaction of the specimens as discussed in paragraph 31.

34. UCS testing was performed on cubes after they had cured for 7, 14, 21, and 28 days. One cube for each batch of binder/FBdI-Ash mixture was tested at these curing periods. The surface area of each cube was determined by using a Flower Max-cal caliper, and each cube was crushed with a Tinius Olsen Super L compression apparatus. UCS was reported as required to fracture the cube.

Contaminant mobility testing

35. Selection of binder ratio for further study. There are a number of ways to assess the success of a S/S process. For the purposes of this testing program, the UCS test was chosen as the parameter to make that determination (USEPA 1987). One cube from each S/S batch was subjected to the UCS test at the completion of the 28-day cure period, as previously discussed. The stabilized FBdI-Ash binder ratio that exhibited UCS values closest to but greater

than 50 psi was the ratio used to assess the affects of S/S on the contaminant-release characteristics of the treated waste. A UCS of 50 psi was chosen based on information found in the Office of Solid Waste and Emergency Response (OSWER) Policy Directive 9487.00-2A (USEPA 1986e), and based on this criteria, one binder-to-ash ratio was selected from each S/S process for TCLP extraction and analysis. TCLP extraction was performed in triplicate for each binder-to-ash ratio selected. Thus, a total of nine TCLP extractions was performed on the three S/S FBdI-Ash selected for evaluation.

36. Toxicity characteristic leaching procedure. The TCLP was selected by the USEPA as the test protocol for evaluating contaminant mobility. The TCLP was conducted using the procedure proposed by the USEPA (1986d). TCLP extracts were collected in sample containers and preserved in accordance with procedures outlined in USEPA (1986f). These extracts were forwarded, under chain-of-custody, to the PEI Associates, Inc. laboratory for chemical analysis.

37. Analytical procedures. TCLP extracts were analyzed for metals according to the methods and within the time constraints summarized in the Federal Register (USEPA 1986d) and specified in SW-846 (USEPA 1986f). The contaminants of interest and the appropriate analytical methods are listed in Table 6. Analyses for volatile and semivolatile compounds were not performed since only minute levels of organic compounds were expected to be present in the incinerated FBdI-Ash.

38. Quality assurance/quality control. The quality assurance/quality control (QA/QC) for this project was divided between WES and the PEI Laboratory. WES was responsible for the TCLP extraction preparation and for preparation of the method blanks for each S/S FBdI-Ash mixture extracted. PEI was responsible for laboratory QA/QC related to the actual chemical analysis of the TCLP extracts. The details of the QA/QC activities performed by PEI are described in the quality assurance plan prepared by PEI (1987).

PART III: DISCUSSION OF RESULTS

Initial Screening Test Results

Cement binder

39. The initial screening test results for the cement binder are presented in Table 7. These data indicate that samples prepared using a 0.2 water ratio developed substantially less strength than samples prepared using the 0.5 and 0.7 water ratios. In fact, both the high and low cement ratios at the 0.5 and 0.7 water ratios produced specimens that achieved a CI value greater than 750 psi after 48 hr of cure. From the values in Table 7, it appears that the 0.2 water ratio was not sufficient for completion of the cement hydration reactions whereas sufficient water was available for cement hydration at the 0.5 water ratio. The data in Table 7 also indicate that at a 0.5 water ratio, the 0.1 cement to FBdI-Ash mixture develops measurable strength. Thus, batch formulations of 0.2, 0.4, 0.6, and 0.8 cement to FBdI-Ash ratios and water-to-FBdI-Ash ratio of 0.5 were selected for further detailed testing and evaluation.

Kiln dust binder

40. Results of the initial screening test for the kiln dust binder are presented in Table 8. These results indicate that the 0.1 kiln dust to FBdI-Ash ratio sample developed little strength at the various water ratios evaluated. At the 0.7 kiln dust to FBdI-Ash ratio, the optimal water to FBdI-Ash ratio was determined to be 0.5. This 0.5/0.7 water/kiln dust-to-FBdI-Ash ratio developed substantial strength. Thus, 0.2, 0.4, 0.6, and 0.8 kiln dust-to-FBdI-Ash ratios at the 0.5 water ratio were selected as the ratios for further detailed testing and evaluation.

Lime/fly ash binder

41. Initial screening test results for the lime/fly ash binder are presented in Table 9. The data indicate that 0.5 water/FBdI-Ash ratio produced materials that developed the highest strength, except at the highest lime/ fly ash ratio. At this high lime/fly ash ratio (0.7/0.7), the water required to fully hydrate the binder exceeds the amount of water supplied by the 0.2 and 0.5 water ratio, resulting in low strength development. Lime/fly ash-to-FBdI-Ash ratios at the 0.1/0.7 and 0.7/0.1 ratio appear to produce materials with substantial strength. Based on this information and the fact that only

limited FBdI-Ash was available for testing, the lime/fly ash ratios listed in Table 10 were selected for additional testing and evaluation.

UCS Results

42. The results of the UCS tests are summarized and discussed below. The raw data for the UCS tests are presented as tables in Appendix B.

Cement binder

43. Figure 2 presents a graph of the average UCS versus curing time for the S/S FBdI-Ash where cement was used as the binder. The cement S/S FBdI-Ash developed substantial UCS. The FBdI-Ash waste having a cement binder-to-waste ratio (BWR) of 0.8 developed a 28-day UCS as high as 4,300 psi, and the 0.2 BWR material developed a 28-day UCS of 849 psi. These data also indicate that the cement S/S FBdI-Ash waste develops greater strength as the BWR is increased. The 0.8 cement BWR developed a UCS seven times larger than the UCS developed by the 0.2 cement BWR after 7 days of curing and four times larger after 28 days of curing.

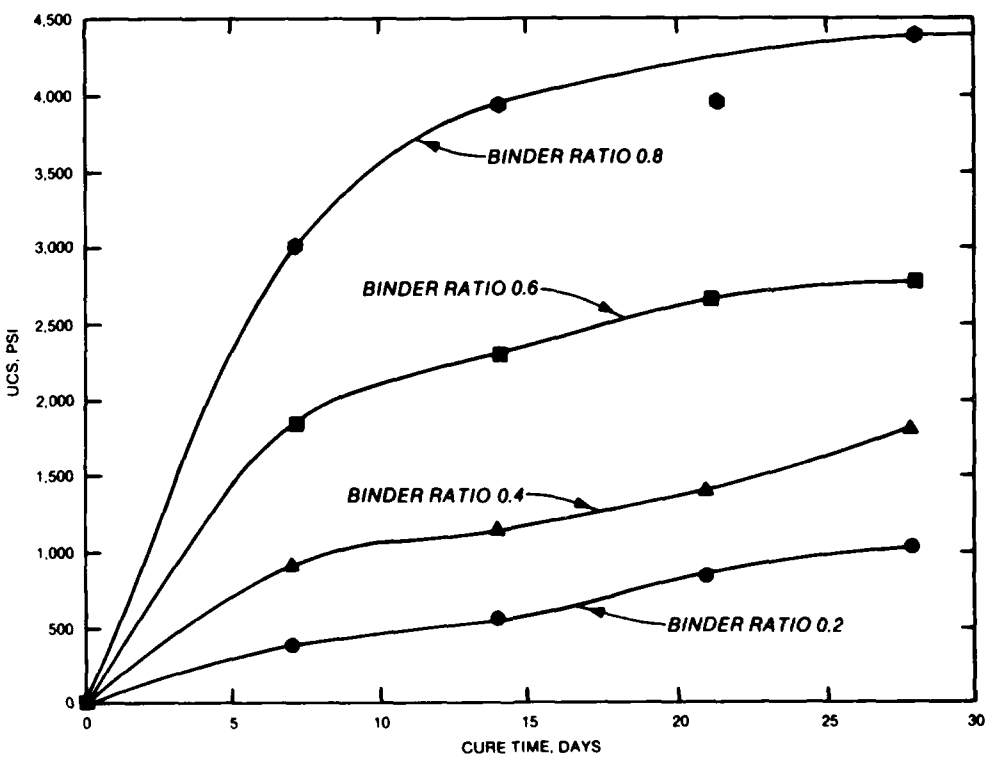

Figure 2. UCS versus curing time for the S/S FBdI-Ash using different cement binder ratios

44. The shape of the UCS curves shows that for all four cement BWR ratios (0.2, 0.4, 0.6, and 0.8) only small gains in strength beyond the 28-day curing period can be expected. Thus, as the cement S/S FBdI-Ash materials continue to cure, the material with the 0.8 BWR will maintain a UCS approximately 4 times larger than the 0.2 BWR material.

Kiln dust binder

45. Results similar to the cement UCS data were observed when kiln dust was used as a binder as indicated in Figure 3. The UCS increases as the BWR is increased, and a BWR of 0.8 develops five times more UCS than the 0.2 kiln dust BWR waste after 28 days of cure. The FBdI-Ash waste treated with kiln dust developed substantially lower UCS than the cement treated FBdI-Ash wastes. The FBdI-Ash waste treated with a 0.2 kiln dust BWR developed a 28-day UCS of 243 psi, and the 0.8 BWR waste developed a 28-day UCS of 1,315 psi. The shape of the curves indicates that these materials will substantially increases in strength as they cure beyond 28 days.

Lime/fly ash binder

46. The interpretation of the lime/fly ash UCS data is more difficult than the cement and kiln dust UCS data because both the lime BWR and the fly

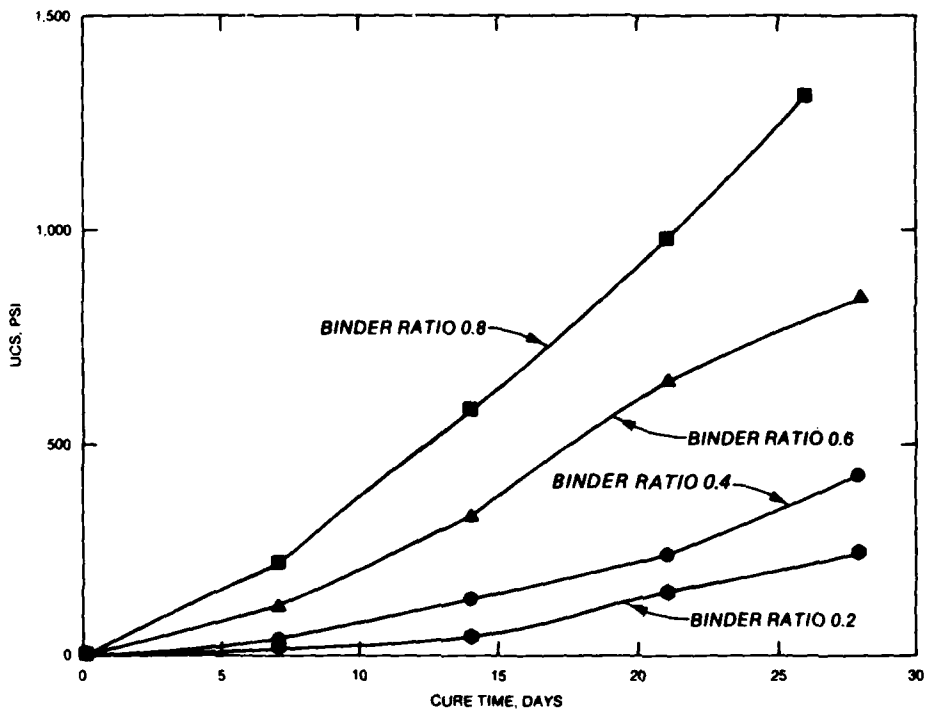

Figure 3. UCS versus curing time for the S/S FBdI-Ash using different kiln dust binder ratios

ash BWR were varied. The UCS versus curing time curves for the lime/fly ash binders tend to overlap as shown in Figure 4. The graphs in Figure 4 also illustrate that at the 28-days cure period the UCS for the 0.4/0.6 lime/fly ash BWR is increasing at a faster rate than the other lime/fly ash BWR batches. Therefore, it is expected that strength development for the 0.4/0.6 lime/fly ash BWR beyond the 28-day cure will be substantially greater than that expected for the other BWR.

47. General trends in the lime/fly ash UCS data can be better illustrated by plotting the 28-day UCS. Figure 5 is a plot of the 28-day UCS data for all of the binder ratios studied. The FBdI-Ash data where lime/fly ash was used as a binder is presented in three groups of bars on the right side of Figure 5. Figure 5 illustrates that varying the lime ratio has less effect on the UCS development of the lime/fly ash waste mixture than varying the fly ash ratio. For example, at the 0.4 fly ash BWR, the UCS is approximately 1,800 psi for each lime ratio (0.2, 04, and 0.6). The highest strength development for the lime/fly ash binder was observed when the FBdI-Ash was solidified at a 0.4/0.6 lime/fly ash BWR.

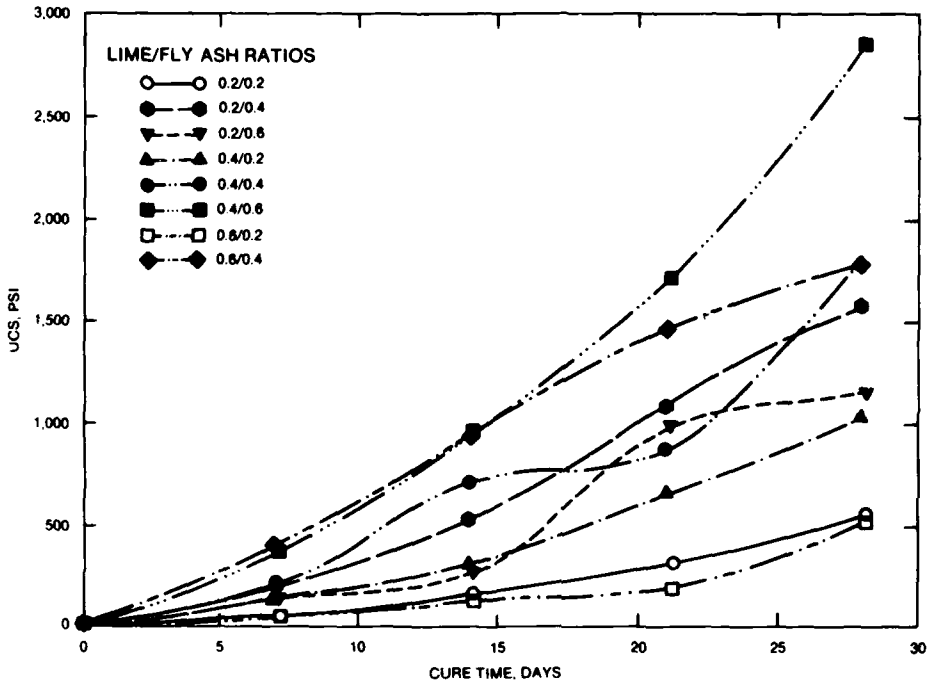

Figure 4. UCS versus curing time for the S/S FBdI-Ash using different lime/fly ash binder ratios

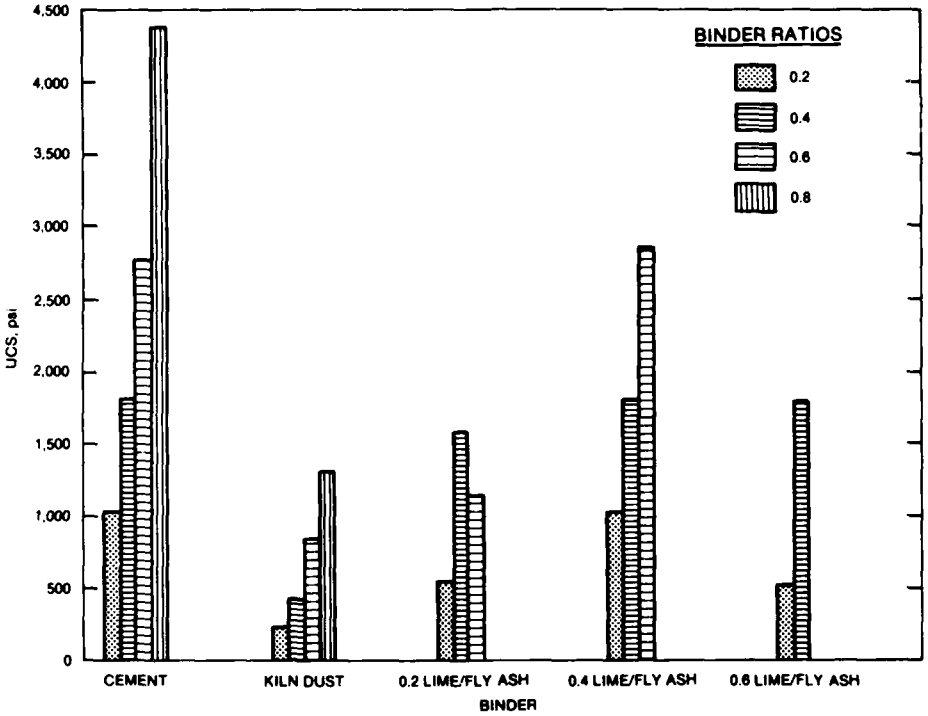

Figure 5. Twenty-eight day UCS for the S/S FBdI-Ash using cement, kiln dust, and lime/fly ash as binders

48. Figure 5 also illustrates that the cement S/S FBdI-Ash developed higher UCS at the 28-day cure time than FBdI-Ash treated with kiln dust or lime/fly ash. It is unclear whether the cement solidified ash will continue to have superior strength development as time increases. This is based on the concept that extrapolation of the UCS curves for the high ratios of kiln dust and lime/fly ash S/S FBdI-Ash (Figures 3 and 4) illustrates that substantial strength development should be observed for these materials beyond the 28-day cure period while extrapolation of the UCS curves for cement S/S FBdI-Ash (Figure 2) indicates these materials are approaching their ultimate strength.

Ratios selected for TCLP extraction

49. As illustrated in Figure 5, all the binders at the BWR investigated developed UCS well above the 50 psi UCS selection criterion. The materials

designated for TCLP analysis were chosen by selecting the batch with the minimum BWR. The BWR's selected for TCLP extraction are listed in Table 11.

TCLP Results

50. Results of the bulk chemical analyses and TCLP for the raw waste are presented in Table 12. The results of the TCLP test for the S/S FBdI-Ash are given in Table 13, presented in Figures 6-9, and located in Appendix C. Of the 22 compounds analyzed, 11 were at or near the detection limit. As indicated in Appendix C, they included: antimony, arsenic, beryllium, cadmium, cobalt, copper, manganese, nickel, silver, thallium, and tin. The 11 compounds detected in the TCLP leachate included: aluminum, barium, total chromium, iron, lead, magnesium, selenium, sodium, vanadium, zinc, and hexavalent chromium. Table 13 and Figures 6-9 present TCLP leachate results for the 11 compounds that leached detectable quantities of the contaminants for which analyses were performed.

51. The TCLP analysis for the untreated FBdI-Ash can be directly compared to the TCLP analyses for S/S FBdI-Ash if the data are normalized. The normalized data are presented as the percent of the contaminant that has been immobilized in the TCLP test as a result of S/S. The data were normalized to the TCLP extract concentration/weight of dry raw FBdI-Ash extracted (the dilution of the raw waste by the binder in the S/S FBdI-Ash has been corrected). The percentage value was derived using the following set of equations.

$$Cd_r = \frac{C_r}{W_r \times M_r} \tag{1}$$

where

Cd_r = TCLP contaminant mass/dry weight untreated waste, mg/g

C_r = untreated FBdI-Ash TCLP mass for the contaminant of interest, mg. (Calculated as: TCLP contaminant concentration, mg/ℓ × TCLP extraction solution volume, ℓ)

W_r = net weight FBdI-Ash extracted, g

M_r = solids content of the untreated FBdI-Ash used in the extraction expressed as a decimal

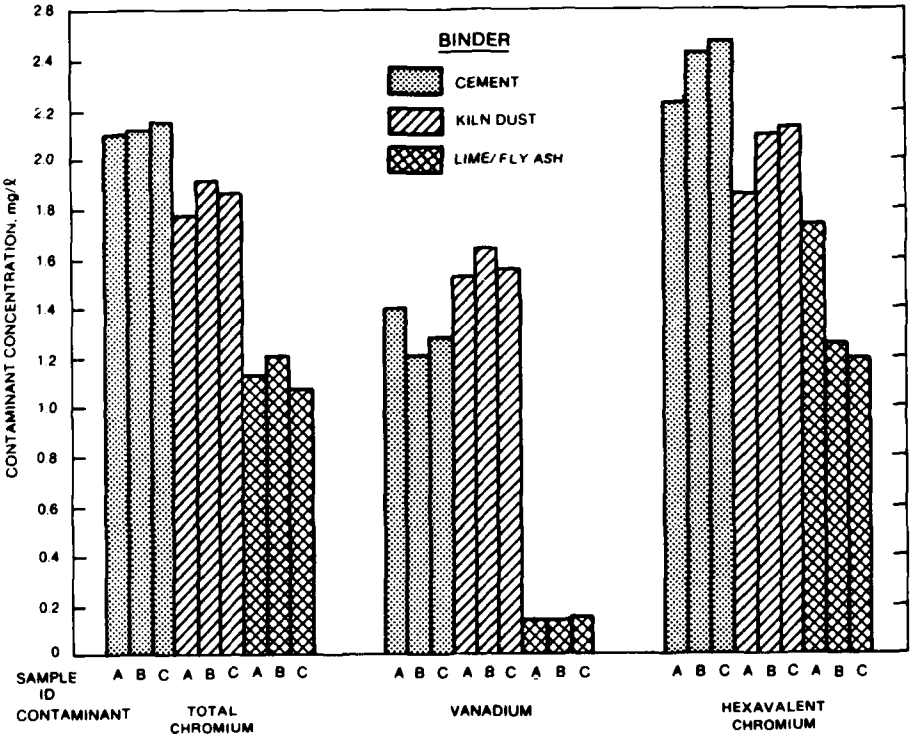

Figure 6. TCLP results for vanadium, total chromium, and hexavalent chromium

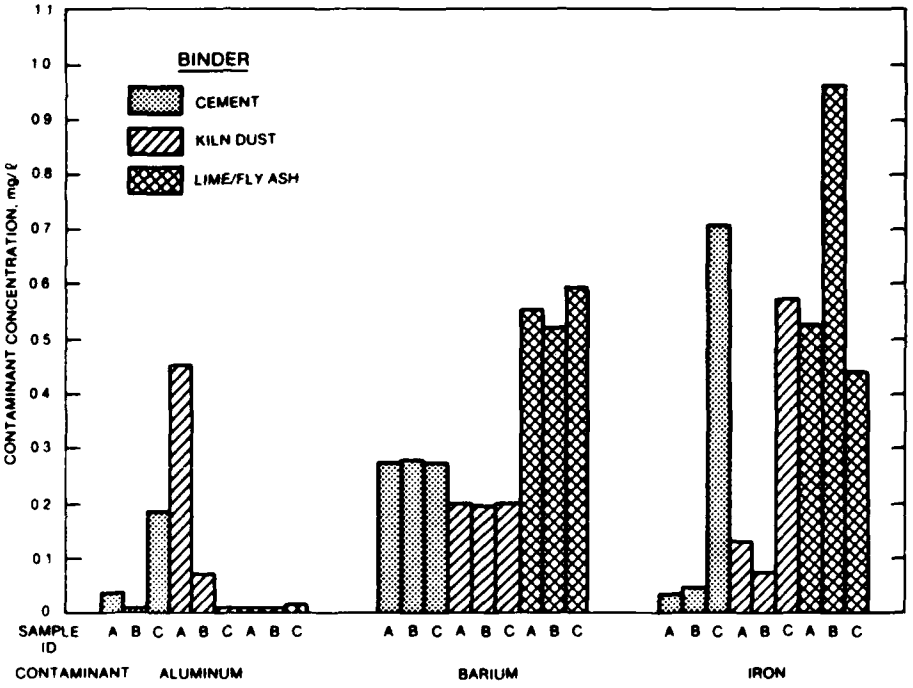

Figure 7. TCLP results for aluminum, barium, and iron

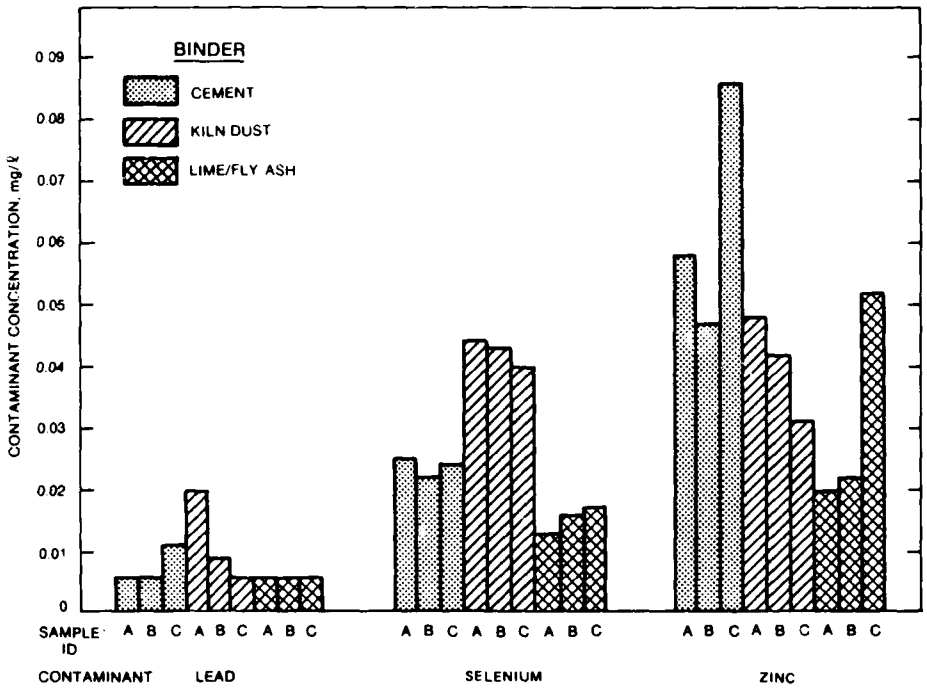

Figure 8. TCLP results for lead, selenium, and zinc

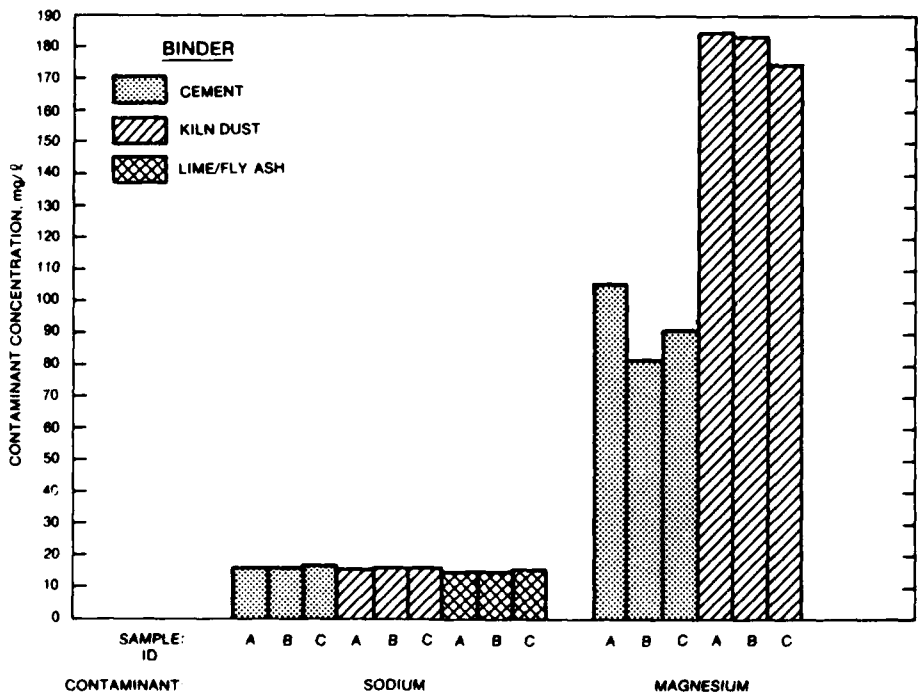

Figure 9. TCLP results for magnesium and sodium

$$Cd_t = \frac{C_t}{W_t \times M_t \times B_t} \tag{2}$$

where

Cd_t = TCLP contaminant concentration/dry weight waste after S/S, mg/g

C_t = S/S FBdI-Ash TCLP mass for the contaminant of interest, mg (Calculated as: TCLP contaminant concentration, mg/ℓ × TCLP extraction solution volume, ℓ)

W_t = weight of wet S/S FBdI-Ash, g

M_t = solids content of the S/S FBdI-Ash used in the extraction, expressed as a decimal

B_t = weight fraction of FBdI-Ash in stabilized/solidified waste calculated as follows:

$$B_t = \frac{\text{weight of FBdI-Ash}}{\text{weight of FBdI-Ash + weight of binder}} \tag{3}$$

$$PT = \frac{Cd_r - Cd_t}{Cd_r} \times 100 \tag{4}$$

where PT = percent of contaminant not leached due to S/S. Normalized data are present in tabular form in Table 14 and graphically in Figures 10 and 11. Thus, the data presented in Figures 10 and 11 compensate for the dilution effects of adding water and binder to the waste material.

52. It is recognized that the binder may add to the total mass of contaminants which are available for leaching. No attempt was made to correct the PT data presented in Table 14 and Figures 10 and 11 for the portion of the contaminant contributed by the binder. Thus, negative values may indicate either: (a) the binder is mobilizing the contaminant contained in the waste; or (b) the binder is actually adding to the mass of leachable contaminant.

53. Each binder was digested, and the resulting liquid was analyzed for the BDAT metals. These data are presented in Table 3. The binders were also subjected to the TCLP test, and the extract was analyzed for the BDAT metals. These data are presented in Appendix D. Details of the raw binder and binder TCLP analyses are presented in Bricka, Holmes, and Pugh (in preparation). The contaminants measured in the raw binder analyses and the TCLP binder analysis cannot be used directly to perform a mass balance for the contaminants which may leach from the S/S waste because these contaminants may not be leachable

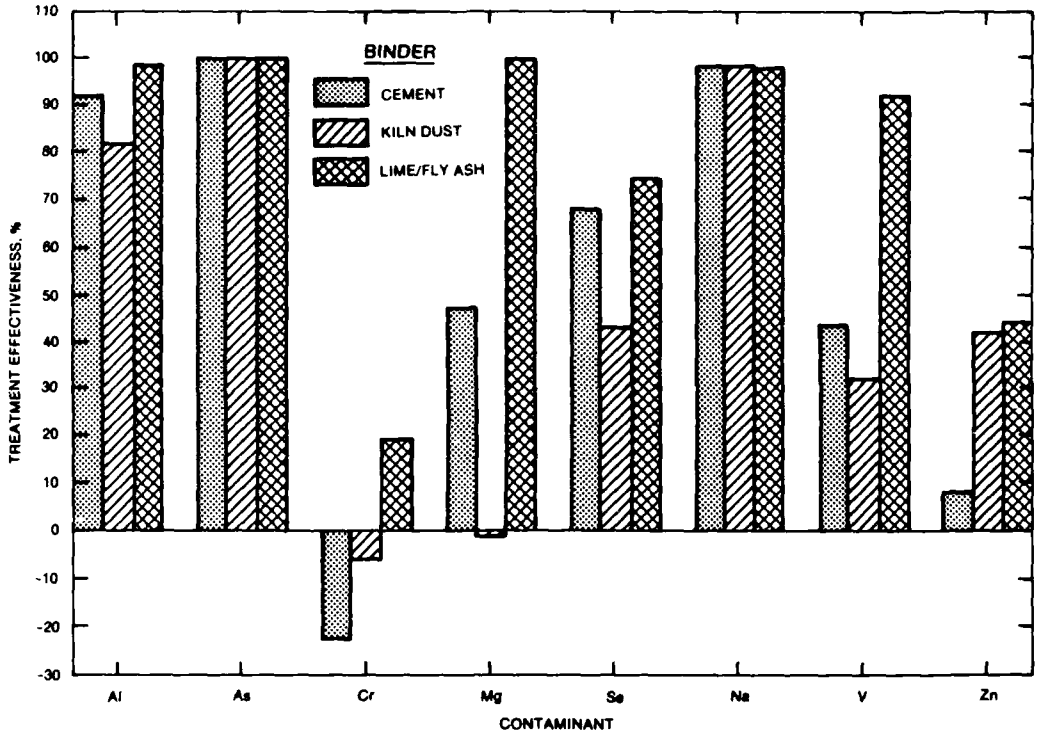

Figure 10. Normalized TCLP data presented as the percent of contaminant immobilized in a single step TCLP extraction for Al, As, Cr, Mg, Se, Na, V, and Zn

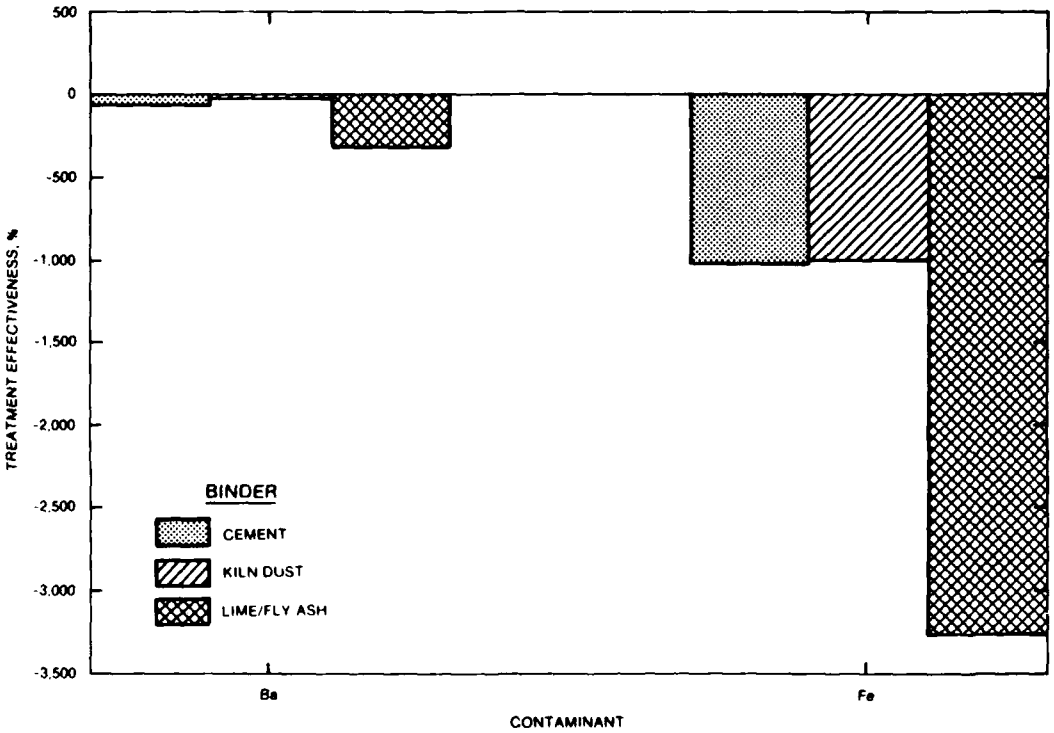

Figure 11. Normalized TCLP data presented as the percent of contaminant immobilized in a single step TCLP extraction for Ba and Fe

when mixed with the waste. Although these data cannot be used for a mass balance determination, they do provide information on whether these contaminants could be added to the system through the addition of the binder.

PART IV: CONCLUSIONS

54. A laboratory study was conducted to investigate the effects of three S/S processes on a FBdI-Ash. Both UCS and TCLP tests were performed on the stabilized/solidified specimens, and based on the results of these tests, the following conclusions can be made:

a. Small quantities of binding agents produce materials with UCS well above the 50-psi criterion.

b. Water must be added to the FBdI-Ash in order for the binders to develop strength.

c. The binders can be easily mixed with the FBdI-Ash waste.

d. The stabilized/solidified waste sets within 24 hr, and no free liquid was observed after this 24-hr period.

e. The S/S processing of the waste was effective in reducing the mobility of many of the contaminants in the FBdI-Ash although some contaminants were apparently mobilized.

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Table 1

Inventory of FBdI-Ash* Samples

Number of Sample Container	Radian's Field Number	Radian's Code
1	AM-301	AM4G(ASH)-1
2	AM-302	AM4G(ASH)-2
3	AM-303	AM4G(ASH)-3
4	AM-304	AM4G(ASH)-4
5	AM-305	AM4G(ASH)-5
6	AM-306	AM4G(ASH)-6
7	AM-307	AM4G(ASH)-7
8	AM-308	AM4G(ASH)-8
9	AM-309	AM4G(ASH)-9
10	AM-310	AM4G(ASH)-10

* FBdI Ash = fluidized bed incinerator ash.

Table 2

Compositional Analyses of the Binder Materials

Compositional Analysis	Cement Type I %	Lime %	Fly Ash Class F %	Kiln Dust %
SiO_2	20.47	0.40	49.67	6.94
Al_2O_3	5.40	0.57	29.15	4.23
Fe_2O_3	3.58	0.16	7.11	1.47
CaO	64.77	72.27	1.26	62.93
MgO	0.87	0.65	1.43	0.44
SO_3	2.73	0.02	0.23	7.01
Insoluble residue	0.17	0.24	70.70*	3.09
Moisture loss	0.43	0.41	0.12**	0.05
Loss on ignition	0.96	24.04	4.07	14.08
TiO_e	0.28	0.01	0.20	0.11
Mn_2O_3	0.06	0.00	0.00	0.00
P_2O_5	0.28	0.02	1.00	0.05
Total alkali				
Na_2O	0.12	0.01	0.23	0.25
K_2O	0.28	0.00	2.33	0.40
Na	0.05	0.004	0.10	0.10
K	0.11	0.00	0.97	0.17
Total as Na_2O	0.30	0.01	1.76	0.51
Acid soluble alkali				
Na_2O	0.12	0.01	0.06	0.25
K_2O	0.28	0.00	0.50	0.40
Na	0.05	0.004	0.03	0.10
K	0.11	0.00	0.21	0.17
Water soluble alkali				
Na_2O	0.018	0.0033	0.050	0.021
K_2O	0.139	0.0220	0.105	0.050
Na	0.0075	0.0013	0.0210	0.0088
K	0.0577	0.0091	0.0440	0.0208

* Insoluble residue includes SiO_2.
** Free water.

Table 3

Chemical Analyses of the Binder Materials

Chemical Analysis	Cement Type I mg/kg	Kiln Dust mg/kg	Lime mg/kg	Fly Ash Class F mg/kg
Si	95,700	1,900	232,200	32,400
S (total)	10,800	700	1,700	31,200
Ti	1,400	50	1,000	600
P	900	60	3,200	200
Sb	<1.77	<1.63	<1.77	13.3
As	13.1	14.7	6.74	172
Be	2.13	4.24	<1.77	28.9
Cd	0.284	2.28	0.639	1.01
Cr	61.3	30.0	14.6	139
Cu	14.9	12.7	<0.355	196
Pb	2.13	15.6	<0.355	57.7
Hg	<0.100	<0.100	<0.100	<0.100
Ni	25.9	33.6	6.39	190
Se	<17.7	<16.3	<17.7	<19.5
Ag	<3.54	<3.26	<3.55	<3.90
Tl	<10.6	<9.78	<10.6	13.6
Zn	41.8	107	17.7	211
Al	23,100	13,500	238	150,000
Ba	178	119	<3.55	1,350
Ca	454,000	440,000	500,000	12,000
Cd	10.6	<9.78	10.6	77.2
Fe	25,400	14,800	1,070	50,700
Mg	5,460	3,040	2,700	6,040
Mn	503	64.2	48.6	156
Na	1,270	2,110	110	2,740
Sn	195	73.0	74.5	118
V	55.6	34.6	11.7	351

Table 4

Matrix of Specimens Prepared for

Initial Waste/Binder Screening

Ratio		Number of Specimens at Indicated Water/FBdI-Ash Ratio		
		0.2	0.5	0.7
Binder:Cement				
Cement/FBdI-Ash				
0.1		1	1	1
0.7		1	1	1
Total = 6 specimens				
Binder:Kiln Dust				
Kiln dust/FBdI-Ash				
0.1		1	1	1
0.7		1	1	1
Total = 6 specimens				
Binder:Lime/Fly Ash Mixture				
Lime/Fly Ash	Fly Ash FBdI Ash			
0.1	0.1	1	1	1
0.1	0.7	1	1	1
0.7	0.1	1	1	1
0.7	0.7	1	1	1

Table 5

Summary of Stabilization Program for the FBdI-Ash

Binder to Ash Description		Batch Designation		
Code	Ratio	Run 1	Run 2	Run 3
		Binder:Portland Cement (C)		
Cement/Ash				
A	0.2	C.1.A	C.2.A	C.3.A
B	0.4	C.1.B	C.2.B	C.3.B
C	0.6	C.1.C	C.2.C	C.3.C
D	0.8	C.1.D	C.2.D	C.3.D
		Binder:Kiln Dust (KD)		
Kiln Dust/Ash				
E	0.6	KD.1.E	KD.2.E	KD.3.E
F	0.6	KD.1.F	KD.2.F	KD.3.F
G	0.6	KD.1.G	KD.2.G	KD.3.G
H	0.8	KD.1.H	KD.2.H	KD.3.H

Binder:Lime/Fly Ash (L/F) Mixture

	Lime/Ash Ratio	Fly Ash/Ash Ratio			
I	0.2	0.2	L/F.1.I	L/F.3.I	L/F.3.1
J	0.2	0.4	L/F.1.J	L/F.2.J	L/F.3.J
K	0.2	0.6	L/F.1.K	L/F.2.K	L/F.3.K
L	0.4	0.2	L/F.1.L	L/F.2.L	L/F.3.L
M	0.4	0.4	L/F.1.M	L/F.2.M	L.F.3.M
N	0.4	0.6	L/F.1.N	L/F.2.N	L/F.3.N
O	0.6	0.2	L/F.1.O	L/F.2.O	L/F.3.O
P	0.6	0.4	L/F.1.P	L/F.2.P	L/F.3.P
Q	0.6	0.6	L/F.1.Q	L/F.2.Q	L/F.3.Q

Table 6

Chemical Analysis Method*

Contaminant of Interest	USEPA Digestion Method	USEPA Analytical Method
Aluminum	3005	6010
Antimony	3005	6010
Arsenic	3020	7060
Barium	3005	6010
Beryllium	3005	6010
Cadmium	3005	6010
Chromium (hexavalent)	7196	--
Chromium (total)	3005	6010
Cobalt	3005	6010
Copper	3005	6010
Iron	3005	6010
Lead	3020	7421
Magnesium	3005	6010
Manganese	3005	6010
Nickel	3005	6010
Selenium	3020	7740
Silver**	3005	6010
Silver†	3020	7740
Sodium	3005	6010
Thallium	3020	7841
Tin	3005	6010
Vanadium	3005	6010
Zinc	3005	6010

* USEPA (1986f).
** Silver analyzed by USEPA method 3005.
† Silver analyzed by USEPA method 3020.

Table 7

Initial Screening Test Results: Cement Binder

Water Ratio	Cement Ratio	48 hr Cone Index Value, psi
0.2	0.1	210
0.5	0.1	>750
0.7	0.1	*
0.2	0.7	233
0.5	0.7	>750
0.7	0.7	>750

* Value not available.

Table 8

Initial Screening Test Results: Kiln Dust Binder

Water Ratio	Cement Ratio	48 hr Cone Index Value, psi
0.2	0.1	10
0.5	0.1	12
0.7	0.1	5
0.2	0.7	15
0.5	0.7	>750
0.7	0.7	285

Table 9

Initial Screening Test Results: Lime/Fly Ash Binder

Water Ratio	Lime Ratio	Fly Ash Ratio	48 hr Cone Index Value, psi
0.2	0.1	0.1	8
0.5	0.1	0.1	53
0.7	0.1	0.1	7
0.2	0.1	0.7	8
0.5	0.1	0.7	>750
0.7	0.1	0.7	300
0.2	0.7	0.1	*
0.5	0.7	0.1	>750
0.7	0.7	0.1	275
0.2	0.7	0.7	8
0.5	0.7	0.7	240
0.7	0.7	0.7	>750

* Value not available.

Table 10

Lime/Fly Ash Ratios Selected for Additional Testing and Evaluation

Lime Ratio	Fly Ash Ratio
0.2	0.2
0.2	0.4
0.2	0.6
0.4	0.2
0.4	0.4
0.4	0.6
0.6	0.2
0.6	0.4

Table 11

Binder Ratios Selected for TCLP* Extraction

Binder	BWR** Selected	Water Ratio
Cement	0.2	0.5
Kiln dust	0.2	0.5
Lime/fly ash	0.2/0.2	0.5

* TCLP means Toxicity Characteristic Leaching Procedure.

** BWR means binder-to-water ratio.

Table 12

Raw Waste Analyses and TCLP Analysis for the Untreated FBdI-Ash Waste

BDAT* Constituent	Average Raw Waste Bulk Analyses** mg/kg	Average TCLP Analysis on Raw Waste mg/ℓ
Antimony	15.0	0.07
Arsenic	15.6	0.018
Barium	161	0.208
Beryllium	0.6	<0.001
Cadmium	2.4	ND †
Chromium (hexavalent)	27	ND †
Chromium (total)	1,520	2.2
Copper	230	0.02
Lead	1,120	ND†
Mercury	ND†	0.00026
Nickel	68	<0.02
Selenium	ND†	0.094
Silver	1.7	ND †
Vanadium	770	2.93
Zinc	1,083	0.088
Aluminum††	10,880	1.25
Calcium ††	58,300	6,070
Cobalt ††	912	0.015
Iron ††	21,300	<0.03
Magnesium††	16,300	225
Manganese††	450	0.096
Potassium ††	740	9.1
Sodium††	1,030	1,250
Tin ††	370	0.7

* BDAT = best demonstrated available technology.
** Raw waste digested according to USEPA method 6010, SW-846 (USEPA 1986f).
† Not analyzed.
†† These are not listed as BDAT constituents. They are ground-water monitoring constituents as listed in Appendix IV of USEPA 1986b.

Table 13

TCLP Average Leachate Concentrations for the Solidified FBdI-Ash Waste

Contaminant	Concentration in mg/ℓ at Binder System/BWR		
	Cement/0.2	Kiln Dust/0.2	Lime/Fly Ash 0.2/0.2
Aluminum	0.078*	0.178*	0.011*
Barium	0.278	0.202	0.560
Chromium (total)	2.13	1.86	1.14
Chromium (hexavalent)	2.37	2.03	1.40
Iron	0.265	0.262	0.647
Lead	0.006*	0.011*	0.003*
Magnesium	93.1	181.3	0.239
Selenium	0.024	0.042	0.015
Sodium	16.3	15.8	15.1
Vanadium	1.30	1.57	0.151
Zinc	0.063	0.040	0.031

* Contaminants below the detection limited were averaged by using a value of half the detection limit.

Table 14

Normalized TCLP Data Presented as the Percent of Contaminant Immobilized Due to Solidification/Stabilization*

Constituent	Binder		
	Cement	Kiln Dust	Lime/Fly Ash
Aluminum (Al)	92.08	82.11	98.63
Antimony (Sb)	DL**	DL	DL
Arsenic (As)	100.00	100.00	100.00
Barium (Ba)	-69.48	-22.35	-319.37
Beryllium (Be)	DL	DL	DL
Cadmium (Cd)	NA†	NA	NA
Calcium (Ca)	NA	NA	NA
Chromium (total) (Cr^{+3})	-22.62	-6.15	19.33
Cobalt (Co)	DL	DL	DL
Copper (Cu)	DL	DL	DL
Iron (Fe)	-1,020.18	-999.84	-3,259.11
Lead (Pb)	NA	NA	NA
Magnesium (Mg)	47.61	-1.37	99.83
Manganese (Mn)	DL	DL	DL
Mercury (Hg)	NA	NA	NA
Nickel (Ni)	DL	DL	DL
Potassium (K)	NA	NA	NA
Selenium (Se)	68.11	43.34	74.61
Silver (Ag)	NA	NA	NA
Sodium (Na)	98.35	98.41	98.12
Thallium (Tl)	NA	NA	NA
Tin (Sn)	DL	DL	DL
Vanadium (V)	43.81	32.32	91.98
Zinc (Zn)	8.16	42.22	44.44
Silver 302 (Ag)	NA	NA	NA
Chromium (Cr^{+6}) (hexavalent)	NA	NA	NA

* Contaminant immobilization is based on a one-step TCLP extraction.
** DL = Compound was at the detection limit.
† NA = Not analyzed.

APPENDIX A: PROJECT ORGANIZATION

1. A project organization chart for this program is shown in Figure A1. Questions related to this program should be directed to Jerry Vobach of the US Environmental Protection Agency:

Mr. Jerry Vobach
USEPA Office of Solid Waste
Waste Treatment Branch
401 M Street SW
Washington, DC 20460
(202) 475-7702

2. The Radian representative who was present while the stabilization procedures were conducted is:

Heidi Welner
Staff Chemical Engineer
Radian Corporation
7655 Old Springhouse Road
McLean, VA 22102
(703) 734-2600

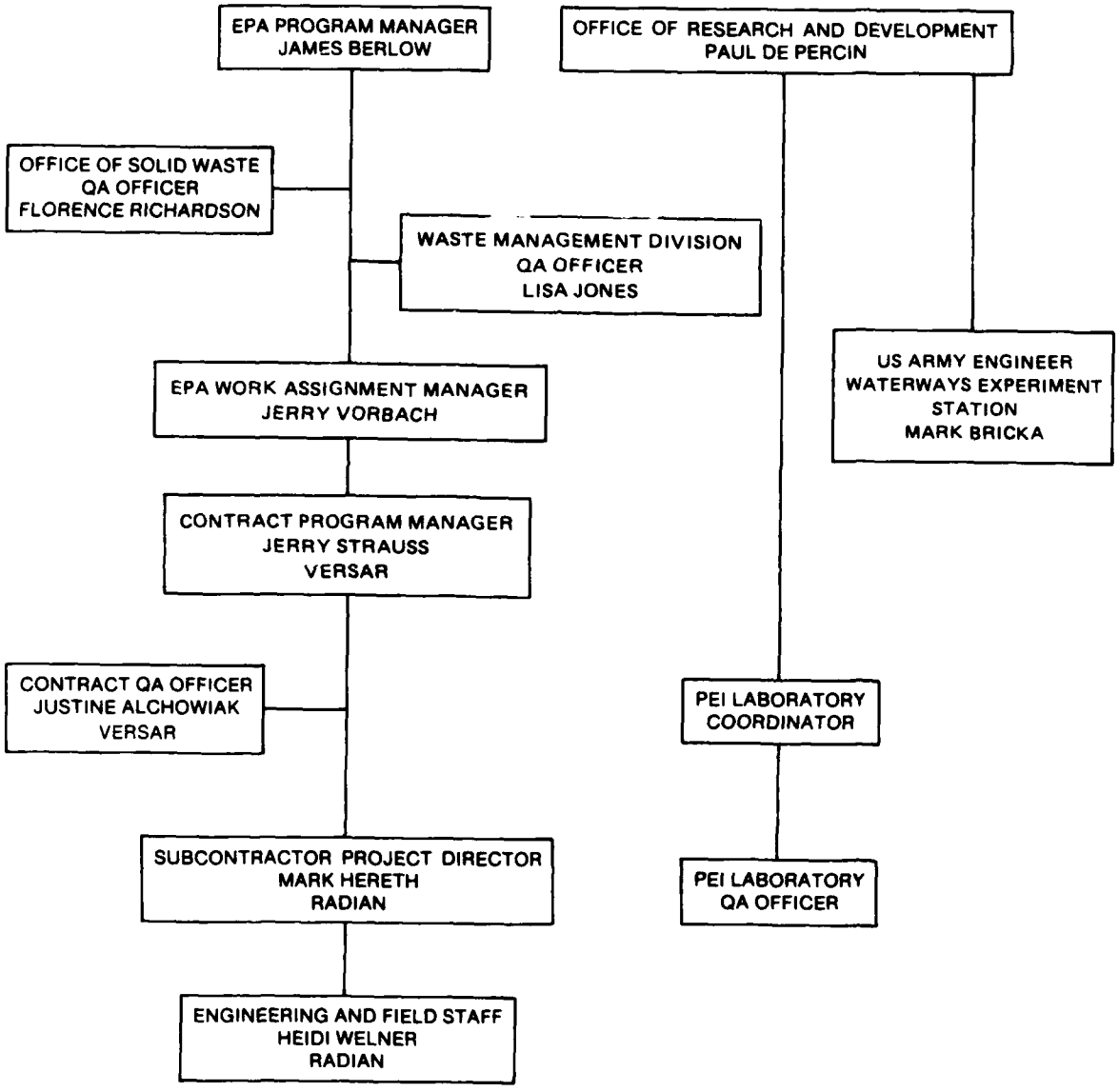

Figure A1. Project organization chart

APPENDIX B: RAW UNCONFINED COMPRESSIVE STRENGTH DATA

This appendix presents the results of the unconfined compressive strength (UCS) testing. The UCS for each cube prepared during this evaluation is provided. Table B1 presents the UCS results for the FBdI-Ash S/S with cement; Table B2 presents the UCS results for the fluidized bed incinerator ash (FBdI-Ash) stabilization/solidification (S/S) with kiln dust; and Table B3 presents the UCS results for the FBdI-Ash S/S with lime/Fly Ash.

Table B1

Raw UCS Results for the FBdI-Ash Waste Cement Binder

Cement Ratio	Subsample ID	Cure Time days	UCS psi
0.2	A	7.1	456
	B	7.1	362
	C	7.1	354
0.2	A	14.1	491
	B	14.1	605
	C	14.1	586
0.2	A	21.0	684
	B	21.0	1,024
	C	21.0	840
0.2	A	28.3	944
	B	28.3	922
	C	28.3	1,270
0.4	A	7.1	947
	B	7.1	1,032
	C	7.1	781
0.4	A	14.1	1,219
	B	14.1	1,420
	C	14.1	823
0.4	A	21.0	1,462
	B	21.0	1,312
	C	21.0	1,439
0.4	A	28.0	2,228
	B	28.0	1,976
	C	28.0	1,264
0.6	A	7.3	1,944
	B	7.3	1,727
	C	7.3	1,918
0.6	A	14.3	2,474
	B	14.3	2,154
	C	14.3	2,296
0.6	A	21.3	2,599
	B	21.3	2,537
	C	21.3	2,863
0.6	A	28.3	2,964
	B	28.3	2,745
	C	28.3	2,667
0.8	A	7.3	2,795
	B	7.3	3,266
	C	7.3	2,992
0.8	A	14.3	3,796
	B	14.3	4,067
	C	14.3	3,931
0.8	A	21.3	3,545
	B	21.3	3,993
	C	21.3	3,612
0.8	A	28.3	3,756
	B	28.3	4,777
	C	28.3	4,647

Table B2

Raw UCS Results for the FBdl-Ash Waste Kiln Dust Binder

Kiln Dust Ratio	Subsample ID	Cure Time days	UCS psi
0.2	A	7.1	24
	B	7.1	16
	C	7.1	20
0.2	A	14.1	40
	B	14.1	67
	C	14.1	35
0.2	A	21.1	187
	B	21.1	135
	C	21.1	134
0.2	A	28.1	223
	B	28.1	268
	C	28.1	241
0.4	A	7.1	38
	B	7.1	40
	C	7.1	46
0.4	A	14.1	88
	B	14.1	112
	C	14.1	211
0.4	A	21.1	236
	B	21.1	236
	C	21.1	233
0.4	A	28.1	408
	B	28.1	478
	C	28.1	399
0.6	A	7.1	115
	B	7.1	119
	C	7.1	121
0.6	A	14.1	371
	B	14.1	279
	C	14.1	345
0.6	A	21.1	627
	B	21.1	655
	C	21.1	653
0.6	A	28.1	771
	B	28.1	885
	C	28.1	868
0.8	A	7.1	244
	B	7.1	198
	C	7.1	239
0.8	A	14.1	596
	B	14.1	550
	C	14.1	606
0.8	A	21.1	1,023
	B	21.1	932
	C	21.1	974
0.8	A	26.1	1,279
	B	26.1	1,268
	C	26.1	1,400

Table B3

Raw UCS Results for the FBdI-Ash Waste Lime/Fly Ash Binder

Lime Ratio	Fly Ash Ratio	Subsample ID	Cure Time days	UCS psi
0.2	0.2	A	7.3	52.9
		B	7.3	46.8
		C	7.3	74.2
0.2	0.2	A	14.2	165.7
		B	14.2	151.7
		C	14.2	167.0
0.2	0.2	A	21.3	302.9
		B	21.3	382.9
		C	21.3	350.6
0.2	0.2	A	28.2	565.8
		B	28.2	512.6
		C	28.2	578.8
0.4	0.2	A	7.1	107.3
		B	7.1	141.9
		C	7.1	169.5
0.4	0.2	A	14.0	328.5
		B	14.0	252.1
		C	14.0	341.8
0.4	0.2	A	21.0	549.0
		B	21.0	668.4
		C	21.0	743.4
0.4	0.2	A	28.1	875.0
		B	28.1	1,114.4
		C	28.1	1,106.4
0.6	0.2	A	7.3	18.2
		B	7.3	77.8
		C	7.3	58.8
0.6	0.2	A	14.2	113.7
		B	14.2	135.7
		C	14.2	131.0
0.6	0.2	A	21.3	203.3
		B	21.3	192.0
		C	21.3	186.3
0.6	0.2	A	28.2	573.6
		B	28.2	439.0
		C	28.2	547.8
0.2	0.4	A	7.1	189.9
		B	7.1	177.7
		C	7.1	210.4
0.2	0.4	A	14.0	517.5
		B	14.0	497.0
		C	14.0	564.6
0.2	0.4	A	21.0	1,095.5
		B	21.0	1,154.0
		C	21.0	1,018.8
0.2	0.4	A	28.1	1,456.7
		B	28.1	1,698.9
		C	28.1	1,582.0

(Continued)

Table B3 (Concluded)

Lime Ratio	Fly Ash Ratio	Subsample ID	Cure Time Days	UCS psi
0.4	0.4	A	7.10	193.4
		B	7.10	228.5
		C	7.10	208.1
0.4	0.4	A	14.0	663.7
		B	14.0	711.6
		C	14.0	741.5
0.4	0.4	A	21.0	1,026.7
		B	21.0	767.8
		C	21.0	832.4
0.4	0.4	A	28.1	1,736.9
		B	28.1	1,870.7
		C	28.1	1,785.5
0.6	0.4	A	7.0	474.3
		B	7.2	431.4
		C	7.0	330.3
0.6	0.4	A	14.1	917.4
		B	14.3	870.9
		C	14.1	1,033.9
0.6	0.4	A	21.1	1,507.6
		B	21.1	1,417.3
		C	21.1	1,464.0
0.6	0.4	A	28.1	1,890.9
		B	28.1	1,936.0
		C	28.1	1,536.5
0.2	0.6	A	7.3	165.8
		B	7.3	120.9
		C	7.3	134.2
0.2	0.6	A	14.2	164.2
		B	14.2	279.3
		C	14.2	349.9
0.2	0.6	A	21.3	1,287.5
		B	21.3	730.7
		C	21.3	929.3
0.2	0.6	A	28.2	786.6
		B	28.2	1,219.3
		C	28.2	1,427.7
0.4	0.6	A	7.2	506.9
		B	7.2	230.4
		C	7.2	271.0
0.4	0.6	A	14.2	1,482.9
		B	14.2	452.6
		C	14.2	976.6
0.4	0.6	A	21.2	1,279.5
		B	21.2	2,276.0
		C	21.2	1,610.7
0.4	0.6	A	28.2	2,386.0
		B	28.2	3,135.2
		C	28.2	3,055.9

APPENDIX C: RAW TOXICITY CHARACTERISTIC LEACHING PROCEDURE DATA

This appendix presents the results of the toxicity characteristic leaching procedure (TCLP) analyses. The TCLP raw data for each cube leached are presented in Table C1. The quality assurance/quality control data are presented in Tables C2 through C6. The results of all the replicate analyses, the method blank analyses, the percent recovery analyses, and the standard reference solution analyses are presented in Tables C2, C3, C4, and C5, respectively.

Table C1

TCLP Leachate Concentrations for the Solidified FBdI-Ash* Waste

Binder	Sample	Contaminant, mg/ℓ						
		Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Total Chromium
Cement	A	0.038	<0.163	<0.004	0.277	<0.001	<0.003	2.11
Cement	B	<0.013	<0.163	<0.004	0.280	<0.001	<0.003	2.12
Cement	C	0.190	<0.163	<0.004	0.278	<0.001	<0.003	2.16
Kiln dust	A	0.454	<0.163	0.005	0.204	<0.001	<0.003	1.78
Kiln dust	B	0.073	0.178	0.005	0.200	<0.001	<0.003	1.92
Kiln dust	C	<0.013	<0.163	0.005	0.204	<0.001	<0.003	1.87
Lime/fly ash	A	<0.013	<0.163	<0.004	0.558	<0.001	<0.003	1.13
Lime/fly ash	B	<0.013	<0.163	<0.004	0.524	<0.001	<0.003	1.21
Lime/fly ash	C	0.020	<0.163	0.006	0.599	0.001	0.003	1.08

		Contaminant, mg/ℓ							
		Hexavalent Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese	Nickel
Cement	A	2.230	<0.019	<0.003	0.030	<0.006	106.000	<0.002	<0.018
Cement	B	2.420	<0.019	<0.003	0.048	<0.006	81.900	<0.002	<0.018
Cement	C	2.470	<0.019	0.015	0.710	0.011	91.300	<0.002	<0.018
Kiln dust	A	1.860	0.200	<0.003	0.134	0.020	185.000	<0.002	<0.018
Kiln dust	B	2.100	<0.019	<0.003	0.077	0.009	184.000	<0.002	<0.018
Kiln dust	C	2.130	<0.019	<0.003	0.576	<0.006	175.000	<0.002	<0.018
Lime/fly ash	A	1.740	<0.019	<0.003	0.529	<0.006	0.265	<0.002	<0.018
Lime/fly ash	B	1.260	<0.019	<0.003	0.967	<0.006	0.192	<0.002	<0.018
Lime/fly ash	C	1.200	<0.019	0.006	0.446	<0.006	0.260	<0.002	<0.018

(Continued)

* FBdI Ash = Fluidized bed incinerator ash.

Table C1 (Concluded)

		Contaminant, mg/ℓ							
		Selenium	Silver*	Silver**	Sodium	Thallium	Tin	Vanadium	Zinc
Cement	A	0.025	<0.006	<0.006	15.90	<0.001	<0.336	1.400	0.058
Cement	B	0.022	<0.006	<0.006	15.90	0.009	<0.336	1.210	0.047
Cement	C	0.024	<0.006	<0.006	17.00	<0.001	<0.336	1.290	0.086
Kiln dust	A	0.044	<0.006	<0.006	15.40	<0.001	<0.336	1.530	0.048
Kiln dust	B	0.043	<0.006	<0.006	16.00	<0.001	<0.336	1.640	0.042
Kiln dust	C	0.040	<0.006	<0.006	16.00	0.009	<0.336	1.560	0.031
Lime/fly ash	A	0.013	<0.006	<0.006	15.00	<0.001	<0.336	0.148	0.020
Lime/fly ash	B	0.016	<0.006	<0.006	14.90	<0.001	<0.336	0.149	0.022
Lime/fly ash	C	0.017	<0.006	<0.006	15.40	<0.001	<0.336	0.156	0.052

* Silver analyzed by USEPA method 3005.
** Silver analyzed by USEPA method 3020.

Table C2

Quality Control/Quality Assurance Data for the Solidified FBdl Ash

Waste Replicate Analyses

		Contaminant, mg/ℓ						
Binder	Sample	Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Total Chromium
Cement	B	*	*	0.004	*	*	*	*
Kiln dust	Blank	0.177	<0.163	<0.004	0.031	<0.001	<0.003	<0.002
Kiln dust	B	<0.013	<0.163	0.006	0.204	<0.001	<0.003	1.91
Lime/fly ash	B	<0.013	<0.163	<0.004	0.533	<0.001	<0.003	1.2

		Contaminant, mg/ℓ							
		Hexavalent Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese	Nickel
Cement	B	2.42	*	*	*	0.012	*	*	*
Kiln dust	Blank	*	<0.019	<0.003	0.051	*	0.014	<0.002	<0.018
Kiln dust	B	2.09	<0.019	<0.003	0.05	0.009	185	<0.002	<0.018
Lime/fly ash	B	*	<0.019	<0.003	0.211	<0.006	0.188	<0.002	<0.018

		Contaminant, mg/ℓ							
		Selenium	Silver**	Silver†	Sodium	Thallium	Tin	Vanadium	Zinc
Cement	B	0.024	*	<0.006	*	*	*	*	*
Kiln dust	Blank	*	<0.006	<0.006	0.578	<0.001	<0.336	0.007	0.036
Kiln dust	B	0.038	<0.006	<0.006	15.9	<0.001	<0.336	1.64	0.038
		0.016	<0.006	<0.006	15.5	<0.001	<0.336	0.149	0.017

* No replicate analyzed.
** Silver analyzed by USEPA Method 3005.
† Silver analyzed by USEPA Method 3020.

Table C3

Quality Control/Quality Assurance Data for the Solidified FBdI-Ash Waste Method Blank Analysis

Binder	Sample	Contaminant, mg/ℓ						
		Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Total Chromium
Cement	Blank	<0.013	<0.163	<0.004	0.089	<0.001	<0.003	<0.007
Kiln dust	Blank	1.32	<0.163	<0.004	0.031	<0.001	<0.003	<0.007

		Contaminant, mg/ℓ							
		Cobalt	Copper	Iron	Lead	Magnesium	Manganese	Nickel	Selenium
Cement	Blank	<0.019	<0.003	0.34	<0.006	0.006	<0.002	<0.018	<0.003
Kiln dust	Blank	<0.019	0.018	0.351	<0.006	0.06	<0.002	<0.018	<0.003

		Contaminant, mg/ℓ						
		Silver*	Silver**	Sodium	Thallium	Tin	Vanadium	Zinc
Cement	Blank	0.025	<0.006	0.317	<0.001	<0.336	<0.007	<0.046
Kiln dust	Blank	<0.006	<0.006	3.64	<0.001	<0.336	<0.007	0.092

* Silver analyzed by USEPA method 3005.
** Silver analyzed by USEPA method 3020.

Table C4

Quality Control/Quality Assurance Data for the Solidified FBdI-Ash Waste Percent Recovery Analyses

Binder	Sample	Contaminants, mg/ℓ							
		Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Total Chromium	Hexavalent Chromium
Cement	B	*	*	136	*	*	*	*	*
Kiln dust	A	52.9	66	*	90	70.6	69.4	75.2	97.6
Kiln dust	C	127	81.5	132	91.1	84.5	83.4	87.4	97.6
Lime/fly ash	C	89.2	75.1	140	96.9	72.8	72.2	76.6	100

		Contaminants, mg/ℓ							
		Hexavalent Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese	Nickel
Cement	B	*	*	*	*	99.4	*	*	*
Kiln dust	A	97.6	88.4	72.1	91.3	*	106	90.7	67.5
Kiln dust	C	97.6	89.4	117	68.5	76.5	**	89.4	81.6
Lime/fly ash	C	100	86.4	74.3	28.3	72	90	88.7	69.8

		Contaminants, mg/ℓ							
		Selenium	Silver†	Silver††	Sodium	Thallium	Tin	Vanadium	Zinc
Cement	B	84.1	*	*	*	61.2	*	*	*
Kiln dust	A	*	70	*	15.9	*	120	43.8	70.7
Kiln dust	C	75.2	83.8	*	**	56.4	108	93.8	84
Lime/fly ash	C	84.5	72.6	*	**	58.3	93.4	93.6	68.2

* Sample not spiked with analyte.
** Spike value = 1 parts per million (insignificant).
† Silver analyzed by USEPA method 3005.
†† Silver analyzed by USEPA method 3020.

Table C5

Quality Control/Quality Assurance Data For the Solidified FBdI-Ash Waste Standard Reference Solution Analyses

Chemical Parameter	True Value, mg/ℓ	Value Obtained, mg/ℓ
Aluminum	1.0	1.08
Antimony	1.0	0.728
Arsenic	0.075	0.077
Barium	1.0	1.09
Beryllium	1.0	1.01
Cadmium	1.0	0.997
Chromium (hexavalent)	*	*
Chromium (total)	1.0	1.02
Cobalt	1.0	1.05
Copper	1.0	0.985
Iron	1.0	1.00
Lead	1.0	1.17
Magnesium	1.0	0.993
Manganese	1.0	1.02
Nickel	1.0	1.01
Selenium	0.05	0.05
Silver**	1.0	0.189
Silver†	1.0	0.951
Sodium	2.0	2.02
Thallium	1.0	0.933
Tin	1.0	0.057
Vanadium	1.0	1.01
Zinc	1.0	1.02

* Analysis not performed.
** Silver analyzed by USEPA method 3005.
† Silver analyzed by USEPA method 3020.

APPENDIX D: BINDER TOXICITY CHARACTERISTIC LEACHING PROCEDURE RESULTS

This appendix presents the results of the toxicity characteristic leaching procedure (TCLP) analyses performed on the binders utilized to stabilize/solidify the K048 and K051 wastes. The results for the triplicate analyses of the binders (cement, kiln dust, and lime/fly ash) are given in Table D1.

Table D1

Binder TCLP Leachate Concentrations

Binder	Sample	Contaminant, mg/ℓ						
		Antimony	Arsenic	Beryllium	Cadmium	Total Chromium	Copper	Lead
Cement	A	<0.005	<0.005	<0.005	0.0001	0.334	0.001	0.006
Cement	B	<0.005	0.006	<0.005	<0.0001	0.307	0.001	0.002
Cement	C	<0.005	0.005	0.005	0.0001	0.300	0.001	0.002
Cement average		<0.005	0.004	<0.005	0.00008	0.314	0.001	0.004
Kiln dust	A	<0.005	0.008	<0.005	0.001	0.060	0.001	0.032
Kiln dust	B	<0.005	0.005	0.006	<0.0001	0.057	0.001	0.038
Kiln dust	C	<0.005	0.007	0.005	0.0001	0.057	0.001	0.044
Kiln dust average		<0.005	0.0066	0.0038	0.00038	0.058	0.001	0.038
Lime/fly ash	A	<0.005	0.014	<0.005	0.0002	0.033	0.003	0.008
Lime/fly ash	B	<0.005	0.020	<0.005	<0.0001	0.024	0.008	0.006
Lime/fly ash	C	<0.005	0.008	<0.005	0.0001	0.022	0.006	0.006
Lime/fly ash average		<0.005	0.014	<0.005	0.0001	0.026	0.0056	0.0067

		Contaminant, mg/ℓ							
		Mercury	Nickel	Selenium	Silver	Thallium	Zinc	Aluminum	Tin
Cement	A	<0.0004	0.002	<0.050	0.035	0.031	<0.030	0.599	<0.200
Cement	B	<0.0004	0.002	<0.050	0.039	<0.030	<0.030	0.702	<0.200
Cement	C	<0.0004	<0.001	<0.050	0.037	<0.030	<0.030	0.596	<0.200
Cement average		<0.0004	0.0015	<0.050	0.037	0.0113	<0.030	0.632	<0.200
Kiln dust	A	<0.0008	0.002	<0.050	<0.010	<0.030	0.093	0.642	<0.200
Kiln dust	B	<0.0004	0.002	<0.050	<0.010	0.034	0.037	0.619	<0.200
Kiln dust	C	<0.0004	0.004	<0.050	0.013	<0.030	0.036	0.615	<0.200
Kiln dust average		0.00003	0.0026	<0.050	0.0077	0.012	0.055	0.625	<0.200

(Continued)

Table D1 (Concluded)

		Contaminant, mg/ℓ							
		Mercury	Nickel	Selenium	Silver	Thallium	Zinc	Aluminum	Tin
Lime/fly ash	A	<0.0004	0.002	<0.050	<0.010	<0.030	0.040	0.716	<0.200
Lime/fly ash	B	<0.0004	<0.001	<0.050	<0.010	<0.030	0.036	0.654	<0.200
Lime/fly ash	C	<0.0008	<0.001	<0.050	0.019	<0.030	0.100	0.515	0.200
Lime/fly ash average		0.00003	0.001	<0.050	0.0097	<0.030	0.029	0.628	<0.200

		Contaminant, mg/ℓ							
		Barium	Calcium	Cadmium	Iron	Magnesium	Manganese	Sodium	Vanadium
Cement	A	1.06	3,340	<0.030	0.134	<0.030	0.095	12.8	<0.005
Cement	B	1.09	3,310	<0.030	0.144	0.059	0.098	12.6	<0.005
Cement	C	0.906	3,370	<0.030	0.071	0.030	0.095	12.6	<0.005
Cement average		1.019	3,340	<0.030	0.166	0.030	0.096	12.67	<0.005
Kiln dust	A	0.549	3,160	<0.030	0.098	0.055	0.096	22.2	<0.030
Kiln dust	B	0.613	3,160	<0.030	0.087	0.047	0.099	22.8	<0.005
Kiln dust	C	0.698	3,260	<0.030	0.078	0.069	0.103	22.9	<0.005
Kiln dust average		0.620	3,193	<0.030	0.088	0.057	0.099	22.6	0.00067
Lime/fly ash	A	2.17	2,820	<0.030	0.054	<0.030	0.077	6.06	<0.030
Lime/fly ash	B	2.13	2,630	<0.030	0.089	<0.030	0.077	6.50	<0.030
Lime/fly ash	C	2.36	2,500	<0.030	0.064	<0.030	0.070	6.88	<0.030
Lime/fly ash average		2.22	2,650	<0.030	0.069	<0.030	0.077	6.48	<0.030