Solidification of Low-Volume Power Plant Sludges

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Research Project 1260-20

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ABSTRACT

A literature review was conducted to obtain information on the status of hazardous waste solidification technology and application of this technology to low-volume power plant waste sludges. Because of scarcity of sludge composition data, anticipated major components were identified primarily by chemical reactions that are known to occur during treatment of specific wastewaters. Chemical and physical properties of these sludges were critically analyzed for compatibility with several types of commercially available solidification processes. The study pointed out the need for additional information on the nature of these sludges, especially leaching characteristics and the presence of substances that will interfere with solidification processes. Laboratory studies were recommended for evaluation of solidification process which have the greatest potential for converting hazardous low-volume sludges to non-hazardous waste forms.

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EPRI PERSPECTIVE

PROJECT DESCRIPTION

Hazardous waste disposal regulations promulgated by the Environmental Protection Agency (EPA) under the Resource Conservation and Recovery Act (RCRA) are expected to have a major impact on a large segment of American industry including the electric power industry. In addition to the large volumes of coal combustion residues and flue gas desulfurization sludges, which are regulated as nonhazardous wastes, there are a number of smaller volume waste streams that could be classified as hazardous under the RCRA regulations. Because the handling and disposal of hazardous wastes entails considerably greater cost than conventional wastes, there is a potential for reducing disposal costs by treating hazardous wastes to produce nonhazardous wastes.

Small-volume wastes produced by steam-electric power plants include ion exchange regenerant wastes, sludges from water and wastewater treatment processes, metal cleaning wastes, cooling-tower sludges, and miscellaneous equipment cleaning wastes.

This project (RP1260-20) is the first phase of a developing project to investigate various processes to convert the small volume of potentially hazardous power plant wastes to nonhazardous forms. This phase has evaluated the state of the art of hazardous waste fixation.

PROJECT OBJECTIVE

The primary objective of the work was to provide EPRI and the industry at large with a comprehensive review and analysis of hazardous waste fixation technology as it may be applied to small-volume power plant wastes.

PROJECT RESULTS

During the study, information collected by a literature survey was analyzed to determine the potential application of fixation-solidification agents on the various low-volume power plant sludges. The major conclusions concerning the fixation-solidification of the utility sludges were:

- Little data are available on sludge composition, an important factor in selecting a suitable fixation-solidification process.
- Little data are available on fixation-solidification of these sludges. However, data are available on fixation-solidification of similar sludges.
- Eight types of fixation-solidification processes have potential application to the sludges. These processes include cement, lime (or pozzolanic), thermoplastic, organic polymer, surface encapsulation, sulfur, and glass.

- Cost estimates for fixation-solidification processes range from \$2 to \$500 per ton, depending on the waste and fixation process. Cement and pozzolanic processes are usually less expensive than other processes. The former use inexpensive raw materials and require little equipment. The trade-off between fixation-solidification and disposal in a hazardous waste landfill should be made on a site-specific basis.

Of the eight fixation-solidification processes recommended for further laboratory evaluation, only one--surface encapsulation--is expected to be suitable for all of the varieties of low volume power plant wastes. However, cost considerations might limit the application of the surface encapsulation technology. All of the fixation-solidification processes are potentially applicable to at least some of the low-volume sludges.

The payoff to utilities for treatment of the potentially hazardous low-volume wastes is threefold:

1. The treatment and disposal costs for treated hazardous wastes, transformed to nonhazardous wastes for conventional disposal is expected to be less than disposal costs for untreated hazardous wastes.
2. Fixation of hazardous wastes (particularly liquid wastes) could potentially provide a greater degree of environmental protection over very long time periods.
3. The potential liability for nonsudden releases of hazardous substances to the environment is reduced by solidifying the wastes.

This Phase I state-of-the-art assessment should be of interest to utility designers and decision makers who participate in the preliminary identification of potential fixation-solidification processes for the treatment of low-volume power plant wastes. The planned Phase II project results are expected to provide detailed information on the processes.

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Section 1

SUMMARY AND CONCLUSIONS

Low-volume wastewaters generated by steam-electric power plants are typically treated to comply with effluent discharge standards. The sludges produced by the wastewater treatment processes along with sludges produced by water treatment processes are potentially hazardous because of toxic substances which may be concentrated in the sludges.

Our major conclusions concerning solidification of these sludges are:

- Little data are available on sludge composition, an important factor in selecting a suitable solidification process.
- Little data are available on solidification of these sludges. However, data are available on solidification of similar sludges.
- Seven types of solidification processes have potential application to the sludges. These processes include cement, lime (or pozzolanic), thermoplastic, organic polymer, surface encapsulation, sulfur, and glass.
- Cost estimates for solidification processes range from \$2 to \$500/ton, depending on the waste and fixation process. Cement and pozzolanic processes are usually less expensive than other processes. The former use inexpensive raw materials and require little equipment. The costs of solidification or disposal in a hazardous waste landfill should be compared on a site-specific basis.

Low-volume power plant sludges include metal cleaning sludges, wastewater treatment sludges, and water treatment sludges or resins. Metal cleaning wastewaters (from fireside and waterside boiler tube cleaning and air preheater washes) are normally treated by lime or sodium hydroxide precipitation. The sludge consists of hydrous metal oxides with or without calcium sulfate and minor amounts of oil and grease. Wastewater treatment sludges are essentially alum or lime sludges. The amount of toxic trace elements in the sludges is dependent on the wastewater composition. Water treatment sludges are also primarily lime or alum sludges with sediments from the intake water. In a closed loop cooling system, cooling tower blowdown may be evaporated to leave a salt cake mixed with sediments from the intake water. Sludge consisting of intake water sediments may also accumulate in cooling tower basins.

All of the solidification processes are potentially applicable to at least some of the low-volume sludges as shown in Table 1. Each waste/process pair in Table 1 was evaluated for compatibility and given a "+" for a probable compatibility, a "0" for potential difficulties and a "-" for pairs with probable incompatibility. Various pairs were given "0" ratings because of anticipated

Table 1

APPLICABILITY OF SOLIDIFICATION PROCESSES ON LOW VOLUME UTILITY WASTE SLUDGES

WASTE	SOLIDIFICATION PROCESS							
	CEMENT - BASED	LIME - BASED (POZZOLANIC)	THERMOPLASTIC	NON - UREA FORMALDEHYDE ORGANIC POLYMERS	UREA FORMALDEHYDE ORGANIC POLYMERS	SURFACE ENCAPSULATION	GLASS	SULFUR - BASED
BOILER WATERSIDE TUBE CLEANING SLUDGE	+	+	+	+	-	+	+	+
BOILER FIRESIDE TUBE CLEANING SLUDGE	0	0	0	+	-	+	0	0
AIR PREHEATER CLEANING SLUDGE	0	0	0	+	-	+	0	0
WASTEWATER TREATMENT SLUDGE	+	+	+	+	-	+	+	+
WATER TREATMENT SLUDGE	+	+	+	+	-	+	+	+
COOLING TOWER BASIN SLUDGE	+	+	+	+	+	+	+	+
COOLING TOWER BLOWDOWN RESIDUE (EVAPORATION)	0	0	0	+	+	+	0	0
SPENT ION EXCHANGE RESIN	0	0	0	+	+	+	0	0

+ = PROBABLY APPLICABLE

0 = POTENTIAL DIFFICULTIES

- = PROBABLY NOT APPLICABLE

problems of incorporating sulfate salts or ion exchange resins in the final waste form. The salts and resins have a tendency to lose water during the solidification process and then rehydrate and swell after solidification and contact with water. This causes cracking problems when cement, lime, thermoplastic, or sulfur processes are used. Some glasses have trouble incorporating sulfate due to phase separation problems. Glass processes also act as incinerators if organic materials such as ion exchange resins are present in the waste. This creates an air pollution problem and does not solidify the waste stream. The "-" rating on some of the urea-formaldehyde processes in Table 1 is due to the high alkalinity of the waste streams, which is incompatible with the acid-catalyzed reactions in the process.

Cement and pozzolan systems have proven effective on industrial waste, such as metal plating wastes. Polymeric processes have effectively solidified a wide variety of wastes successfully. Thermoplastic and glass processes have extensive use on wastes from nuclear facilities. Sulfur processes have not been widely used, but should have the characteristics of cement or thermoplastic processes, depending on the sulfur process used.

Section 2

RECOMMENDATIONS

Low volume power plant sludges should be chemically characterized. Little data are presently available on the composition of these sludges, and the sludge composition is the major factor in determining whether or not a solidification process will be applicable for a particular sludge. Representative samples of each type of sludge should be collected and analyzed for major components and toxic trace compounds. The EPA extraction procedure should be performed on the untreated sludges to determine if the sludges are hazardous.

Solidification processes should be tested on representative samples of metal cleaning waste sludges because these sludges are likely to be the most hazardous. Sludges from both lime and sodium hydroxide precipitation of metal cleaning waste water should be tested because both precipitation methods are commonly used. Typical water treatment sludges, cooling system sludges and ion-exchange resin wastes should also be tested to determine the effectiveness of selected solidification processes. Glass processes should be tested only if any of the wastes contain extremely high levels of toxic contaminants.

The solidification products should be tested for compressive strength, expansion, permeability and leaching potential. ASTM tests exist for the compressive strength, expansion, and permeability of many materials. Leaching potential should be analyzed by the EPA test. The cost and complexity of the various processes should also be evaluated. The processes can then be compared on the basis of technical feasibility and cost.

Section 3

INTRODUCTION

Hazardous waste disposal regulations which are being promulgated by the U.S. Environmental Protection Agency (EPA) under the Resource Conservation and Recovery Act (RCRA) are expected to have a major impact on a large segment of American industry including the electric power industry. Restrictions on disposal of large volumes of ash and flue gas desulfurization sludge, for example, could substantially increase the costs of producing power from coal. In addition to the large volumes of waste ash and flue gas desulfurization sludge, there are a number of smaller volume waste streams that could be classified as hazardous under RCRA regulations. The determining factor in classifying a waste as "hazardous" is the leachability of toxic substances by water or a slightly acidic buffered acetate solution. If a leachate obtained from a standard test described in RCRA regulations contains concentrations of toxic substances (including certain heavy metals and organics) exceeding specified levels, the waste will be classified as hazardous. Because the handling and disposal of hazardous wastes usually entails considerably greater costs than conventional wastes, there are potential economic incentives for minimizing the quantities of hazardous waste produced.

Small volume wastes produced by steam-electric power generation include ion exchange regenerant wastes, sludge from water and wastewater treatment processes, metal cleaning wastes, cooling tower sludges, and miscellaneous equipment cleaning wastes. Wastewater treatment sludges are typically produced at all steam electric power plants. Low volume wastewaters such as spent ion exchange regenerant, floor drainage, air preheater washes, and laboratory wastewater are generally collected, blended, and treated at a common facility at the power plant. The treatment process produces a sludge which may leach toxic heavy metals and organics at concentrations exceeding RCRA limits. Coal-fired plants usually have a separate wastewater treatment system for coal pile runoff. The sludge from this system may also be hazardous.

Metal cleaning wastes pose a particularly difficult problem because they may contain metal chelating agents. These chelating agents tend to keep toxic heavy metals soluble and readily available for leaching.

Conversion of these small volume, potentially hazardous power utility wastes to nonhazardous forms may be accomplished by several different methods. The primary method is "fixation" which binds the toxic substances in an insoluble form, thus reducing the leaching potential. Various materials have been identified as fixation agents including portland cement, silicates, asphalt, sulfur and polymeric resins. Some of these materials, such as silicate, may chemically react with a toxic substance to produce an insoluble compound. Others, such as asphalt, may encapsulate a soluble toxic substance thereby preventing direct contact with leach water.

Fixation of hazardous wastes for conventional landfill disposal could potentially provide a greater degree of environmental protection over very long time

periods than disposal of nonfixed hazardous wastes in secure landfills. Secure landfills require continuous administrative control to assure that the buried wastes are not exposed by acts of man or nature. It is highly questionable that adequate administrative control can be maintained over these disposal sites for time periods on the order of a hundred years or more. Satisfactory containment in a conventional landfill will require demonstration of long-term stability of the fixed form of the hazardous wastes.

Section 4

LOW VOLUME WASTE CHARACTERISTICS

METAL CLEANING WASTE SLUDGES

The removal of scale, corrosion products, and depositional products from heat transfer surfaces is necessary for the maintenance of high heat transfer rates. Removal of these products also lessens problems due to plugs or obstructions in boiler tubes. To accomplish the removal of the undesired products, periodic cleaning of the heat transfer surfaces in a boiler is performed. This cleaning leads to the generation of metal cleaning wastes that may contain acidity, alkalinity, organic solvents, or chelating agents in addition to the removed scale. Furthermore, small volumes of metal cleaning wastes may be generated by the cleaning of small equipment (such as air compressor coolers and condensate coolers), by stack cleaning, and by cooling tower basin cleaning.

Boiler Waterside Tube Cleaning

The boiler tubes are cleaned periodically to remove accumulated scale and corrosion products from the inside of the boiler tubes. The frequency of the cleaning varies from once every 7 months to once every hundred months, with a mean frequency of once every 30 months ± 18 months (Nichols 1974). Data from TVA indicates that utility boilers in that system are cleaned approximately once every 36 months with two or three-stage cleaning methods which generate 0.3 to 0.9 million gallons per unit per cleaning (Chu, Ruane and Steiner 1976). Power reports cleaning frequencies of once every 3 to 5 years (Rice and Strauss 1977). The amount of wastewater generated is dependent on the fill volume of the boiler and the type of chemical cleaning agent(s) used. Most single-stage solvent/neutralizer systems produce three to four boiler volumes of waste per application. The composition of the waste water produced varies with the cleaning process. Four processes in general use include (Rogoshewski and Carstea 1980):

1. hydrochloric acid with copper complexants
2. ammoniated EDTA
3. hydroxyacetic acid/formic acid
4. citric acid based solutions

The hydrochloric acid process uses a 5 to 7.5% solution of inhibited hydrochloric acid with copper complexants such as thiourea or derivatives of thiourea added. A citric acid rinse and a passivation stage often follow the use of the hydrochloric acid solution. Copper oxidizing and complexing solutions may be added in a separate stage during acid cleaning. These solutions may include free ammonia, ammonium salts, and oxidizing agents such as ammonium bromate.

Ammoniated EDTA (ethylenediaminetetracetic acid) is the basis of the Dow proprietary Alkaline Copper Removal Process. The process is a one solution two-stage process in which iron scale is dissolved and chelated in the first stage

by a hot, basic solution. The temperature is then lowered and the solution is oxidized in the second stage. This causes a stable copper chelate to form in the solution which is then drained.

The hydroxyacetic acid/formic acid process is widely used to clean once-through boilers. A 2:1 mixture of hydroxyacetic acid to formic acid along with a copper complexing agent such as ammonium bifluoride is used in a 3 to 5% solution.

Citric acid based solutions are also frequently used to clean moderately dirty boilers. A proprietary Halliburton Services process, Citrosolv,[®] uses a 3% solution of citric acid ammoniated to a pH of 3.5. Anhydrous ammonia is added in later stages to dissolve copper scale.

Reported concentrations of major heavy metals (Fe, Cu, Ni, Zn) in samples of waste water from boilers undergoing cleaning by each of these processes are given in Table A-1, Appendix A.

TVA has reported the use of a hydroxyacetic acid/formic acid solution or a citric acid/ammonium hydroxide acid phase with a hydrazine hydrate/ammonium hydroxide neutralization stage for cleaning once-through boilers (Chu, Ruane, and Steiner 1976). A three stage process consisting of a hydrochloric acid/ammonium bifluoride acid stage, a potassium bromate/ammonium bicarbonate alkaline stage, and a hydrazine/trisodium phosphate neutralization stage has been used for soaking TVA's drum type boilers with complex tubing arrangements. The characteristics of these waste streams are shown in Tables A-2 through A-4, Appendix A. It should be noted that each acid or alkaline stage is combined with the demineralized water rinse following the acid or alkaline phase. In general, the major potential contaminants in boiler tube cleaning waste solutions are iron, nickel, copper, zinc, oil, and grease.

A laboratory study conducted for the EPA has indicated that waste-water produced by each of the four cleaning processes discussed above can be treated by lime precipitation to meet current effluent guidelines (Rogoshewski and Carstee 1980). Under optimal conditions of dilution and pH, lime precipitation removes essentially all of the heavy metals along with other components such as sulfate which may be present in the dilution water (fireside/air preheater cleaning wastewater). Three significant benefits accrue from lime precipitation treatment of these wastes: (1) volume reduction of heavy metal waste forms, (2) separation of excess water, and (3) insolubilization of heavy metals. The wastewater from the ammoniated EDTA process was found to be the most difficult to treat and this process was selected for further study. Only the sludge produced by lime precipitation of diluted ammoniated EDTA waste was analyzed. The concentrations of Fe, Cu, Ni, and Zn in this sludge are shown in Table 2. Because of the limited scope of the EPA study, comprehensive analyses of the cleaning solutions and associated lime precipitation sludges were not performed. The hydrous metal oxides of Fe, Cu, Ni, and Zn account for roughly 10% of the solids in the sludges listed in Table 2. Much of the solids in these sludges is believed to be CaSO_4 formed by the reaction of lime with sulfate salts and/or sulfuric acid found in the fireside/air preheater waste. Because of the large ratio (~9:1) of fireside/air preheater waste to ammoniated EDTA waste used in these experiments, the sludge would be more characteristic of the former than of the latter. A large dilution was required to attain low levels of dissolved heavy metals in the supernatant solution. The concentrations of Fe, Ni, and Zn are greater in the fireside/air preheater waste than in the ammoniated EDTA waste. Also, the ammoniated EDTA wastewater is not expected to contain substantial amounts of sulfate.

Table 2

SLUDGE METAL CONCENTRATIONS
(Rogoszewski and Carstea 1980)

Sample	Metal Concentration (mg/l)			
	Fe Total	Cu Total	Ni Total	Zn Total
Sludge before	7,540	79	1,040	38.5
Filtration ⁽¹⁾	7,860	83	1,080	40.7
(21.85% Solids)	7,920	83	1,070	40.7
Sludge after	11,600	121	1,600	59.0
Filtration ⁽²⁾	12,100	128	1,660	63.0
(33.6% Solids)	12,200	128	1,650	63.0

- (1) Three sludge samples were analyzed.
 (2) Filtrate concentrations (average of 5 samples) were <0.1, 0.1, 7.3, and <0.1 mg/l for Fe, Cu, Ni, and Zn, respectively. Metal concentrations in the filtered sludge (33.6% solids) were calculated assuming complete material balance closure.

Boiler tube cleaning wastes may be disposed of as liquids in hazardous waste landfills in some areas of the country (e.g., California and New York). However, the trend among utilities is toward treatment with lime or caustic soda to precipitate the heavy metals. The precipitated solids or sludge may be separated from the liquid phase in a clarifier or settling pond. Based on the characteristics of the acid-phase components given in Table A-2 of Appendix A, the sludge formed by lime or caustic soda treatment consists predominantly of hydrous iron and nickel oxides. Lime treatment of the alkaline phase composites given in Table A-3, Appendix A, should yield much less sludge than the acid phase components. The alkaline phase sludge would consist predominantly of hydrous copper oxide except for wastes with high phosphate concentrations where calcium hydroxyapatite [$\text{Ca}_5(\text{OH})(\text{PO}_4)_3$] may predominate in the sludge. Treatment with caustic soda would not precipitate the phosphate; therefore, hydrous copper oxide would predominate in the sludge. Neutralization drain wastewater (see Table A-4, Appendix A) should yield a predominantly calcium hydroxy apatite sludge upon treatment with lime and very little sludge on treatment with caustic soda. Based on the range of pollutants given in Tables A-2 through A-4, Appendix A, other significant components of metal cleaning waste sludge may be calcium fluoride (from lime precipitation of wastes with high fluoride content) and oil and grease.

Boiler Fireside Cleaning

Fireside boiler deposits are typically removed with high pressure water jets while the boiler is still hot. The fireside of the boiler tubes is likely to be cleaned at the same time as the waterside of the tubes. It has been estimated that 5 gallons per day of fireside cleaning wastes will be produced per MW of generating capacity (Rice and Straus 1977). Fireside cleaning has been reported to occur 2 to 12 times per year (Nichols 1974). The heavy metal content of fireside/air preheater wastewater is shown in Table A-5, Appendix A. In

general, low pH levels and high concentrations of dissolved and suspended solids characterize fireside cleaning waste. The waste solutions are currently considered hazardous only if chemical cleaning agents are added to the waste water. If chemical cleaning is used, the waste solution may be treated along with the boiler waterside tube cleaning waste solutions. Water wash wastes are frequently discharged to ash ponds for treatment.

Regulatory agencies may reclassify fireside waste water as hazardous at some future date, even though no chemical cleaning agents are added. Lime or caustic soda treatment may then be required as in the case of waterside cleaning wastes. Caustic soda treatment would be expected to produce a hydrous heavy metal oxide sludge if the pH does not exceed about 10. At higher pH levels precipitation of magnesium hydroxide may occur. Lime treatment may produce large quantities of calcium sulfate in addition to hydrous metal oxides.

Air Preheater Cleaning

Air preheater cleaning is performed weekly to semiannually with high pressure water jets (Nichols 1974). Cleaning volumes are estimated to be 100 gallons per day per MW (Rice and Straus 1977). Oily matter and polynuclear hydrocarbons may be presented at detectable levels if much soot is in the preheater deposits.

Treatment with lime or caustic soda would be expected to produce sludges similar to those produced by the same treatment of fireside wastes. However, the generally higher heavy metal concentrations in air preheater cleaning wastes will produce greater quantities of sludge. Heavy metal concentrations in these wastes are given in Table A-6, Appendix A.

Miscellaneous Metal Cleaning Waste Streams

Miscellaneous metal cleaning wastes include feedwater heater cleaning wastes, condenser cleaning wastes, stack cleaning wastes, and small equipment cleaning wastes. The limited information available on these wastes is summarized in the following paragraphs (Hart and Delaney 1978).

Feedwater Heater Cleaning. Preoperational cleaning to remove oil, grease, dirt, and preservative coatings is accomplished with trisodium phosphate solutions. Hydrochloric acid solutions are used for copper alloy tubing cleaning. The acid solutions are neutralized with soda ash or caustic soda.

Condenser Cleaning. Preoperational cleaning is done with alkaline solutions and operational cleaning is done with hydrochloric acid solutions.

Stack Cleaning. Fly ash and soot are removed with high pressure hoses. Major pollutants are total suspended solids, metals, oils, and extreme pH values.

Small Equipment Cleaning. Small equipment is commonly cleaned with hydrochloric acid solutions which may contain detergents or wetting agents. Small volumes of waste are generated with potentially high total suspended solids, high metal contents, extreme pH values, and oils.

From the limited data available, we believe that these waste streams could be incorporated with the larger volume boiler cleaning waste streams and subjected to the same lime or caustic soda precipitation processes.

WASTEWATER TREATMENT SLUDGES

Physical/Chemical Treatment Sludges

Many utilities have installed a common wastewater treatment facility to process a combined flow of several different low-volume wastewater streams generated within a plant area. These wastewater streams may include spent ion exchange regenerants, boiler blowdown, coal pile drainage, floor and yard drainage and other miscellaneous wastewaters which are generally less polluted with heavy metals and other contaminants than metal cleaning wastes. The combined wastewater may be neutralized to a pH of 6 to 9 and treated with lime, alum, polymer or other coagulant/flocculating agents to facilitate the separation of suspended matter by sedimentation and in some instances filtration. The characteristics of the sludge would depend on the composition of the wastewater treated and the type of chemical coagulants used. For example, a wastewater containing coal pile drainage may be higher in heavy metal concentration than a wastewater from an oil fired plant containing no coal pile runoff. The use of lime as a coagulant could produce a sludge containing substantial amounts of calcium carbonate and calcium hydroxyapatite if the bicarbonate/carbonate and phosphate concentrations are relatively high in the wastewater.

Sanitary Waste Sludges

Sanitary wastes are produced at all power plants. In many plants, this waste is discharged to municipal sewers. Plants that do not have access to municipal sewers may have a small self-contained sanitary waste treatment facility. Such facilities are usually designed so that little sludge is produced. Sludge from these units is typically removed by off-site contractors and discharged to approved treatment facilities such as municipal sewage treatment plants.

WATER TREATMENT SLUDGES

Suspended Matter

Water treatment facilities for removal of suspended matter are included at power stations where high quality well water or municipal drinking water is not available. A local surface water, frequently the same source as the cooling water, is treated by chemical coagulation, flocculation, and sedimentation and/or filtration. The sludge collected from the clarifier and filter backwashes consists largely of the coagulant (c.g., aluminum hydroxide if alum is used), clays, silts, color colloids and miscellaneous organics (Nichols 1974). Chemical coagulation processes will tend to concentrate some pollutants, especially heavy metals, in the sludge. This should not be a problem except in those areas with a relatively high level of pollution in surface water supplies. Alum sludges generally have a very low solids content and are difficult to dewater.

Lime Softening Sludge

Lime or lime-soda softening of water supplies produces a sludge that consists primarily of calcium carbonate plus smaller amounts of magnesium hydroxide, magnesium carbonate, aluminum hydroxide, iron hydroxide, silica, clays, silts, and sand (Nichols 1974). These sludges may also concentrate certain pollutants, such as heavy metals and fluoride, contained in the water. Lime sludges generally have higher solids concentration than alum sludges and are easier to dewater.

Cooling System Wastes

Closed cycle cooling tower systems are in operation in some areas of the country, particularly water-short regions of the Southwest, where the cooling water is reused to the maximum extent possible. Cooling tower blowdown, which is a relatively small volume stream under these conditions, is typically discharged to an evaporation pond where dissolved components are ultimately crystallized to produce a salt cake. In a few instances the blowdown is evaporated to dryness in commercial evaporators and driers and the residual salts are drummed for disposal. Although data are not available on the composition of the residual salt wastes, the predominant constituents expected are sulfate, chloride, and bicarbonate salts of sodium, potassium, magnesium, and calcium. Carbonates and algae are removed from cooling tower basins by water washing which produces wastewaters containing high suspended solids.

Spent Ion Exchange Resins

Ion exchange resins are infrequently disposed of from fixed bed systems because these resins can normally be regenerated many times over a period of several years before the ion exchange capacity of the resins diminishes below acceptable limits. Systems employing powdered ion exchange resins (e.g., condensate polishing units) may discharge these materials on a much more frequent basis because these resins also act as filter media and are not regenerated. The resins are discharged in a slurry form which contains exchanged calcium, magnesium, sulfate, chloride, iron, copper, and zinc. The suspended solids content of the slurry will range from 5000 to 10,000 mg/l, and 50 to 500 mg/l iron, copper and zinc will be present (Hart and DeLaney 1978).

Section 5

SOLIDIFICATION PROCESSES

CEMENT-BASED TECHNIQUES

Process Technology

Cement-based processes are the most common type of fixation technique. The raw materials are readily available and inexpensive, and the cement technology is well known (Conner 1979, Maugh 1979). Unlike other types of processes which require a dry waste, cement processes can be applied to liquid wastes and sludges because water is required for the reaction. The solid product has low permeability and high compressive strength, although fixation product strength is usually less than that of concrete (Barton and Palermo 1972). Disadvantages include the increase in waste volume and possible cement degradation under conditions of low pH.

Cement processes are primarily used on inorganic wastes. They have been used to treat radioactive wastes, metal plating and finishing wastes, electronic industry wastes, and utility flue gas desulfurization (FGD) sludges (Christenson and Wakamiya 1980). They are particularly effective on wastes containing heavy metals. At the high pH (9 to 11) of the cement mixture, metals precipitate as hydroxides, carbonates, and silicates and are incorporated into the cement matrix (Lindsey 1975). For example, the minimum solubilities of cadmium, copper, lead, nickel, and zinc occur between pH 9 and 11 (Malone et al. 1980). It has been noted that the fixation of metals is better in FGD sludges than in industrial wastes (Thompson 1979). Cement processes are generally tolerant of chemical variations; additives can be used to adjust for problem compounds. Cements are not effective vapor barriers because of porosities greater than 35%.

Common cement or "portland cement" is usually produced by firing limestone or chalk and clay in a rotary kiln at about 2600°F (Czernin 1962). The resulting clinker is ground to a fine powder. This powder is composed of tricalcium silicate (typically 50%), dicalcium silicate (25%), tricalcium aluminate (10%), tetracalcium aluminoferrite (10%), and magnesia, sulfate, and impurities (5%). Concrete is formed when the cement powder is combined with rock, sand, and water. The concrete sets up as a colloidal calcium silicate gel. Over a period of time the cement hardens into a rock-like matrix as fibrils grow from the cement particles. This matrix is composed of tobermorite (tricalcium disilicate hydrate). The setting time, rate of hardening, and final strength are affected by temperature, humidity, water/cement ratio, porosity, cement particle size, and chemical composition of the cement. Important chemical composition factors include the amount of calcium, the ratio of silica to the sum of alumina and ferric oxide, the ratio of alumina to ferric oxide, and additives or impurities.

The silica and alumina compositions of portland cement can be adjusted to produce special cements with high hardening rates, low heats of hydration, and

high resistance to corrosion. Five types of portland cement are commercially available. Other compounds such as sodium silicates and polymers are frequently added to treat special wastes. Sodium silicates will produce a rapid set in portland cement. They also precipitate metal ions into the cement gel, binding them more tightly than cement would alone (Malone and Jones 1979). Clay is occasionally added to increase adsorption of metals and reduce leachability (Neilson and Colombo 1979). Encapsulation of cement by polymers has been proposed to reduce leaching.

Aluminous cements are also available (Czernin 1962, Double and Hellawell 1977). These cements are produced from bauxite and limestone. They harden quickly (within 24 hr) and are resistant to chemical attack. However, they have a high heat of hydration, cost more, and can rapidly lose strength at temperatures $>25^{\circ}\text{C}$ and high humidity.

Impurities in the limestone, clay, and waste, and additives will also affect cement. Magnesia is present in most limestones. Unlike calcium, magnesium oxide does not react with silica or alumina. Instead, it undergoes a slow slaking process (reaction with water) after the cement has set, causing expansion and breakage. Concentrations of magnesia are usually limited to 5% in cement (Czernin 1962). If the magnesium is already slaked in the waste, (present in the form of $\text{Mg}(\text{OH})_2$), this expansion will not occur.

Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is added to most cements to retard the rapid setting of alumina compounds. However, if too much sulfate is present the excess sulfate will react with excess calcium oxide in the concrete after the mixture has set, causing expansion and cracking. Typical cement standards limit the sulfate content to 3% of the cement (Czernin 1962). The presence of gypsum in the wastes can also cause expansion. Some wastes (such as flue gas desulfurization sludges) have high calcium sulfite/sulfate concentrations. In addition to the normal cement reactions, the sulfites and sulfates in these wastes react with alumina to form ettringite ($6\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 3\text{SO}_3 \cdot 32\text{H}_2\text{O}$) and tetracalcium aluminum sulfate hydrate (Coltharp et al. 1979). Calcium sulfite is believed to react faster than calcium sulfate. These compounds form soil-like solids and low strength concretes.

Other inorganic compounds which can retard setting include boron compounds and sodium and potassium salts, particularly sodium phosphates, arsenate, iodate, borate, and sulfide (Malone and Jones 1979). Borates are a problem in treatment of low level radioactive waste. Silt, clay, coal, and lignite may also slow the setting reaction, although silica in these compounds may react to increase final strength (Conner 1979). Organic compounds which retard setting include water-soluble starches, gum arabic, humic acids, some sugars, and large amounts of oils or greases.

Other compounds are known to accelerate the setting and hardening rate of cement; these include sodium carbonate, aluminum compounds, and some organics (Czernin 1962). Usually the final strength is reduced. Calcium chloride is frequently added to cement because it accelerates the rate of hardening without affecting setting time or final strength. Large amounts of calcium chloride may be incorporated into calcium alumina chloride compounds (Coltharp et al. 1979).

Other cement properties can be affected by minor components. Salts of manganese, tin, zinc, copper, and lead may reduce strength while causing variations in setting time (Malone and Jones 1979). Sulfides, asbestos and latex

may increase the compressive strength. Solid plastics can improve tensile strength and elasticity. Some compounds e.g., albumin and sugar act as plasticizing agents; they improve cement workability. Air entrainment is frequently used to protect against freeze-thaw damage. Oils, fats, and resins in small quantities can act as frothing agents for air entrainment (Czernin 1962). Soaps and oil emulsions can act as water-proofing agents.

Commercial Suppliers

The Chemfix® process uses soluble silicates and a setting agent to yield a silicon dioxide chain structure similar to the mineral pyroxene instead of a cement. Possible setting agents include lime, gypsum, and portland cement. Metals are fixed within the structure as silicates or hydroxides (Pojasek 1979). The reaction occurs in three stages: sodium silicates and metals react and precipitate, sodium silicates and portland cement react to form a gel, and the gel and precipitates are hydrated. The reaction occurs in the pH range of 4 to 11; lime may be added to raise the pH (Coltharp et al. 1979). This process has been used on FGD sludges, metal finishing wastes, primary metal wastes, and inorganic chemical process wastes.

The Stablex Corporation operates three hazardous waste landfills in England using the patented Sealosafe® process. This process combines portland cement or cement dust, fly ash, waste, and sometimes lime to form a rock-like product called Stablex. The process handles inorganic wastes and up to 3 to 5% organics. Heavy metals are incorporated into the cement matrix. The process has been used effectively on metal plating and finishing wastes.

Environmental Technology Corporation uses a variation of the portland cement process. In addition to lime and portland cement, they add bentonite clay. The bentonite serves two functions: silica in the clay contributes pozzolanic action, and clay acts as an ion exchanger for metals.

Other companies which offer cement processes (primarily for radioactive wastes) include Ontario Liquid Waste (Canadian Waste Technology), Solidtec, Inc., Stock Equipment Co., United Nuclear Corporation, John Sexton Contractors, and Stabatrol.

Both the Chemfix® and Sealosafe® processes are available in Europe. In another European process, the Perrier process, hydroxide wastes are centrifuged before silicates are added.

Portland cement processes are common in Japan. Hiroaka and Takeda (1979) report that a portland cement process has successfully treated soda industry muds containing mercury. Sodium sulfide is added to the cement in this process. Japanese companies offering portland cement processes for industrial wastes include Chichibu Cement, Sumitomo Cement, and Fuji Sash. TJK Inc. offers the Takenaka Sludge Treatment (TST), a portland cement process which has been used on dredge spoils containing heavy metals in Japan. The TST process was developed and is marketed in Japan by the Takenaka Komuten Co.

LIME-BASED TECHNIQUES

Process Technology

Lime-based processes are based on the reaction of lime with fine-grained silica (or pozzolana) and water at ambient temperatures. The product is similar to

portland cement. Lime-based processes have the advantages of low reagent costs, widely available reagents, and well-known technology. Because water is required for the reaction, lime-based processes may be used on wet sludges and slurries as well as dry solids. The solid product has low permeability and high compressive strength. The use of a lime-based process adds to the volume of waste to be disposed of. Like cement, the lime product is vulnerable to acidic solutions. The pozzolanic reaction is similar to the cement reaction and can be affected by the same components that affect cements.

Lime-based processes are used on inorganic wastes and are particularly effective on heavy metals. At the high pH (9 to 11) of the mixture, metals precipitate as hydroxides and carbonates and are incorporated into the product matrix (Malone et al. 1980).

Sources of fine-grained silica include volcanic ash, burnt clay, diatomaceous earth, fly ash from electric utilities, cement kiln dust, and granulated blast furnace slag (Czernin 1962). These are called pozzolana after Pozzuoli, Italy, the city where the Romans mined volcanic ash for cement. Baghouse lime waste from quicklime manufacture contains calcium and magnesium oxides and silicates and has also been used (Sandesara 1980). Pozzolanic cements react slowly, limiting the heat released and allowing additional reaction with excess lime. Portland cement is sometimes added to accelerate the setting reaction. Pozzolanic cements are more resistant to chemical attack than portland cement and are widely used in maritime structures. The pozzolanic material usually contains appreciable quantities of unreactive materials. The amount of inactive silica and alumina, and therefore the amount of waste that can be treated, can only be determined by strength tests.

Blast furnace slag cements form a special kind of pozzolanic cement. The slags are formed when iron ore, coke, and limestone are heated to about 2900°F and molten iron is drawn off (Czernin 1962). The slag left is low in iron and high in magnesia and calcium sulfide. Unlike magnesia in cement, this magnesia does not cause expansion because it is evenly distributed at the microscopic level. Like other pozzolanic cements, slag cements harden more slowly than portland cement and have a higher resistance to chemical attack. The hardening rate of some slags (those high in alumina) can be accelerated by the addition of 10 to 15% gypsum. These supersulfated cements have a hardening rate similar to that of portland cement but a low heat of hydration.

Commercial Suppliers

I. U. Conversion Systems has patented the Poz-O-Tec® and Poz-O-Pac® processes. In the Poz-O-Tec® process, fly ash, lime, and FGD sludges are combined. The sulfite in the FGD sludge accelerates the reaction between lime and fly ash. This process should be applicable to other wastes containing calcium sulfite/sulfate. The Poz-O-Pac® process is a combination of lime, fly ash, and crushed stone. This process has been used on steel mill wastes, electroplating wastes, and some organic wastes.

Dravo Lime Company combines Calcilox® (a patented granulated blast furnace slag) with lime, portland cement and/or fly ash, and wastes to form a soil-like product called Synearth®. They have treated flue gas desulfurization sludges, uranium mill tailings, and coal preparation/cleaning plant fines.

Enviro Energy Systems has patented a fixation process involving flyash and cement or lime kiln dust. Because both additives are wastes, the process should

be relatively inexpensive. The company can supply kiln dust to a utility who can then fix its own wastes.

Two pozzolanic process are available in Europe. Petrifix uses iron manufacturing wastes and a catalyst on radioactive wastes. The product contains calcium silicates and calcium silicate-aluminates. The Quienot process is similar; metallurgical slag, fly ash, and waste are combined to form a solid.

Some wastes may be treated by carbonate bonding. The wastes are mixed with water and hydrated lime and then compacted. Next carbon dioxide is bubbled through the mixture. Calcite (CaCO_3) structures are formed which incorporate waste particles. Permeability of the product is similar to that of cement. This process has been tested on taconite tailings (LaRosa et al. 1974, Conner 1979).

Self-cementing processes for calcium sulfate sludges may also be possible. Malone and Jones (1979) report that Sludge Fixation Technology, Inc., offers a self-cementing process called Terra Crete[®] for flue gas desulfurization sludges. In this process, a portion of the sludge is dried and calcined. This dried material is then combined with the rest of the sludge. The product is similar to and probably contains plaster of paris ($\text{CaSO}_4 \cdot 1/2\text{H}_2\text{O}$). This process should be applicable to other sludges containing large amounts of calcium sulfate/sulfite.

THERMOPLASTIC TECHNIQUES

Process Technology

Thermoplastic techniques involve mixing dried waste with a heated plastic matrix. The hot plastic/waste mix is then cooled to allow the mix to solidify. Typical thermoplastic materials that have been used include bitumen (the asphaltic residue from petroleum distillation), paraffin, and polyethylene. A variation of this technique is to mix wet sludge with a bitumen emulsion. The mixing of the waste and emulsion can then take place at any temperature below the boiling point of the mixture. The mixture is heated to evaporate water and then cooled to solidify the mixture. The solid generally contains 50% to 67% waste (on a dry basis) with the remainder being fixative (Malone and Jones 1979). The thermoplastic coats the waste particles rather than chemically combining with them.

The advantages of thermoplastic techniques include significantly lower leach rates than with cement systems, high resistance to attack by aqueous solutions, and resistance to microbial degradation. As the waste must be disposed of in a dry condition, the volume of the waste is greatly reduced.

Disadvantages of thermoplastic techniques include the need for complicated equipment and specialized labor, the risk of fire in working with heated organic materials, and the large amounts of energy needed to dry the waste. An additional problem is the possible production of noxious oil and odors during heating.

Several types of waste cannot be suitably solidified by thermoplastic techniques. Any organic solvent that can dissolve the thermoplastic is unsuitable. Strong oxidizers cannot be incorporated without causing reactions with the matrix materials. Fire is also a possibility when strong oxidizing agents are

processed at high temperatures. Anhydrous salts cannot be incorporated due to their tendency to rehydrate, expand, and crack the mixture. Care must be taken that hydrated salts do not dehydrate at the elevated processing temperatures. Materials which decompose at the processing temperature are also excluded.

Commercial Suppliers

Several companies sell thermoplastic waste solidification processes, including Newport News Industrial Corporation, Teledyne Energy Systems, and Werner and Pfleiderer Corporation. The Newport News Industrial Corporation process is still in a developmental stage. The Teledyne System will handle asphalt, cement, urea-formaldehyde and Dow polymer binders. The waste is mixed with the binder and appropriate catalysts or promoters are added if needed. The mixture is then poured into a drum and allowed to solidify. The process was originally developed for nuclear waste, but could be utilized for nonradioactive hazardous waste as well. The Werner and Pfleiderer process utilizes a plastic or bitumen binder. The waste is mixed with binder material and extruded with a screw extruder. Asphalt encapsulation of arsenic wastes has been investigated by the US EPA. The process was designed for industrial solid and liquid waste and has been used in Europe for over 15 years on nuclear wastes.

ORGANIC POLYMER TECHNIQUES

Process Technology

Organic polymer techniques involve mixing waste with organic resins and then polymerizing the resins with a catalyst. Typical resins in use include urea-formaldehyde, vinyl ester-styrene, and polyesters. The mixing process is either a batch process with mixing and polymerization occurring in the waste receptacle or semi-batch with mixing occurring in specially designed mixers and polymerization occurring in waste containers. The waste is not chemically bonded to the polymer. Instead, the waste is incorporated in a continuous polymer matrix that encloses cells of the aqueous waste.

The advantages of this technique include higher waste to fixative ratios and lower product density than in cement processes and low processing temperatures. The disadvantages of this technique include the possible production of noxious fumes during polymerization and the use of corrosive catalysts requiring special mixers and container liners. In addition, urea-formaldehyde processes require low pH waste mixtures for proper polymerization. Urea-formaldehyde resins also shrink with age and produce uncombined "weep" water during aging (Malone and Jones 1979).

Washington State University has developed a similar process utilizing emulsified polyester resins and peroxide catalysts to produce a solid monolith composed of droplets of waste encapsulated by thin polyester shells (Subramanian et al. 1977). The monolith has a compressive strength approaching that of concrete. The process can be used on aqueous, slurried or solid waste streams with a pH >5. Many wastes have been encapsulated on a laboratory scale and in pilot plants, including boric acid solutions, sodium sulfate waste solutions, simulated metal finishing waste including heavy metals and organics, and cyanide slurries containing heavy metals. No utility wastes have been solidified to date.

The Washington State University process is not currently in commercial use. Pilot plant studies are underway wherein wastes are mixed with water and fed into a tank containing the binder to form an emulsion. The emulsion is then pumped into a solidification container and an initiator and promoter are added. The emulsion is then solidified in the container. The process uses a commercially available water extensible polyester. The initiators are commercially available organic peroxides. Promoters consist of cobalt naphthenate, manganese naphthenate, or dimethylaniline. The result is a lightweight, homogeneous dispersion of small spherical droplets encapsulated in cured resin.

Commercial Suppliers

Dow Chemical Co. offers a process utilizing a modified vinyl ester resin as the binder. As waste is encapsulated by the nonporous binder material, no free-standing water is left. The process can handle liquids, slurries, or solids and produces a stable, homogeneous, free-standing, nonflammable monolith. The pH of the waste must be between 2.5 and 11. Dow is currently conducting tests on the containment of heavy metal by their process. The process was originally developed for use on low-level nuclear wastes such as ion exchange resins, evaporator bottoms, spent decontamination solutions, and filter sludges.

The polymer is formed through free radical polymerization which is initiated by a catalyst. Waste, binder, catalyst, and a promoter are mixed in a drum or tank, allowed to cure and then sealed in a drum. The binder is a mixture of vinyl ester in styrene monomer. The catalyst is a commercially available emulsion of benzoyl peroxide and the promoter is a commercially available tertiary amine, N,N dimethyl toluidine. The fixed waste is a dispersion of small spherical liquid droplets in a continuous matrix of cured resin. The Dow process has been licensed to six utilities for use at eight nuclear power plants. Several equipment manufacturers and engineering firms are licensed to design and install Dow process equipment. Mobile solidification facilities are also available.

Teledyne Corporation offers a urea-formaldehyde binder called U-Form which polymerizes without leaving free-standing liquid after solidification, unlike other urea-formaldehyde processes. The encapsulation takes place by condensation polymerization of the urea and formaldehyde to produce a cross-linked polymeric matrix. The process requires an acid catalyst which necessitates acidic conditions in the waste streams.

Two other organic polymer processes are also in use in Europe. Ecopol offers a thermo-setting resin embedding system which uses a polyester in styrene solution in much the same way as the Washington State University process. The Soliroc process uses a polymer to bond the waste and form a thick slurry for disposal.

GLASS TECHNIQUES

Process Technology

Glass techniques involve mixing waste with glass forming compounds and then fusing the mixture to produce a glass. Any volatile components in the waste are driven off by the high temperatures (1000°C) used to form the glass. This limits the use of glass techniques to relatively nonvolatile inorganic substances. The inorganic components remain in the glass in the form of dissolved metallic oxides. Some advantages of glassification techniques are the high degree of containment achieved (very low leach rates) and the relatively low

cost of the additives. Disadvantages include the fact that the process is energy intensive and uses specialized equipment and trained personnel.

There are four types of glass products that could be used to encapsulate wastes. These include phosphate glass, borosilicate glass, glass ceramics, and supercalcines. Phosphate glass consists primarily of metal oxides fused in phosphorous oxide. Phosphate glass compositions were developed for encapsulation of nuclear wastes. The melting temperatures of phosphate glass are lower than those of borosilicate glasses. Borosilicate glasses consists of oxides of silicon, boron, sodium, and other metals. Borosilicate glasses are also used for encapsulation of nuclear wastes. Borosilicate glasses are not normally capable of incorporating sulfate-containing waste, due to phase separation in the glass. Glass ceramics can be produced from borosilicate glasses by controlled crystallization. The glass is annealed twice to yield a continuous glassy phase with a uniform distribution of crystals within it. The ceramic has a greater mechanical impact stability and should be thermally more stable than glass. Phosphate glass ceramics are not produced from phosphate glass, but may be produced by heating and melting of crystalline sodium aluminum phosphates. Supercalcines are tailor-made ceramics in which certain constituents are added to the waste to produce crystalline phases. The additives are commonly oxides of silicon, calcium, aluminum and strontium and are usually only about 25% of the waste glass weight.

Research is continuing on glass fixation techniques for high and low-level nuclear waste. Several of the national laboratories including Pacific Northwest Laboratory and Savannah River Laboratory, and international research laboratories, such as the Hahn-Meitner-Institute, are developing glass fixation processes.

Commercial Suppliers

Penberthy Electromelt of Seattle, Washington is involved in commercial applications of waste glassification. A proprietary melting process is used. No industrial wastes have been solidified, but work is under way on industrial applications.

SURFACE ENCAPSULATION TECHNIQUES

Process Technology

Surface encapsulation techniques involve coating or encapsulating bulk solidified waste materials. For example, a waste may be solidified with an organic polymer or cement and then coated with a layer of high density polyethylene (HDPE). The purpose of the coating is to provide an additional barrier to leaching of the waste. This additional barrier may or may not be needed to meet leachate standards. The advantage of lower leaching must be weighed against the disadvantages of high energy usage, high cost of coating materials, and the need for skilled operating labor.

A process was developed by TRW utilizing HDPE. The HDPE may be fused onto the surface of the solidified waste, fused or sprayed onto preformed waste containers, or welded into a waste container overpack. Dry wastes, sludges, and containerized wastes have all been encapsulated. The coating prevents water from entering the solidified waste and also seals in any water already in the waste. The coating also increases the mechanical and physical strength of the solidified waste.

Commercial Suppliers

Environmental Protection Polymers of Hawthorne, California currently markets the surface encapsulation process developed at TRW.

SULFUR TECHNIQUES

Process Technology

Several different sulfur techniques are available for hazardous waste solidification. In the simplest technique, dry waste is mixed with molten sulfur and the mixture is then allowed to cool and solidify. This process produces a dry, brittle, concrete-like material. A second technique uses sulfur with various plasticizing agents to produce an asphalt substitute. The plasticized sulfur may be used for encapsulation of waste in the same manner that asphalt is used. A third technique is to use sulfur as an impregnation agent for concrete. The sulfur fills voids in the concrete and reduces water absorption. The sulfur increases the strength and leach resistance of solidified sludges.

Commercial Suppliers

Randustrial, Inc. offers a sulfur/cement compound called Sulfaset® which has been used to solidify Kepone-contaminated sludges (Dawson 1978). Southwest Research Institute has a modified sulfur compound called Sulflex® which can be used as an asphalt substitute for waste encapsulation. Chevron Chemical Co. has developed a sulfur cement called Sucoat® which could possibly be used to solidify wastes.

COSTS

Costs of fixation processes depend on the waste, the fixation process technology, the fixation agent, and the mode of application. In the Guideline to Disposal of Chemically Stabilized and Solidified Wastes (Malone, Jones and Larson 1980), Stablax Corporation reported variations of \$5 to \$350/ton for their process depending on the waste. Six other vendors reported costs of 0.2¢ to 7¢/lb (or \$2 to \$60/ton at a specific gravity of unity), averaging \$27/ton. Colthorp et al. (1979) reported values of \$7 to \$12/ton for fixation of flue gas desulfurization sludge.

Malone, Jones and Larson (1980) compared costs of different processes. They found that cement and pozzolanic processes had the lowest material costs: \$60/ton for cement and pozzolanic processes, \$392/ton for thermoplastic processes, \$554/ton for organic polymer processes, and \$90/ton for surface encapsulation processes. Furthermore, organic polymer, thermoplastic, surface encapsulation, and glass processes had high energy costs and expensive equipment. On the other hand, Osmeyer (1980) calculated operating costs for fixation of radioactive wastes and found that cement, glass, asphalt, urea-formaldehyde, and organic polymer process had annual operating costs within 10% of each other. Costs will also vary depending on whether the fixation process is applied by the utility onsite, by a vendor onsite (in either a stationary or mobile unit), or by a vendor at a central disposal site. Thus, fixation costs are highly process and waste dependent.

Whether fixation and disposal in a solid waste disposal site is more cost effective than disposal in a hazardous landfill depends on the cost of fixation, the costs of disposal, and the costs of transportation. Engineering-Science (1979) estimated disposal costs for high volume utility wastes (ash and FGD sludge) in different geographical areas. Costs for nonhazardous solid waste disposal (under RCRA regulations) ranged from \$10 to \$22/ton, and costs for hazardous waste disposal were \$25 to \$65/ton.

Section 6

APPLICABILITY OF FIXATION PROCESSES

METAL CLEANING WASTE SLUDGES

Boiler tube cleaning and air preheater waste sludges contain hydrous metal oxides, especially $\text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O}$. Waterside boiler tube cleaning waste sludges may contain calcium hydroxyapatite, calcium fluoride, and cleaning agent residuals. Fireside boiler tube cleaning waste sludges may contain calcium sulfate, while air preheater cleaning waste sludges may contain calcium sulfate and oily materials. The pH range of the interstitial fluid of the sludges is 6 to 12.

Nearly all of the fixation processes considered in this study are expected to be applicable to boiler tube and air preheater cleaning waste sludges. Possible exceptions are urea-formaldehyde based processes. These processes utilize an acid catalyst and therefore require acidic wastes. Acidifying the boiler tube and air preheater waste sludge would appear to be counterproductive since precipitated heavy metals may be dissolved. Elutriate tests on raw and fixed electroplating and nickel cadmium sludges indicate an increase in elutriate Cu, Ni, Zn, and Cr concentrations (metals likely to be found in power plant wastes) under acidic conditions (Thompson 1979).

Cement-based processes generally are adaptable to fixation of metal oxide sludges. The presence of gypsum in fireside boiler cleaning waste sludges and air preheater wastes may pose a problem if an excess of this material is available to react with aluminum components of the portland cement. This reaction may lead to expansion and cracking. Dehydration of the gypsum during the curing period (hydration of the portland cement may remove water from gypsum) and later rehydration may also cause swelling and cracking. Sulfate content of the concrete should be kept below 3 wt% to preserve the integrity of the concrete. Although structural integrity is desirable to minimize water flow through the fixed waste, it is not essential to achieve satisfactory leach rates in many instances. The setting time and strength is best determined in the laboratory with actual wastes and portland cement. The presence of soots and oily material should not have a great affect on the concrete unless they are present in large quantities.

Lime-based processes are generally very effective on inorganic wastes. However, specific reactions cannot be predicted, and pozzolan-lime waste mixtures should always be tested. Lime-based processes are less sensitive to trace components than cement processes, but lime-based processes are also more unpredictable. The reactions involved in lime-based processes are similar to those in cement processes and are sensitive to the same types of impurities as the cement processes.

Thermoplastic processes can handle most waste streams with the exception of solvents which can dissolve the matrix material, strong oxidizing agents which can react with the matrix material, and anhydrous salts which can later swell

and crack the matrix. A possible problem in fixation of the boiler cleaning waste sludge and preheater waste sludges is the presence of gypsum in sludge. Gypsum may undergo partial dehydration when the sludge is mixed with the thermoplastic material at elevated temperatures. The formation of anhydrous salts in thermoplastic processes would have to be examined in the laboratory.

Organic polymer processes should be applicable for fixation of air preheater and boiler tube cleaning waste sludges, except that at the low pH conditions required for the urea-formaldehyde processes heavy metals may dissolve.

Glass techniques could be used for fixation of air preheater and boiler tube cleaning waste sludges. The presence of sulfate ion in the waste could cause problems for certain glass compositions. Soot and oily matter in the sludge would be incinerated in the melter and the inorganic residue would be incorporated into the glass.

Surface encapsulation techniques could be used on any waste that is already solidified by another technique.

Insufficient data are available on sulfur fixation techniques to evaluate their applicability to boiler tube and air preheater waste sludges.

WASTEWATER AND WATER TREATMENT WASTES

Wastewater treatment wastes are essentially alum or lime sludges with hydrous metal oxides, calcium carbonate if lime is involved, and sediments. Water treatment wastes consist of alum sludges, lime or lime-soda sludges, and sediments. The sludges may contain calcium carbonate, magnesium hydroxide, and calcium hydroxy apatite. The pH of sludges is between 7 and 11.

Nearly all of the solidification processes should be applicable for wastewater and water treatment sludges. The exception would be urea-formaldehyde processes which require acidic conditions.

Cooling Tower Basin Sludges

Cooling tower basin sludges consist mainly of sediments from intake water and materials scrubbed out of the air. Traces of cooling water additives may also be present. Very little information is available on the sludge composition, which would be extremely site specific. The possibility exists that hazardous sludges could be produced if the air or intake water was extremely polluted. The processes discussed in this report are expected to be capable of fixing pollutants in these sludges, but analysis of the sludge and testing of the processes would be necessary before any particular process is chosen.

Cooling Tower Blowdown Residues

Cooling tower blowdown residues from evaporation ponds consist mainly of chloride, sulfate, carbonate, and bicarbonate salts of sodium, potassium, calcium, and magnesium plus suspended matter present in the blowdown at the time of discharge. All of the processes are potentially capable of fixing heavy metals. The sulfate content of the residue may cause cracking problems in thermoplastics, cements, and lime-based processes. Glass may also be unable to accommodate large amounts of sulfate. The sodium and potassium ions may

retard the setting time of cements or pozzolans, while calcium chloride may accelerate the setting time. The actual setting time would have to be determined by testing.

Spent Ion Exchange Resins

Spent powdered ion exchange resin contains heavy metal ions and metal oxides. Spent ion exchange resin bead contains heavy metal ions. Most of the solidification processes may be able to handle these wastes although a problem may exist with cracking of cement due to swelling of the resins when wet. Shrinking of ion exchange resins occurs due to dehydration of the resin while mixing with the cement. The cement matrix then forms around the shrunken resin particles. After the cement is set, the cement block absorbs liquid water and water vapor, which swells the resin back to its original size. Another problem that could occur is the displacement of heavy metal ions in the resin by ions (e.g., Ca^{+2}) in the cement. This may allow the heavy metals to be leached out of the fixed waste. These problems have been long recognized in the nuclear industry where ion exchange resins are commonly used. In response to this problem, several organic polymer systems were developed to handle these wastes. The organic polymer systems work well on these wastes. Glass systems can also incorporate inorganic ion exchange materials such as zeolites. Encapsulation processes are also potentially applicable to ion exchange wastes.

Section 7

REFERENCES

- Bartos, M. J., Jr, and M. R. Palermo. 1977. Physical and Engineering Properties of Hazardous Industrial Wastes and Sludges, EPA-600/2-79-139.
- Christensen, D. C., and W. Wakamiya. 1980. "A Solid Future for Solidification Fixation Processes," in Toxic and Hazardous Waste Disposal Vol. 4, R. B. Pojasek, ed., Ann Arbor Science, Ann Arbor, Michigan, p. 75-90.
- Chu, T. Y. U., R. J. Ruane and G. R. Steiner. 1976. "Characteristics of Wastewaters Discharges from Coal-Fired Power Plants." Proceedings of the 31st Industrial Waste Conference, Purdue University, Lafayette, Indiana.
- Coltharp, W. M. et al. 1979. Review and Assessment of the Existing Data Base Regarding Flue Gas Cleaning Wastes, EPRI Report FP-621, Vol 1, prepared by Radian Corporation.
- Conner, J. R. 1979. "Considerations in Selecting Chemical Fixation and Solidification Alternatives-The Engineered Approach," Proc. 2nd Annual Conf. of Applied Research and Practice in Municipal and Industrial Waste, Madison, Wisc, p. 129-147.
- Czernin, W. 1962. Cement Chemistry and Physics for Civil Engineers, Chemical Publishing Co., Inc., New York.
- Dawson, G. W. et al. 1978. "The Feasibility of Mitigating Kepone Contamination in the James River Basin." Appendix A of Mitigation Feasibility for the Kepone Contaminated Hopewell/James River Area, EPA 440/5-78-004A.
- Double, D. D. and A. Hellawell. 1977. "The Solidification of Cement," Scientific American, p. 82-90.
- Engineering-Science. 1979. Evaluation of the Impacts of Proposed RCRA Regulations and Other Related Federal/Environmental Regulations on Utility and Industrial Sector Fossil Fuel-Fired Facilities, Phase I. Interim Report. Prepared for DOE.
- Hart, F. C. and B. T. Delaney. 1978. "The Impact of RCRA (PL-94-580) on Utility Solid Wastes," EPRI FP-878.
- Hiroaka, M., and N. Takeda. 1979. "Behavior of Hazardous Substances in Stabilization and Solidifications Processes of Industrial Wastes," Presented at the ACS 177th National Meeting, Honolulu, Hawaii.
- International Atomic Energy Agency. 1979. "Characteristics of Solidified High-Level Products," IAEA Technical Report Series No. 187.

- LaRosa, P. J., K. A. Ricciardella, and R. J. McGarvey. 1974. Carbonate Bonding of Taconite Tailings, EPA-670/2-74-001.
- Lerch, R. E., W. D. Greenhalgh, J. A. Partridge, and G. L. Richardson. 1979. "Treatment and Immobilization of Intermediate Level Radioactive Wastes," in Management of Low Level Radioactive Wastes, Vol. 1, M. W. Carter, A. A. Moghissi, and B. Kahn, eds., Pergamon Press, New York.
- Lindsey, A. W. 1975. "Ultimate Disposal of Spilled Hazardous Materials," Chemical Engineering, p. 107-114.
- Malone, P. G., R. J. Larson, and T. E. Meyers. 1980. "Stabilization/Solidification of Waste from Uncontrolled Disposal Sites," USEPA Conference on Management of Uncontrolled Hazardous Waste Sites, Washington, D.C. p. 108-183.
- Malone, P. G. and L. W. Jones. 1979. Survey of Solidification/Stabilization Technology for Hazardous Industrial Wastes, EPA-600/2-79-56.
- Malone, P. G., L. W. Jones and R. J. Larson. 1980. Guideline to the Disposal of Chemically Stabilized and Solidified Wastes. EPA-SW-872.
- Maugh, T. H., II. 1979. "Burial is Last Resort for Hazardous Waste," Science 204 (22) p. 1295-1298.
- Neilson, R. M. Jr., and P. Colombo. 1979. "Solidification of Liquid Concentrate and Solid Waste Generated as Byproducts of the Liquid Radwaste Treatment Systems in Light-Water Reactors," in Management of Low-Level Radioactive Waste, Vol 1, M. W. Carter, A. A. Moghissi, and B. Kahn, eds., Pergamon, New York.
- Nichols, C. R. 1974. "Development Document for Effluent Limitations, Guidelines and New Source Performance Standards for the Steam Electric Power Generating Point Source Category," NTIS Report No. PB-240 853.
- Osmeyer, W. E. 1980. "Operational Cost Comparisons for Various Radwaste Disposal Techniques." ANS/ENS International Conf. Washington, D.C.
- Pojasek, R. B. 1979. "Solid Waste Disposal: Solidification," Chemical Engineering, p. 141-145.
- Rice, J. K., and S. D. Strauss. 1977. "Water Pollution Control in Steam Plants," Power 120, No. 4, p. S-1 to S-20.
- Rogoshewski, P. J. and D. D. Carstea. 1980. "Evaluation of Lime Precipitation for Treating Boiler Tube Cleaning Wastes," EPA-600/7-80-052.
- Sandesara, M. D. 1980. "Fixation of Heavy Metals for Secure Landfill Disposal," in Toxic and Hazardous Waste Disposal Vol IV, R. R. Pojasek, ed., Ann Arbor Science, Ann Arbor, Michigan, p. 127-134.
- Subramanian, R. V. et al. 1977. "Polymer Encapsulation of Hazardous Industrial Wastes" in Treatment and Disposal of Industrial Wastewaters and Residues, Proc. Natl. Conf. Houston, Texas. p. 97-118.
- Thompson, D. W. 1979. Elutriate Test Evaluation of Chemically Stabilized Waste Materials. EPA-600/2-79-154.

Appendix A
METAL CLEANING WASTEWATER COMPOSITIONS

Table A-1

REPORTED MAJOR HEAVY METAL CONCENTRATIONS
IN SPENT WATERSIDE CLEANING SOLUTIONS*

Waste Solution	++++	Concentrations in mg/l			
		Fe	Cu	Ni	Zn
1. Hydrochloric Acid with Copper Complexants	Ave	4,100	390	240	420
	High	6,470	960	500	840
	Low	1,900	20	3	10
2. Ammoniated EDTA	Ave	5,000	1,400	48	94
	High	8,328	11,700	140	330
	Low	1,000	0.17	0.33	3.8
3. Hydroxyacetic Acid/Formic Acid	Ave	4,640	4.6**	1.9	9.6**
	High	9,800	4.8	2.62	12
	Low	944	4.2	1.16	7.1
4. Citric Acid Based Solutions	Ave	1,240	934	5.4	29.3
	High	10,800	1,912	130	390
	Low	180	8.0	2.5	3.1

* Reference: Information Responding to EPA's Request Regarding Burning and Co-treatment/Co-disposal of Low Volume Wastes Generated at Fossil Fuel Fired Electric Generating Stations. Report prepared by EnviroSphere Company for Utility Solid Waste Activities Group and Edison Electric Institute (August 1981).

** Average of only two determinations.

Table A 2

CHARACTERISTICS OF CHEMICAL CLEANING WASTEWATER-ACID PHASE COMPOSITE
(Chu, Ruane and Steiner 1976)

Constituents	Concentration (mg/l) unless otherwise indicated					
	Plant A ^a	Plant C	Plant G	Plant I	Plant K	Plant L
Waste Volume (million gal)	0.175-0.250	0.217	0.099	0.087	0.070	0.090
pH (units)	3.3	0.8	0.7	0.7	0.5	0.7
Suspended Solids	57	8	120	18	35	33
TOC	4600	240	90	1800	220	120
COD	9900	1200	1500	1200	1900	1500
Oil and Grease	23	<5	11	7.6	20	23
Phenols	0.050	0.065	0.070	0.035	0.020	0.025
Silica	19	66	120	240	31	-
Ammonia Nitrogen	325	140	80	220	290	150
Organic Nitrogen	225	0.06	140	75	10	870
Nitrate and Nitrite as N	-	0.07	<0.01	<0.01	<0.01	-
Phosphorus	1.2	30	50	35	50	45
Sulfate	-	<1	10	<1	<1	-
Aluminum	-	65	6.6	7.0	8.2	-
Arsenic	0.008	0.060	0.010	0.030	0.055	0.035
Barium	-	<0.1	0.4	0.1	0.3	-
Beryllium	-	<0.01	<0.01	<0.01	<0.01	-
Cadmium	<0.001	0.010	0.051	0.032	0.10	<0.001
Calcium	16	42	70	53	64	74
Chromium	<0.005	1.5	6	1.1	8.8	<0.005
Copper	0.69	2.2	7.6	18	13	47
Iron	4200	1300	3820	1420	3720	2780
Lead	-	0.4	3.8	0.86	5.2	<0.010
Magnesium	-	8.7	6.5	5.7	8.8	-
Manganese	19	6.9	29	10	28	22
Mercury	-	<0.0002	<0.0002	0.0002	0.0002	-
Nickel	110	77	260	170	300	150
Potassium	-	1.4	2.3	1.5	1.8	-
Selenium	-	<0.004	<0.002	<0.002	<0.002	-
Silver	-	0.02	0.02	0.07	0.03	-
Sodium	-	31	74	40	49	-
Tin	-	<1	7.3	<1	2.8	-
Zinc	0.94	5.9	170	34	53	24

^aCirculation method used. All other plants used soaking method.

Table A-3

CHARACTERISTICS OF CHEMICAL CLEANING WASTEWATER-ALKALINE PHASE COMPOSITE
(Chu, Ruane and Steiner 1976)

Constituents	Concentration (mg/l) unless otherwise indicated				
	Plant C	Plant G	Plant I	Plant K	Plant L
Waste Volume (million gal)	0.217	0.165	0.116	0.140	0.120
Dissolved Solids	340	1400	1400	1900	1600
Suspended Solids	8	71	47	200	7
COD	24	120	61	84	160
Oil and Grease	<5	<5	<5	<5	-
Silica	7.2	14	50	13	-
NH ₃ as N	700	2000	2100	4200	4700
Organic N	40	<10	270	2600	3600
NO ₂ + NO ₃ as N	0.04	0.51	0.21	0.46	-
Phosphorus	10	30	2.0	400	275
Bromide	52	<5	-	-	<5
Chloride	60	-	350	110	180
Fluoride	1.5	6.1	6	5.6	-
Sulfate	<1	<1	<1	18	-
Aluminum	<0.2	<0.2	0.4	0.3	-
Arsenic	0.048	<0.005	0.012	<0.010	0.030
Barium	<0.1	<0.1	<0.1	<0.1	-
Beryllium	<0.01	<0.01	<0.01	<0.01	-
Cadmium	<0.001	<0.001	<0.001	<0.001	-
Calcium	3.0	0.4	<1.0	4.9	-
Chromium	<0.005	<0.005	<0.005	<0.005	-
Copper	100	790	510	680	590
Iron	1.7	4.9	2.9	2.2	<0.05
Lead	<0.010	<0.010	<0.010	<0.010	-
Magnesium	2.9	0.67	0.1	0.51	-
Manganese	0.03	0.04	0.03	0.05	-
Mercury	<0.0002	<0.0002	0.0006	0.0006	-
Nickel	0.52	2.5	0.94	3.3	0.62
Potassium	70	220	<0.01	230	260
Selenium	<0.002	<0.002	<0.002	<0.002	-
Silver	<0.01	0.02	<0.01	0.04	-
Sodium	3.7	15	0.1	12	-
Tin	<1	<1	<1	<1	-
Zinc	0.06	0.54	0.17	0.35	0.19

Table A-4

CHARACTERISTICS OF CHEMICAL CLEANING WASTEWATER-NEUTRALIZATION DRAIN
(Chu, Ruane and Steiner 1976)

Constituents	Concentration (mg/l) unless otherwise indicated					
	Plant A ^a	Plant C	Plant G	Plant I	Plant K	Plant L
Waste Volume (million gal)	0.110	0.72	0.033	0.029	0.035	0.030
pH (units)	9.5	11.9	12.2	12.0	10.7	11.9
Dissolved Solids	70	4000	4500	5400	2500	5300
Suspended Solids	10	88	140	20	10	12
COD	92	68	68	45	68	76
Oil and Grease	<5	-	<5	-	-	<5
Ammonia Nitrogen	80	3.2	12	22	21	32
Organic Nitrogen	110	4.3	5	38	5	<0.00
Nitrate and Nitrite as N	-	<0.01	0.03	0.50	0.01	0.03
Phosphorus	-	-	770	850	420	980
Copper	0.13	0.65	25	1.7	0.4	2.8
Iron	4.6	3.2	28	4.4	2.3	1.3
Sodium	-	150	1800	1.3	960	2400
Hydrazine	0.025	-	-	-	-	0.001

^aCirculation method used. All other plants used soaking method.

Table A-5

REPORTED HEAVY METAL CONCENTRATIONS IN FIRESIDE WATER WASH WASTE
Concentration in mg/l (except where noted)

Plant	A	B
Cleaning Frequency (cycles/yr)	2	8
Batch Volume (1000 ℓ)	2725	90.8
Chromium (total)	0.005	5.0
Copper	--	1.2
Iron	150	150
Nickel	5.0	--
Zinc	4.8	10

References: See Table A-1.

Table A-6

REPORTED HEAVY METAL CONCENTRATIONS FOR AIR PREHEATER CLEANING WASTES
Concentrations in mg/l (except where noted)

Plant	A	B	C	D	E	F	G
Cleaning Frequency (cycles/yr)	12	12	8	12	5	6	4
Batch Volume (1000 ℓ)	408.8	851.6	1395	2325	271.3	166.6	378.5
Chromium (total)	1.2	12.9	13.0	11.8	1.3	1.3	0.64
Copper	4.9	--	--	0	5.0	5.0	2.2
Iron	1800	1700	1700	1700	6.0	5.9	2.9
Nickel	75	75	75	75	50	50	25
Zinc	4.9	4.8	5.0	5.0	0.5	5.0	2.5

References: See Table A-1.

Appendix B

CONTACTS

CONTACTS WITH POSSIBLE SUPPLIERS

Company Name	Location	Contact	Phone	Process Type
Dow Chemical	Midland MI	Larry Donovan	(517)636-3402	Organic polymer
Permutit	Seattle WA	Dave Fort	(206)271-5077	Iron sulfide precipitation
Washington State U	Pullman WA	R. V. Subramian	(509)335-6784	Organic polymer
Teledyne (Protective Packaging)	Timonium MD	W. E. Osmeyer	(301)252-8220	Thermoplastic
Randustrial	Cleveland OH		(216)283-0300	Sulfur/cement
Ontario Liquid Waste	Cambridge, Ontario, Canada	Neil Cook	(416)495-9502	Silicate base
Solidtec Inc.	Morrow GA	Bob Salas	(404)361-6181	Cement/silica
American Fly Ash	Chicago IL	Joseph Pound	(312)694-5566	Fly ash and lime. Haven't treated wastes other than fly ash.
Industrial Resources	Denver CO	Ed Rosar	(303)232-2942	Sodium wastes-sintering or fixation
Chemonazone Div., Ionization Int'l	Chicago IL	Andrew Pincon	(312)226-0744	No longer in this business. Used soil and dolomite
Stock Equipment Co.	Chagrin Falls OH	Doug Warren	(216)543-8211	Cement or polymer for radioactive wastes
United Nuclear Corporation	Richland WA	Roy Peterson	(509)375-3535	Cement for radioactive wastes
John Sexton Contractors	Oakbrook IL	Joseph W. Spears	(312)449-1250	Cement for treatment of industrial wastes
Stabatrol	Norristown PA	Mike Scornovacchi	(215)825-2675	Cement
Dravo Lime	Pittsburgh PA	Dave Hoffman	(412)566-4444	Calcilox (blast furnace slag)
TRW	Redondo Beach CA		(213)536-4105	No longer in this business. Process offered by Environmental Protection Polymers
Environmental Technology Corp	Pittsburgh PA	Dennis Escher	(412)381-5011	Portland cement, lime, bentonite
Todd Shipyards	Galveston TX	C. W. Hathaway	(713)744-7141	Proprietary polymer
TJK, Inc.	North Hollywood CA	Robert Jensen	(213)875-0410	Cement
Chem Nuclear	Bellevue WA	Shel Wooddle/ Dan Lauriens	(206)827-0711	Urea-formaldehyde, cement, Dow polymer
IUCS	Horsham PA	Steve Getwiler	(215)441-5920	Fly ash and lime (Poz-O-Tec or Poz-O-Pac)

CONTACTS WITH POSSIBLE SUPPLIERS (contd)

<u>Company Name</u>	<u>Location</u>	<u>Contact</u>	<u>Phone</u>	<u>Process Type</u>
Stablex	Radnor PA	Susan West	(215)688-3131	Fly ash, lime, cement dust (Sealosafe)
Chemfix	Kenner LA	George Lane	(504)729-4561	Silicate and cement
Newport News Industrial	Newport News VA	Gary Prater	(804)380-3084	Thermoplastic
Chevron	San Francisco CA	Jim Paulson	(415)894-0400	Sucoat (sulfur)
Hittman Nuclear	Columbia MD	Dave Dimmick	(301)730-7800	FSSC, cement
Aerojet	Sacramento CA	Frank Ulbrich	(916)355-2933	Volume reduction, Dow polymer, cement
Rockwell	Canoga Park CA	Lcu Cooper	(213)341-2485	Molten salt incineration
SRI	San Antonio TX	Allen Ludwig	(512)684-5111	Sulfex research (sulfur)
Penberthy Electromelt	Seattle WA	Dennis Hotaling	(206)762-4244	Glass
Environmental Protection Polymers	Hawthorne CA	H. R. Lubowitz	(213)675-3555	Surface encapsulation
Werner & Pfleiderer	Waldwick NJ	Dick Doyle	(201)327-6300	Asphalt
Enviro Energy Systems	Toledo OH	Jim Thomas	(419)535-6374	Flyash and cement or lime kiln dust

OTHER CONTACTS
(Informational)

Company Name	Location	Contact	Phone	Process Type
U.S. Army Waterways Experiment Station	Vicksburg MS	Philip Malone	(601)634-3960	ASTM Committee on hazardous wastes
Stablex Corp	Radnor PA	Steve Taub	(215)688-3131	ASTM Subcommittee on fixation of Hazardous wastes
Waldes-Kohinoor. Tru-Plate Div.	Long Island City NY	Alan Brooks	(212)392-3100	Plating wastes
Stone & Webster	Boston MA	Bruce McCampbell	(617)973-2446	Architect & engineer
Engineering Science	Berwyn PA	B. Charles Malley	(215)644-4200	Consultant
Manchak Environment	Santa Barbara CA	Frank Manchak	(805)963-3731	Consultant
Gene Kausman & Assoc.	Bel Air TX	Gene Kausman	(713)774-3737	Consultant
Hydrofax	Ambler PA	Mike Marino	(215)628-1201	Consultant
Southern California Edison Co.	Los Angeles CA	Carlos Alcaino	(213)572-1638	Metal cleaning waste treatment and disposal
Tennessee Valley Authority	Chattanooga TN	Gerald R. Steiner	(615)755-3173	Metal cleaning waste treatment and disposal
Commonwealth Edison Company	Chicago IL	Al Miscalak	(312)294-4341	Metal cleaning waste treatment and disposal
Environmental Protection Agency	Cincinnati OH	Robert Landreth	(513)684-7876	Fixation processes
Environmental Protection Agency	Research Triangle Park NC	Julian Jones	(919)541-2489	Treatment and disposal of utility wastes
Resources Conservation Company	Seattle WA	Lanny Weimer	(206)828-2466	Disposal of cooling tower blowdown residues
Nalco Chemical Company	Oak Brooks IL	Ken Fulks	(312)887-7500	Disposal of cooling tower blowdown residues
PQ Corp	Lafayette Hills PA	Iris Ailin-Pyzik	(215)825-5000	Company sells silica products