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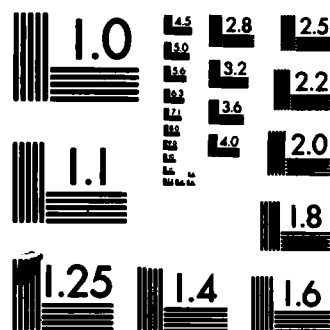
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**AN INVESTIGATION OF TECHNOLOGIES FOR  
HAZARDOUS SLUDGE REDUCTION AT AFLC  
INDUSTRIAL WASTE TREATMENT PLANTS  
VOLUME I: Sodium Borohydride Treatment  
and Sludge Handling Technologies**

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Hazardous waste disposal costs have risen dramatically in recent years, making the volume of sludge generated by industrial waste treatment nearly as important as the quality of the effluent water. Because of the magnitude of the Air Force's aircraft maintenance mission, over a billion gallons of mixed industrial wastewater require treatment each year. The result of this operation is tens of thousands of tons of hazardous sludge requiring disposal. This project was initiated to examine treatment technologies that could reduce this sludge disposal burden. In addition to volume, factors such as operator (continued)		

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20. ABSTRACT (continued).

expertise required, system operating and maintenance costs, and the ability of a given technology to treat a mixed industrial waste stream were considered. Available technologies were first screened from literature and then those deemed most promising were subjected to laboratory scale testing. The results of the literature search, laboratory testing, and a contractor suggested R&D program direction are reported in three volumes, as follows:

VOLUME I: Sodium Borohydride Treatment and Sludge Handling Technologies volume reports on the laboratory scale testing results of all treatment technologies and some innovative sludge treatment methods. Sodium borohydride was the selected technology because not only is this technique capable of reducing the sludge volume by nearly 75 percent, the effluent water quality is better than can be achieved with the standard treatment methods.

VOLUME II: Literature Review of Available Technologies for Treatment Heavy Metal Wastewaters contains a comprehensive review of treatment methods ranging from laboratory scale to commercially available techniques. All technologies are related to a standard wastewater treatment method, namely, acidic reduction of chromium and lime precipitation.

VOLUME III: Heavy Metal Waste Treatment Research and Development Needs was based on a survey of Navy electroplating and waste treatment facilities, but encompasses both ongoing and planned research projects among all three major service branches. By extending the project to other than strictly Air Force facilities, the contractor was able to suggest a coordinated R&D program eliminating redundancy among the three branches.

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## PREFACE

This document was prepared by CENTEC Corporation, Reston, Virginia, under Contract No. 086-35-81-C-0258 for the Air Force Engineering and Services Center Air Force Engineering and Services Laboratory (ESL).

The objective was to develop treatment techniques for reducing the volume and toxicity of hazardous heavy metal sludges generated at Air Force Logistics Command (AFLC) Industrial Waste Treatment Plants (IWTP). The research performed between August 1981 and August 1983 included five major tasks: literature review, AF sludge characterization, metal removal studies, sludge treatment studies, and preparation of preliminary designs. First Lieutenant James Aldrich was the RDV Project Officer.

This technical report has been reviewed by the Public Affairs Office (PA) and is releasable to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication.

  
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## SECTION I

### INTRODUCTION

#### A. GENERAL

Electroplating processes employed at Air Force Logistics Command Air Logistics Centers (ALCs) generate wastewaters that require treatment to remove cyanide, toxic metals, and oil and grease before their discharge into AF sanitary waste treatment systems, public-owned treatment works (POTWs), or receiving streams. The pretreatment processes used at ALCs concentrate most of the pollutants from the plating operation into a sludge. These sludges contain toxic metals from the plating operation and chemicals used in the treatment process. The U.S. Environmental Protection Agency (EPA) has classified electroplating wastewater treatment sludges as hazardous wastes (Reference 1). As such, the storage, transportation, and disposal of these sludges are regulated under the Resource Conservation and Recovery Act (RCRA). The strict regulation of these sludges has significantly increased the overall treatment costs of electroplating wastes. In particular, hauling/disposal costs have increased from \$8 to \$15 per ton to between \$58 and \$117 per ton (Reference 2).

Wastewater treatment sludges from electroplating are classified as hazardous wastes because they usually contain cadmium, chromium, and nickel. These metals often leach from sludges subjected to the aqueous, acidic environments found in many sanitary landfills.

To determine the leachability of hazardous wastes, EPA has adopted a test procedure to simulate conditions of disposal in such environments. This test is referred to as the Extraction Procedure (EP). During the test, a measured sample of waste is placed in distilled water, acid is added, and the mixture is agitated for 24 hours. The aqueous portion of the mixture is then tested for toxic constituents to determine the extent of leaching. The results of the analysis are then compared to a set of standards to determine if the sludge leached toxic amounts of metals.

If leachate metal concentrations are below the EPA standards, the sludge may be reclassified as nonhazardous if the results are consistent, with a reasonable margin of safety. This would allow the generator of the sludge to dispose of the waste via methods approved for nonhazardous wastes. EPA has set forth a delisting procedure whereby generators of sludges can petition for this reclassified status.

It has been demonstrated that the leachability of electroplating treatment sludge is highly variable (Reference 1). The major factors affecting leaching are the type and concentration of metals in the sludge, the amount of free and interstitial wastewater present in the sludge, and the final pH of the aqueous solution used in the EP test. The sludges from ALCs have shown a tendency to leach chromium and cadmium, therefore disqualifying them from delisting.

The major focus of this project is to reduce sludge disposal costs. This goal can be achieved by use of treatment techniques which reduce the leachability of the toxic metal sludges from the ALC Industrial Waste Treatment Plants (IWTP) to a point which would allow ultimate disposal via methods approved for nonhazardous wastes and by use of sludge volume reduction technologies.

## B. PROJECT SCOPE

This project consisted of 5 tasks conducted over a 2-year period. Task I was a comprehensive literature review to establish the current processes for removing dissolved metals from industrial wastewaters and subsequently separating these metals from mixed-metal sludges. In Task II the sludges generated at the Air Force IWTPs were characterized using the EP test. This provided baseline data on the hazardous nature of these sludges. Task III focused on reducing the dry weight of solids generated during the metals precipitation process by investigating innovative precipitation chemicals and methods. Task IV was to develop sludge treatment techniques to reduce the leachability of toxic metals. In addition, a portion of the Task IV effort was devoted to investigating methods of separating and recovering metals from the mixed metal sludges. Task V was directed at developing basic design and cost data for prototype systems that employ the most promising methods developed under Tasks III and IV.

## C. EXPERIMENTAL PROCEDURES

Experiments conducted during this study can be characterized as bench-scale tests. Laboratory equipment was used to perform precipitation studies and to simulate other treatment processes. Actual treatment equipment or pilot-scale units were not employed.

The experiments were conducted with both contrived and actual wastes. The formulation of the contrived wastes was based on data from analytical tests of actual wastewaters and sludges and on waste-stream characterization data supplied by the five ALCs. The contrived wastewaters were prepared using reagent grade chemicals and deionized water.

TABLE 1. AIR FORCE STUDY CHEMICAL AND EQUIPMENT LIST

Chemicals

Chromium nitrate- $\text{Cr}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ , Certified Fisher  
Cadmium nitrate- $\text{Cd}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$ , Mallinkrodt Crystals  
Ferrous sulfate- $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ , Certified ACS Fisher  
Nickel nitrate- $\text{Ni}(\text{NO}_3)_2 \cdot \text{H}_2\text{O}$ , Fisher  
Cupric sulfate- $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ , Certified ACS Fisher  
Sodium Bicarbonate- $\text{NaHCO}_3$ , Certified ACS Fisher  
NaOH-Certified ACS Electrolytic Pellets, Fisher  
CaO-Industrial Grade, Barrick Hydrated Lime  
 $\text{NaBH}_4$ -Thiokol-Ventron, 12% in caustic  
Acetic Acid-(Glacial) 99.7%, Fisher  
Ammonium Chloride- $\text{NH}_4\text{Cl}$ , Certified ACS Fisher

Equipment

EP Stirring Apparatus - Dayton 0.1 HP, AC-DC Motor, Model 2M037A  
connected to Staco Type 3PN1010 Variable Transformer with  
Polypropylene Stirring Rod  
Phipps & Byrd Six-Paddle Stirrer-Model 300  
Millipore Stainless Steel Hazardous Waste Pressure Filtration  
Device, Teflon<sup>®</sup>-coated  
Perkin-Elmer Model 306 Atomic Absorption Spectrophotometer  
Fisher/Ainsworth Model 2400 Top-loading Balance  
Mettler Model H34 Analytical Balance (good to 0.1 mg)  
Corning Model 6104 pH Meter  
Millipore Type HA 0.45  $\mu\text{m}$  (micron) Methyl Cellulose Fiber  
Filters  
Millipore Type AP Prefilter  
Nitrogen Gas-Industrial Grade, Air Products  
Cyanamid Magnifloc<sup>®</sup> 836A Flocculant  
Sludge Barrel - Advanced Chemical Technology Poly Drum -  
A10B 25 gallon



## SECTION II

### ENABLING REGULATIONS

The industrial waste treatment operations at ALCs are governed by both wastewater and hazardous waste regulations. Present wastewater regulations are a result of the Clean Water Act of 1977 (Public Law 92-217), which amended the Federal Water Pollution Control Act of 1972. The Clean Water Act required industrial waste generators to install base-level pollution control technology by July 1, 1977 and more stringent treatment by July 1, 1984. The base-level technology is called Best Practicable Control Technology Currently Available (BPCTCA), or simply BPT. The more stringent level was termed the Best Available Technology Economically Achievable (BATEA) and is usually referred to as BAT. By 1984, EPA must also develop limitations for conventional pollutants, i.e., pH, total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and oils and greases. These limitations are to be based on the Best Conventional Pollutant Control Technology Available (BCPCTA), or simply BCT. Both BPT and BAT regulations have been developed by EPA on an industry-by-industry basis. The industrial regulations most applicable to ALC activities are the metal-finishing regulations. For this industry, BPT and BAT regulations are identical (Table 2).

TABLE 2. BPT AND BAT EFFLUENT REGULATIONS\*

<u>Pollutant</u>	<u>Maximum for Any 1 Day mg/l</u>	<u>Average of daily Values for 30 Consecutive Days (mg/l)</u>
Cadmium	0.69	0.26
Chromium (Total)	2.77	1.71
Copper	3.38	2.07
Lead	0.69	0.43
Nickel	3.98	2.38
Silver	0.43	0.24
Zinc	2.61	1.48
Cyanide	1.20	0.65
Total Toxic Organics	2.13	--

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\* Federal Register Vol. 48, No. 137, July 15, 1983.

Although the BPT and BAT standards were intended for national compliance, regardless of location, they are actually minimum standards. If the BPT pollution control techniques are inadequate to meet the established water quality standards for a stream, both EPA and the States are required to impose stricter pollution control requirements. As an example of more stringent state standards, the discharge requirements for McClellan AFB are presented in Table 3.

The individual discharge permits for each ALC are issued by state agencies, under authority of the National Pollutant Discharge Elimination System (NPDES). (If states do not have NPDES authority, the Regional EPA office issues permits.) Present ALC effluent limitations set by NPDES permits currently represent BAT or slightly lower effluent levels and will extend through June 30, 1984. At that time the permits will be reviewed to determine if more stringent requirements are necessary to protect local receiving waters.

Regulations governing hazardous wastes are a result of the Resource Conservation and Recovery Act (RCRA), 1976 (Public Law 94-580). RCRA hazardous waste regulations are designed to manage and control the country's hazardous wastes from generation to final disposal.

The RCRA regulations differ from water pollution regulations in that all industries that generate, store, haul, or dispose of hazardous waste must comply with these rules, while water pollution regulations vary according to specific industry; e.g., metal finishing.

Under RCRA, EPA has set strict definitions for hazardous waste. Some wastes, such as electroplating wastewater treatment sludge, are specifically listed as hazardous (Table 4). For other wastes, the EPA has established criteria that determine if the waste is hazardous (Table 5). If a waste is hazardous, it must be stored, transported, and disposed of in accordance with RCRA hazardous waste regulations.

RCRA includes a delisting procedure for excluding generically classified hazardous wastes from regulation. The major advantage of delisting is in disposal cost; the waste can be disposed of in a nonhazardous landfill.

Since the AF sludges are listed as hazardous, the delisting process is of major interest to this project. If technologies can be developed to render these wastes nonhazardous, they can be delisted and the overall cost of sludge handling at ALCs can be reduced.

EPA has received a substantial number of delisting petitions (350 by 1982), with approximately 150 approved. The majority of the approved petitions were for electroplating and metal-finishing wastes and in particular sludges from waste treatment.

TABLE 3. NPDES EFFLUENT LIMITATIONS FOR McCLELLAN AFB

<u>Pollutant</u>	<u>Maximum for Any 1 Day mg/l</u>	<u>Average of daily Values for 30 Consecutive Days (mg/l)</u>
Cadmium	0.2	0.1
Chromium (Total)	1.0	0.5
Chromium (Hex)	0.1	0.05
Copper	1.0	0.5
Lead	0.1	0.05
Nickel	1.0	0.5
Silver	0.1	0.05
Zinc	1.0	0.5
Cyanide (Total)	1.0	0.5
Cyanide (Amenable)	0.1	0.05
Total Suspended Solids	60	30
Phenol	0.2	0.1
Settleable Solids	0.2	0.1
Oil and Grease	15	10

**TABLE 4. RCRA HAZARDOUS WASTES GENERATED BY ELECTROPLATING OPERATIONS**

<b>EPA Hazardous Waste Number</b>	<b>Hazardous Waste</b>
F006	Wastewater treatment sludges from electroplating operations
F007	Spent plating bath solutions from electroplating operations
F008	Plating bath sludges from the bottom of plating baths from electroplating operations
F009	Spent stripping and cleaning bath solutions from electroplating operations

**TABLE 5. RCRA HAZARDOUS CRITERIA FOR EVALUATING SOLID WASTES**

<b>Criterion</b>	<b>Characteristics</b>
Ignitability	<p>Waste is liquid with a flash point less than 140°F.</p> <p>Waste is solid that burns vigorously and persistently when ignited.</p> <p>Waste is ignitable compressed gas.</p>
Corrosivity	<p>pH is less than or equal to 2.</p> <p>pH is greater than or equal to 12.5.</p> <p>Waste is highly corrosive to steel.</p>
Reactivity	<p>Substance is unstable and readily undergoes violent changes without detonating.</p> <p>Substance reacts violently in water.</p> <p>Waste forms potentially explosive mixtures with water.</p> <p>Material generates toxic gases when mixed with water.</p> <p>Waste contains cyanide or sulfide.</p>
Toxicity	<p>Waste fails the Extraction Procedure (EP) test for toxicity.</p>

EPA can delegate RCRA authority to individual states provided they meet a set of standards and request the authority. Thirty-four states now have interim authorization. When a delisting petition is received by EPA from a generator in an authorized state, the petition is sent to the state for processing. One exception under this rule is when the waste will be transported across state boundaries to an unauthorized state. In this case, EPA processes the delisting petition.

To prepare a delisting petition, the waste generator must collect and analyze representative samples of the waste. A minimum of four samples is required. The analytical tests must include all parameters for which the waste was listed as hazardous. For metal-finishing waste treatment sludges, this rule requires that the EP toxicity test and a metals analysis be performed. Aside from the analytical data, petitions must include the following: (1) amounts of waste generated, (2) operation or process which produced the waste, (3) disposal scenario, (4) sampling methodology, (5) analytical methods performed, and (6) a reproduction of the statement certifying that the information is true and accurate.

EPA deals specifically with several delisting situations. One of these covers stabilized wastes. Fearing that the extraction procedure test will not adequately determine whether or not stabilized wastes will resist environmental weathering over long periods of time, EPA officials have recently developed a multiple-extraction test in which the waste must be ground to a fine powder (100 mesh) and then extracted a total of 10 times, using an acid-rain mixture for nine of the extractions. If analysis of the leachate shows a continuing increase in waste concentration, then the probability of delisting is small. Low constituent concentrations in each successive extraction indicate environmental stability over long periods of time. At least one firm which stabilize wastes, including electroplating waste treatment sludge, has received approval for a delisting petition (Reference 3).

Additional information or procedures for delisting electroplating sludge are presented in Appendix A.

### SECTION III

#### LITERATURE SURVEY

The initial task of this project involved a comprehensive literature review. The objective was to establish the current state of technologies for both removing dissolved metals from industrial wastewaters with minimal generation of hazardous sludges and for separating heavy metals from wastewater sludges. Information regarding process descriptions, economics, advantages, and disadvantages was collected. The review focused on literature from 1975 through 1981 and used existing literature searches for related topics, in addition to government reports, patents, professional journals, trade journals, and new technology advertising.

The literature survey produced a list of 31 technologies for removing dissolved metals from wastewater and recycling or neutralizing process residuals. A comprehensive report, under the title "Literature Review, Hazardous Sludge Reduction," Feb. 82, was prepared which describes each technology, presents abstracts of the most relevant articles (141 abstracts), and contains a bibliography (222 additional articles) and a list of applicable patents (40 patents). A summary describing the technologies identified in the literature search is presented in Table 6.

TABLE 6. SUMMARY OF TECHNOLOGIES IDENTIFIED DURING LITERATURE SEARCH

Process	State of Technology	Economics	Major Advantages/Disadvantages
Acidification volatilization for cyanide removal	Laboratory scale in 1971. No further efforts underway.	Considered inefficient and costly	Advantages: o None found Disadvantage: o Further treatment of adsorbent liquid required
Aldehyde treatment	Approximately 40 instal- lations, most applications with zinc or cadmium.	Capital cost is relatively low while operating cost (chemicals) is higher than conventional treatment.	Advantages: o Easy operation o Improved filterability and dewatering of sludge Disadvantages: o Danger of entrainment of insoluble metal- cyanides in sludge o Process effluent contains organics
Alkaline chlorination for CN destruction	Most widely used method for CN destruction.	Relatively low equipment and operating costs.	Advantages: o Well proven and reliable o Easily automated Disadvantage: o Uses toxic reagents (e.g., Cl <sub>2</sub> )
Barium compounds for precipitation of hexavalent chromium	Laboratory scale only. No known electroplating applications.	Operating costs assumed to be high because of toxic nature of sludge.	Advantage: o Chromium reduction step unnecessary Disadvantage: o Produces toxic sludge
Carbon adsorption for CN and metals removal	Tested on laboratory and pilot scale.	Capital cost is relatively low. Operating cost is high from need to regenerate carbon and disposal of regeneration solutions.	Advantages: o None found Disadvantage: o Treatment of regenerate required
Catalytic treatment to aid precipitation	Laboratory testing only.	No economic information available.	Advantage: o Metal recovery possible Disadvantage: o Does not recover all metals

TABLE 6. SUMMARY OF TECHNOLOGIES IDENTIFIED DURING LITERATURE SEARCH (CONTINUED)

Process	State of Technology	Economics	Major Advantages/Disadvantages
Cementation	Used w/ores and precious metal recovery. Bench scale only for waste-water application.	No economic information available.	<p>Advantage:</p> <ul style="list-style-type: none"> <li>o Ability to separate noble metals from mixed metal sludges</li> </ul> <p>Disadvantages:</p> <ul style="list-style-type: none"> <li>o Recovered water contains nonmetallic impurities</li> <li>o Slow reaction rate</li> </ul>
Sodium metabisulfite from chromium reduction	Widely used by industry.	Capital and operating costs are relatively low.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o Process is easily automated</li> <li>o Does not produce sludge</li> </ul> <p>Disadvantages:</p> <ul style="list-style-type: none"> <li>o Process can evolve SO<sub>2</sub></li> <li>o Reaction must be performed at low pH</li> </ul>
Dialysis	Demonstrated on plant scale. No commercial units available.	Capital costs are expected to be relatively high. Operating cost is low.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o Does not produce sludge</li> <li>o Recovers chemicals and water</li> <li>o Low energy consumption</li> </ul> <p>Disadvantages:</p> <ul style="list-style-type: none"> <li>o Waste streams must be segregated</li> <li>o Process susceptible to impurity build-up</li> <li>o Membrane easily fouled by solids</li> </ul>
Electrochemical treatment for metal recovery and cyanide oxidation	Many units (20-50) operating in industry, mostly for cadmium recovery.	Capital costs vary depending on sophistication of system. Operating costs are relatively low.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o Commercial units available for simultaneous CN oxidation and metal removal</li> <li>o No treatment chemicals required for process</li> <li>o Process does not increase TDS</li> </ul> <p>Disadvantage:</p> <ul style="list-style-type: none"> <li>o Commercial units limited to certain metals</li> </ul>
Evaporation	Commercially available for recovery of plating chemicals.	Capital cost is moderate. Operating cost is relatively high due to energy intensiveness of process.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o Applicable to most plating baths</li> <li>o Recovers chemicals and water</li> </ul> <p>Disadvantages:</p> <ul style="list-style-type: none"> <li>o High energy use</li> <li>o Concentrates impurities or contaminants</li> </ul>
Extraction (liquid-liquid and solid-liquid)	Commercial applications in Europe to recover metals from nonplating wastes.	No economic information available.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o Metals may be selectively recovered</li> <li>o Extraction reagents can be regenerated and reused</li> <li>o Good recovery efficiencies are possible</li> </ul> <p>Disadvantages:</p> <ul style="list-style-type: none"> <li>o Extensive pH control required</li> <li>o Extraction reagents are expensive</li> <li>o Electrodeposition is required after extraction step</li> </ul>



TABLE 6. SUMMARY OF TECHNOLOGIES IDENTIFIED DURING LITERATURE SEARCH (CONTINUED)

Process	State of Technology	Economics	Major Advantages/Disadvantages
Foam (ion) Flotation	Demonstrated on laboratory and pilot scale w/ electroplating wastes. Commonly used in refining industry for separation of ores.	The process itself is moderate in cost. However, further treatment of processed solution is required that may be costly.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o Process does not require segregated waste streams</li> </ul> <p>Disadvantages:</p> <ul style="list-style-type: none"> <li>o Further treatment required after flotation</li> <li>o Process is not effective for all ions of interest</li> </ul>
Freezing	Demonstration has reached pilot scale; no commercial demonstration	Not determined	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o Lower energy cost than evaporation</li> </ul> <p>Disadvantages:</p> <ul style="list-style-type: none"> <li>o Separation effectiveness is questionable</li> <li>o Material handling problems are significant</li> </ul>
Heat treatment of sludge	Demonstrated on a laboratory scale.	Capital cost of equipment is relatively high. Operating cost is high due to energy intensiveness of process.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o Hazardous characteristics of sludge and sludge volume can be simultaneously reduced</li> </ul> <p>Disadvantages:</p> <ul style="list-style-type: none"> <li>o No resource recovery is practiced</li> </ul>
High Surface Area (HSA) Electrochemical Reactor	Commercially available for recovery of Cd, Cu and Zn.	Capital and operating costs can be less than conventional treatment.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o No sludge is produced</li> <li>o Metals are recovered for reuse</li> <li>o Modular construction allows for easy installation</li> </ul> <p>Disadvantages:</p> <ul style="list-style-type: none"> <li>o Requires segregated waste streams</li> <li>o Only applicable to several metals</li> </ul>
Hydrolysis for cyanide oxidation	Demonstrated on laboratory and pilot scale. Large scale demonstration is planned.	Capital and operating costs will probably be similar to alkali chlorination process.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o Avoids use of chlorine gas - a poisonous chemical</li> </ul> <p>Disadvantages:</p> <ul style="list-style-type: none"> <li>o Process is energy intensive</li> <li>o Process requires high temperature and pressure equipment</li> </ul>

TABLE 6. SUMMARY OF TECHNOLOGIES IDENTIFIED DURING LITERATURE SEARCH (CONTINUED)

Process	State of Technology	Economics	Major Advantages/Disadvantages
Hydroxide precipitation	This process is considered as the conventional technology because of its wide use.	As the conventional technology the process is considered the basis for evaluating other technologies.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o Adaptable to most treatment situations</li> <li>o Well suited to automation</li> <li>o Uses inexpensive treatment reagents</li> </ul> <p>Disadvantages:</p> <ul style="list-style-type: none"> <li>o Creates a hazardous sludge that is difficult to dewater</li> <li>o Chelating compounds interfere with process</li> <li>o Cannot consistently remove metals below 1 mg/l</li> </ul>
Insoluble Starch Xanthate (ISX)	A substantial amount of research has been performed during past 8 yrs. Process is now commercially available for plating wastes.	Capital cost is similar to conventional treatment. Operating cost may be lower than conventional because of small reagent requirements.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o Metals are precipitated in recoverable form</li> <li>o Short reaction times are required</li> <li>o Precipitate settles rapidly</li> <li>o Process can remove complexed ions</li> </ul> <p>Disadvantages:</p> <ul style="list-style-type: none"> <li>o Reagents are expensive and perishable</li> <li>o Metal recovery requires segregated waste streams</li> <li>o Sludge contains organics and may be unsuitable for some landfills</li> </ul>
Ion Exchange (IX)	Many commercial installations in the electroplating industry.	A combined ion exchange/conventional system can be less expensive (capital) than just conventional. Operating cost is moderately high.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o In some applications process can recover both metals and water</li> </ul> <p>Disadvantage:</p> <ul style="list-style-type: none"> <li>o IX resins can be destroyed or fouled during operation</li> </ul>

TABLE 6. SUMMARY OF TECHNOLOGIES IDENTIFIED DURING LITERATURE SEARCH (CONTINUED)

Process	State of Technology	Economics	Major Advantages/Disadvantages
Iron Compounds for chromium reduction	Commercial processes are available.	Capital cost is similar to conventional treatment. Operating cost is usually higher due to increased sludge production.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o Can be employed w/ sulfide precipitation to simultaneously treat Cr<sup>+6</sup> and precipitate metals</li> <li>o Can reach lower effluent concentrations than conventional treatment</li> </ul> <p>Disadvantage:</p> <ul style="list-style-type: none"> <li>o High sludge generation</li> </ul>
Membrane technologies	Some types of membrane technologies are commercially available.	Process is economically proven for certain metals such as chromium.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o Minimal amount of sludge is produced</li> <li>o Allows for recovery of metals</li> <li>o No treatment reagents are required</li> </ul> <p>Disadvantages:</p> <ul style="list-style-type: none"> <li>o Limited application</li> <li>o Significant maintenance required</li> </ul>
Ozonation for cyanide oxidation	Full scale demonstration system in plating shop.	Capital cost is high due to price of ozone generator. Operating cost is low.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o May aid in the precipitation of certain metals and in dewaterability of sludge</li> <li>o Eliminates use of toxic chemicals for cyanide destruction</li> <li>o pH control is unnecessary</li> <li>o Effective w/ ferrocyanide complexes</li> </ul> <p>Disadvantages:</p> <ul style="list-style-type: none"> <li>o Possible ozone emission</li> <li>o Stable cyanide complexes may require UV radiation treatment</li> </ul>
Pyrolytic techniques for sludge decomposition	Process has been applied to many types of organic/inorganic sludge mixtures.	Capital cost is high. Operating cost is significant but can be reduced by savings in energy recovery and reduced sludge hauling.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o Reduces sludge volume</li> <li>o Renders organic sludges inert</li> </ul> <p>Disadvantages:</p> <ul style="list-style-type: none"> <li>o Energy intensive process</li> <li>o Feed material must be 25% (minimum) organic</li> </ul>

TABLE 6. SUMMARY OF TECHNOLOGIES IDENTIFIED DURING LITERATURE SEARCH (CONTINUED)

Process	State of Technology	Economics	Major Advantages/Disadvantages
Reverse osmosis (RO)	Commercial units available for plating waste streams.	Capital cost is moderate. Operating cost is low except where membrane replacement is frequent.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o Recovers metals and recycles water</li> <li>o No sludge is produced</li> <li>o Low energy consumption</li> </ul> <p>Disadvantage:</p> <ul style="list-style-type: none"> <li>o Requires segregated waste streams</li> </ul>
Use of separation for chromium reduction	Process is in theoretical stage. No tests have been performed.	Low capital cost expected. Operating cost projected to be 50% of conventional.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o None found</li> </ul> <p>Disadvantages:</p> <ul style="list-style-type: none"> <li>o No existing reliable source for materials of treatment</li> <li>o Long reaction times expected</li> </ul>
Sludge aging	Only bench scale testing has been performed.	Capital cost is moderately high. Operating cost is fairly low.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o Sludge volume and toxicity are simultaneously reduced by the natural drying process</li> </ul> <p>Disadvantage:</p> <ul style="list-style-type: none"> <li>o Requires large amount of space</li> </ul>
Sodium borohydride precipitation process	Process successfully applied on full scale but at a limited number of installations.	Capital cost is higher than conventional treatment. Operating cost is high due to cost of chemical ( $\text{NaBH}_4$ ).	<p>Advantage:</p> <ul style="list-style-type: none"> <li>o Can remove metals to levels below conventional technology</li> </ul> <p>Disadvantage:</p> <ul style="list-style-type: none"> <li>o Reduces sludge volume</li> </ul> <p>Disadvantage:</p> <ul style="list-style-type: none"> <li>o Performance on mixed metal solutions has not been generated</li> <li>o Process evolves hydrogen gas</li> </ul>
Sulfide precipitation	Several full scale systems are in operation.	Capital cost is similar to conventional treatment. Operating cost is moderately high.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o Produces a higher quality effluent than conventional</li> <li>o Process can treat wastewater containing chelating agents</li> <li>o Process simultaneously reduces chromium</li> </ul> <p>Disadvantage:</p> <ul style="list-style-type: none"> <li>o Increased sludge production</li> </ul>

TABLE 6. SUMMARY OF TECHNOLOGIES IDENTIFIED DURING LITERATURE SEARCH (CONCLUDED)

Process	State of Technology	Economics	Major Advantages/Disadvantages
Ultrafiltration	Equipment is commercially available. No applications known for plating wastes.	Capital cost is moderate. Operating cost may be high due to replacement of membranes.	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o Allows for recycle of water</li> <li>o Produced a higher quality effluent than conventional treatment</li> </ul> <p>Disadvantage:</p> <ul style="list-style-type: none"> <li>o High maintenance expected</li> </ul>
Waste - plus - waste precipitation	Demonstrated successfully in laboratory. No full scale installations.	Capital cost is similar to conventional treatment. Operating cost is low since no reagents	<p>Advantages:</p> <ul style="list-style-type: none"> <li>o A small amount of sludge is produced</li> </ul> <p>Disadvantages:</p> <ul style="list-style-type: none"> <li>o Process will evolve hydrogen cyanide (HCN) gas</li> </ul>

## SECTION IV

### SLUDGE CHARACTERIZATION

#### A. INTRODUCTION

Task 2 of this project was directed at characterizing the sludges currently generated at ALC IWTPs in terms of their metal content and toxicity. These sludges are generated by hydroxide precipitation of heavy metals contained in wastewaters and spent process solutions discharged from plating operations.

The volume of sludge produced and its characteristics are dependent upon several key variables involving the raw waste and the treatment process. Information and data relating to these variables for each IWTP were collected during the project. The available information and data are presented and discussed in this section.

To determine the characteristics of sludges produced at the IWTP, two sludges were analyzed from each of the five IWTP. The sludges were analyzed for metals and other parameters and each was subjected to the EP to determine if the sludges leached hazardous amounts of metals. The results of the sludge characterization study are presented and discussed in this section.

#### B. FACTORS AFFECTING SLUDGE VOLUME AND CHARACTERISTICS

A wide variability exists between waste treatment sludges generated at different electroplating facilities (Reference 1), even though most facilities use a metal hydroxide precipitation process. The variability can be attributed to several inter-related factors:

- Wastewater volume and characteristics
- Type of treatment chemicals
- Treatment chemical dosage
- Wastewater treatment equipment
- Solids concentration techniques and equipment

Wastewater volume and characteristics are the primary parameters that determine the type and dosage of treatment chemicals. These factors in turn affect the amount of sludge produced and the sludge characteristics in terms of metal content and toxicity. Formulas have been developed that can be

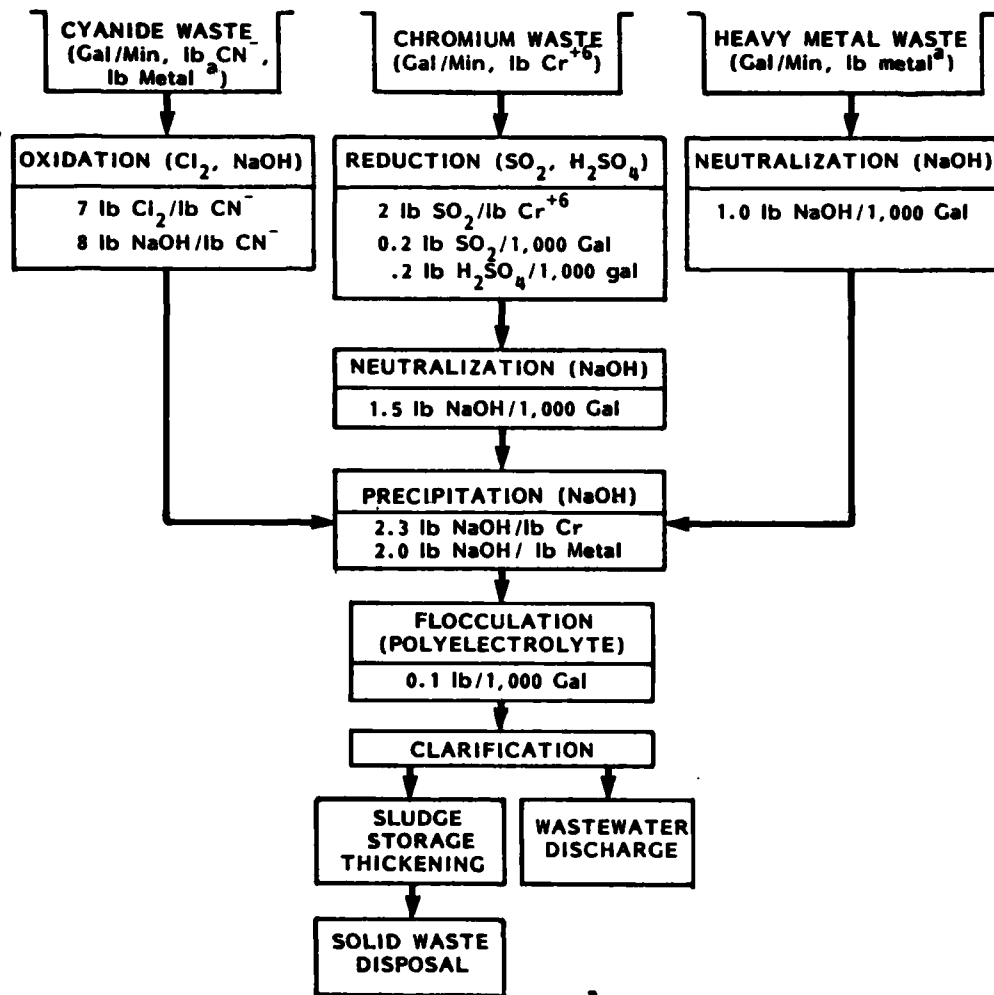
used to estimate the demand for various treatment chemicals and project sludge generation rates (Reference 4). As an example, chemical dosage requirements and sludge production for conventional treatment, using chlorine for cyanide destruction, sulfur dioxide for chromium reduction and sodium hydroxide (caustic) and sulfuric acid for pH adjustment, are presented in Figure 1. These formulas are based on stoichiometric requirements plus conservative allowances for reaction interferences. In actual practice, chemical dosage and sludge generation rates must be determined by experiment, using representative samples of the actual wastewater.

The process illustrated in Figure 1 uses caustic soda for precipitating heavy metals. Other chemicals such as lime, sodium sulfide, ferrous sulfide or sodium borohydride have also been used for precipitation processes. The selection of a precipitating chemical will affect sludge volume and toxicity. In general, caustic soda, sodium sulfide and sodium borohydride processes generate lower amounts of sludge than lime or ferrous sulfide. Lime precipitation, however, as discussed during this project, often produces a sludge which resists leaching and is generally less toxic than caustic soda sludges.

The wastewater treatment process and equipment selected for treating a given wastewater has an effect on the volume of sludge generated. For instance, the chromium reduction unit process can be performed either on a segregated chromium waste stream or on the entire combined waste stream (both processes are observed at AF-ALCs). When the entire waste flow is treated in the reduction process (which is performed at a pH of 2-3), extra acid and caustic soda (or lime) are required to lower the pH for reduction and then raise the pH of the combined volume for precipitation. This results in additional total solids and increases the sludge volume.

Equipment and instrumentation selection also affects sludge production. For instance, chemical feed systems and controls must be properly selected to reduce overdosage of treatment chemicals. These systems are often controlled by flow rate rather than pH or oxidation reduction potential (ORP). When chemicals are added on a flow rate basis, there is no consideration for the variable concentration of pollutants in the wastewater. Since underdosage could result in noncompliance with discharge regulations, the tendency with such systems is to overdose treatment chemicals by a wide margin, thus generating additional sludge.

Solids concentration techniques (thickening and dewatering) affect both the volume and toxicity of sludges. Various methods of solids concentration techniques are applied to electroplating sludges. The objective in each method is to reduce the amount of water in the sludge and, therefore, reduce the sludge volume. The amount of sludge in terms of dry weight is unaffected by dewatering.



<sup>a</sup>Lb Metal expressed in lb metal ion

Figure 1. Consumption Factors for Wastewater Treatment Chemicals



Sludge thickening can produce sludge solids concentrations of 3 to 10 percent and there appears to be little variability between the efficiency of thickening equipment. However, some thickening processes are aided by sludge-conditioning chemicals. On the other hand, the effectiveness of dewatering equipment and techniques is highly variable. The least efficient method--drying beds--may produce a solids content of only 5 percent while pressure filtration equipment can dewater a sludge to more than 50 percent solids (References 2,4).

The dryness of sludge has been shown to affect its toxicity (Reference 1). Sludge is more likely to pass the EP when the majority of water associated with the sludge, termed interstitial water, is removed.

Data and information from the ALC, which relate to the various factors affecting sludge volume and sludge toxicity, were collected during this project and during previous work (Reference 2). A review of the available information and data for each ALC follows.

1. McClellan AFB (SM-ALC)

McClellan AFB is one of two ALCs that have segregated treatment of electroplating wastewaters. The treatment processes for plating rinse waters (Figure 2) include cyanide oxidation, acid/alkali waste neutralization and chromium recovery. The chromium recovery process (Figure 3) is a combination of ion exchange and evaporation. Some problems have been reported with the recovery system such as deteriorating resin capacity which shortens the time between resin regeneration cycles. After preliminary treatment, the acid/alkali and cyanide waste streams are combined with spent regenerate from the ion exchange system and piped to the IWTP (Figure 4). McClellan also has batch treatment for concentrated wastes such as spent solutions and spills.

The average daily flow rate at the IWTP is approximately 490,000 gallons per day (gpd). Available data (Table 7) indicate that the waste received at the IWTP contains fairly dilute concentrations of metals and an undetectable level of cyanide. On the average, 5,500 gal/day chromium waste and 3,800 gal/day cyanide waste are processed in the batch treatment operations (Table 8).

The treatment chemicals used at the IWTP include lime, alum (used as a coagulant), sulfuric acid, sulfur dioxide, and chlorine (used for disinfection). Under consideration is a plan to switch from lime to caustic soda. The switch is expected to reduce sludge generation and cut down on calcium carbonate carryover in the IWTP effluent. The concern over calcium carbonate carryover arose this past year when a practice of effluent reuse was instituted and scaling occurred in cooling towers.

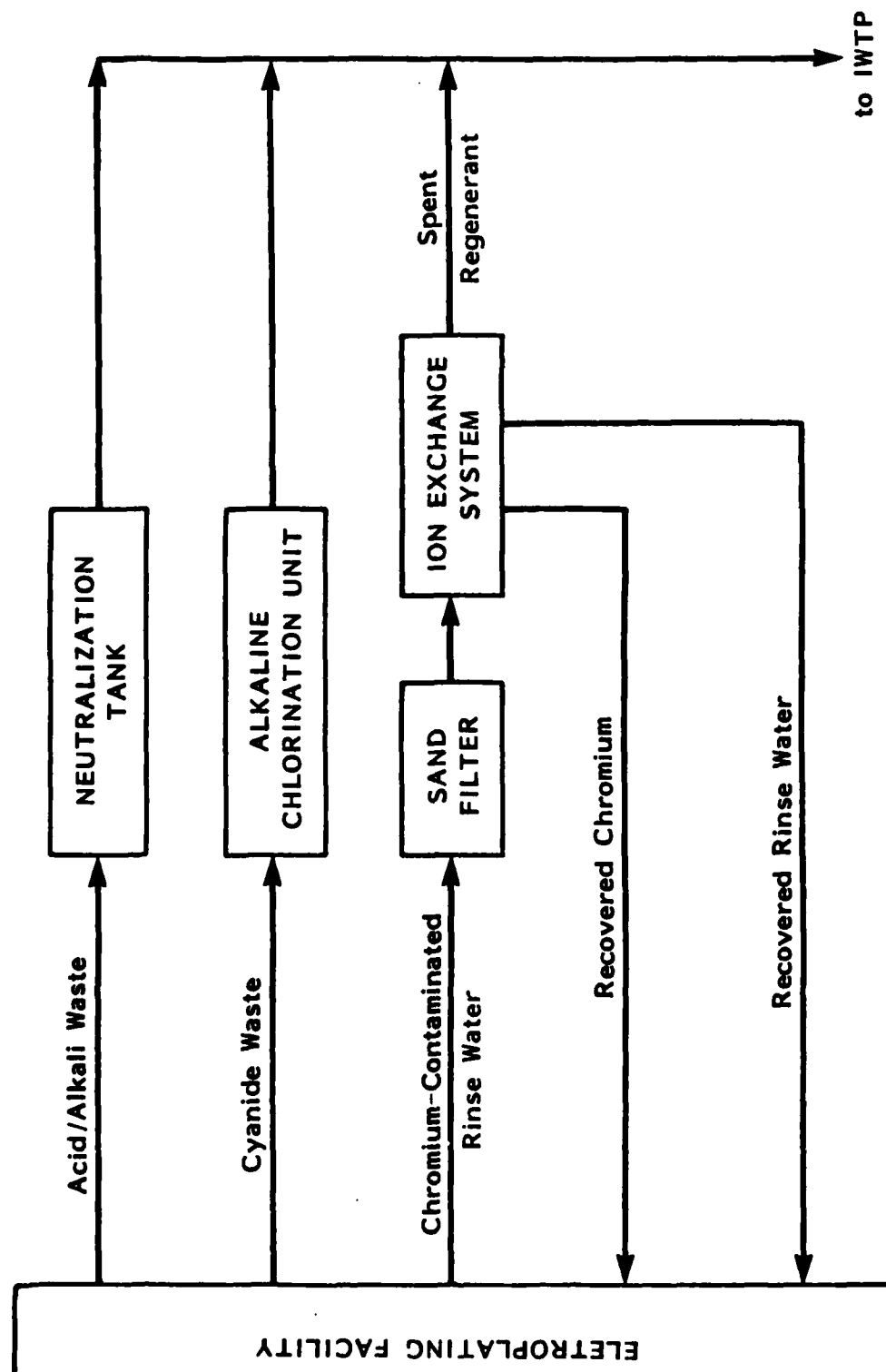


Figure 2. Process Flow Diagram, McClellan AFB Industrial Waste Treatment Plant (Electroplating Shop)

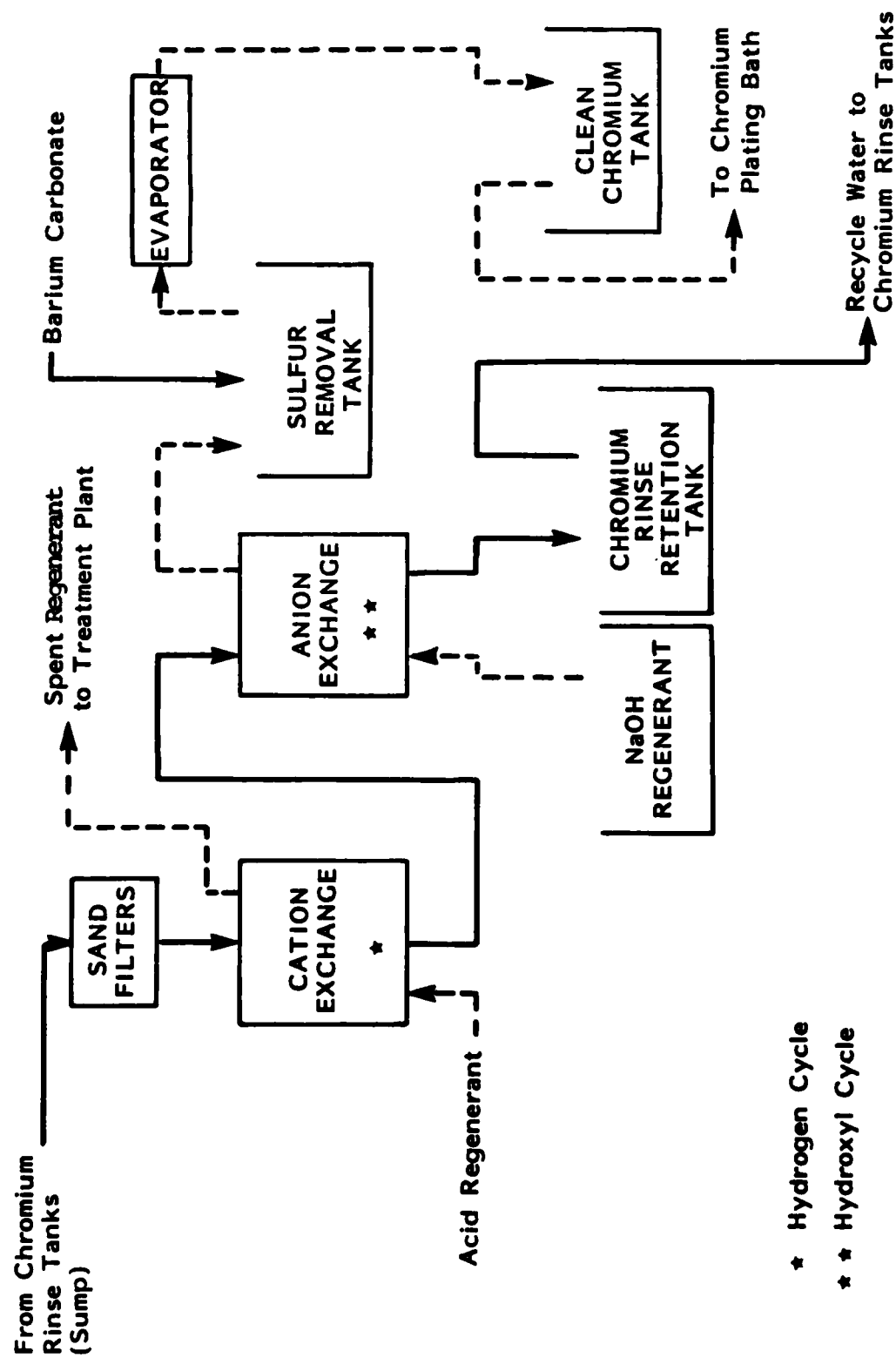


Figure 3. Generalized Schematic of Chromium Recovery at SM-ALC

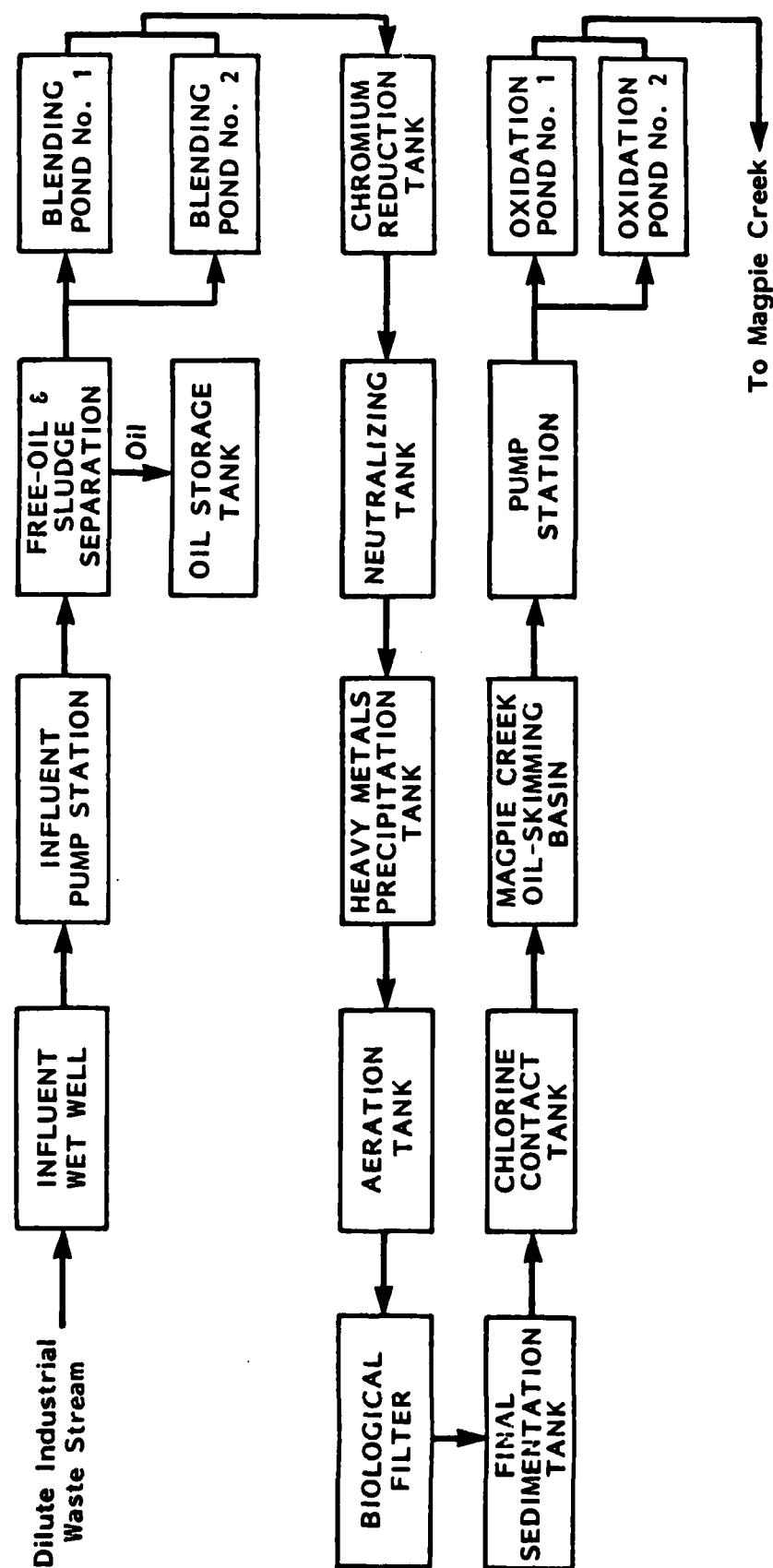


Figure 4. Process Flow Diagram, McClellan AFB Industrial Waste Treatment Plant

TABLE 7. RAW WASTE CHARACTERISTICS, SLUDGE PRODUCTION  
AND CHEMICAL CONSUMPTION AT MCCLELLAN AFB IWTP  
(ELECTROPLATING SHOP)

Month	Flow gal x 10 <sup>-3</sup>	Hex. Total			Lead mg/l	Nickel mg/l	Zinc mg/l	Cyanide mg/l	Total Sludge Hauled gals	Lime lbs	Alum lbs	Acid lbs	SO <sub>2</sub> lbs	Cl <sub>2</sub> lbs	Polymer lbs
		Cadmium mg/l	Copper mg/l	Chrom. mg/l											
1981															
Sept.	14,022	—	.06	.87	1.68	—	—	—	130,000	62,500	7,704	49,135	3,975	1,215	316
Oct.	12,419	—	.14	1.3	2.2	—	—	.05	165,000	45,800	5,820	45,750	3,310	465	294
Nov.	18,028	—	.09	1.6	1.4	—	—	.05	115,000	57,500	9,060	53,250	2,875	220	270
Total	44,469	—	—	—	—	—	—	—	410,000	165,800	22,584	148,135	10,160	1,900	880
Avg.	14,823	—	.02	1.3	1.8	—	—	.05	136,667	55,267	7,528	49,378	3,387	633	293

TABLE 8. BATCH TREATMENT DATA--MCCLELLAN AFB

Month	Chromium					Cyanide						
	Vol. gal	Avg. Conc. mg/l	Reduced lbs. Cr	SO <sub>2</sub> lbs	H <sub>2</sub> SO <sub>4</sub> lbs	Caustic lbs	Sod. Bisulfite lbs	Vol.	Avg. Conc. Destroyed Ing. mg/l lbs. CN	Cl <sub>2</sub> lbs	Caustic lbs	
1981												
Sept.	196,500	448	735	0	327	742	4,515	140,000	13.4	15.6	1,541	90
Oct.	185,000	541	835	0	266	1,314	3,748	80,000	.24	.16	517	15
Nov.	110,000	98	90	0	430	2,447	495	120,000	1.0	1.0	1,302	50
Total	491,500	—	1,660	0	1,023	4,503	8,758	340,000	—	16.8	3,360	155
Avg.	163,833	362	553	0	341	1,501	2,919	113,333	4.9	5.6	1,120	51.7

Solids from the IWTP precipitation process are thickened and then dewatered using a centrifuge. The solids content of the dewatered sludge has been reported to be in the range of 10 to 25 percent (Reference 2).

The cost for wastewater treatment and sludge disposal at SM-ALC was estimated using chemical consumption rates, current chemical costs (Table 9), and actual sludge disposal costs supplied by IWTP personnel (Table 10). The combined cost for treatment chemicals and sludge disposal (including hauling) is \$0.47 per 1,000 gallons. On an annual basis this is approximately \$84,000.

TABLE 9. COSTS FOR WASTEWATER TREATMENT CHEMICALS

<u>Chemical</u>	<u>Cost \$/lb*</u>	<u>Basis</u>
Chlorine	0.08	Single Tanks
Calcium Hypochlorite	1.04	100 lb drums
Sulfur Dioxide	0.15	Drums
Sodium Bisulfite	0.19	38% solution
Lime (Hydrated)	0.02	Bags
Caustic Soda	0.13	50%
Sulfuric Acid	0.04	Tanks
Alum	0.13	Bags
Polymer	2.50	Estimate
Ferrous Sulfate	0.07	Bulk

\*Shipping costs are included at 10 percent FOB price

## 2. Hill AFB (00-ALC)

The average waste flow at the Hill AFB IWTP is 414,000 gal/day (Table 11). The waste stream is relatively concentrated with the major contaminant being chromium. On an average day, 120 pounds of chromium are treated.

Hill AFB does not have a separate treatment facility for plating wastes (Figure 5). Chromium rinse waters are introduced to the industrial waste stream just before equalization.





TABLE 11. RAW WASTE CHARACTERISTICS, SLUDGE PRODUCTION AND CHEMICAL CONSUMPTION AT HILL AFB IWTP

Month	Flow gal x 10-3	Hex. Total				Lead mg/l	Nickel mg/l	Zinc mg/l	Cyanide mg/l	Total Sludge Hauled gals	H <sub>2</sub> SO <sub>4</sub> lbs	Caustic lbs	SO <sub>2</sub> lbs	Polymer lbs
		Cadmium mg/l	Copper mg/l	Chrom. mg/l										
1981														
Oct.	14,247	.32	.57	6.1	5.9	1.9	1.6	.25	.48	113,100	NA	42,625	2,800	157
Nov.	7,675	.67	.15	9.2	50.0	2.6	.08	.15	1.27	85,250	NA	34,652	19,000	152
Dec.	No data available													
1982														
Jan.	9,033	.05	.20	3.8	14.6	0.5	2.5	.14	.01	41,800	NA	23,252	NA	67
Feb.	Flow meter out of order													
Mar.	16,243	.43	<.01	12	25.4	1.3	.17	.14	<.01	43,600	NA	26,316	15,430	143
April	12,409	.45	.8	12	25	.25	1.25	<.01	<.01	38,862	NA	37,481	21,406	80
May	12,742	<.05	1.3	8.0	20	<.1	<.3	.12	<.01	39,950	NA	34,341	18,305	113
June	15,160	1.6	<.1	4.4	17	<.1	<.3	<.1	<.01	72,338	NA	28,814	19,605	81
July	10,677	1.2	.50	11.8	84	.75	1.1	.21	.18	121,880	3,415	39,459	12,645	142
Aug.	13,574	1.7	2.7	5.0	77	2.4	NA	5.2	0.2	135,610	2,614	36,192	17,100	126
Total	111,760	--	--	--	--	--	--	--	--	717,440	6,029	298,132	126,291	1,061
Avg.	12,418	0.47	0.69	8.0	35.4	1.1	0.84	0.69		71,744	3,015	33,126	15,786	118

NA=Not available.



Figure 5. Process Flow Diagram, McClellan AFB, IWTP

The pH of the waste stream is then adjusted downward and the hexavalent chromium is reduced with sulfur dioxide. The pH of the waste stream is then adjusted upward with caustic soda and combined with the cyanide waste stream that has been pretreated with chlorine. A polyelectrolyte is added and the heavy metals are precipitated as a hydroxide sludge. After clarification, the sludge is dewatered in a drying bed to 3 to 5 percent solids. Cement is added to the sludge to improve the handling of the waste. Dewatered sludge is hauled by contractor to a landfill located approximately 120 miles from the base. The costs associated with wastewater treatment and sludge disposal are presented in Table 10.

Future plans at OO-ALC include a thickener to improve dewatering and switching from caustic soda to lime for precipitation.

### 3. Tinker AFB (OC-ALC)

The industrial wastewater treatment process at Tinker AFB (Figure 6) is unique in that no preliminary treatment of cyanide or chromium waste streams is performed; all wastewaters are combined into a single waste stream prior to treatment. Following the initial steps of free oil separation and equalization, the pH of the entire waste stream is lowered to pH 3, using sulfuric acid. Chromium reduction is then performed, using sulfur dioxide. Following chromium reduction, the pH is increased using lime, and precipitation of heavy metals occurs. Neither polymers or alum are used in the precipitation process. Precipitation is followed by biological treatment. Since the cyanide concentration of the raw waste stream is relatively low, no specific treatment of cyanide is needed.

The IWTP at Tinker AFB treats an average of 801,000 gallons per day (Table 12) with the major waste constituents from electroplating being chromium and nickel.

Sludge generated during the treatment process is dewatered on a vacuum filter to approximately 15 to 20 percent solids (2). The dewatered sludge is hauled by contractor to a hazardous landfill in Lamberton, Alabama. Costs associated with wastewater treatment and sludge disposal at OO-ALC are presented in Table 10.

### 4. Kelly AFB (SA-ALC)

The IWTP at Kelly AFB (Figure 7) treats an average flow of 1,270,000 gal/day. The main waste stream is relatively dilute with a total metals content usually less than 1 mg/l (Table 13). Concentrated chromium (3,500 gal/day) and cyanide wastes (6,600 gal/day) receive preliminary batch treatment before being combined with the main waste stream (Table 14). The preliminary treatment for cyanide wastes is chemical oxidation using calcium hypochlorite. Concentrated chromium wastes

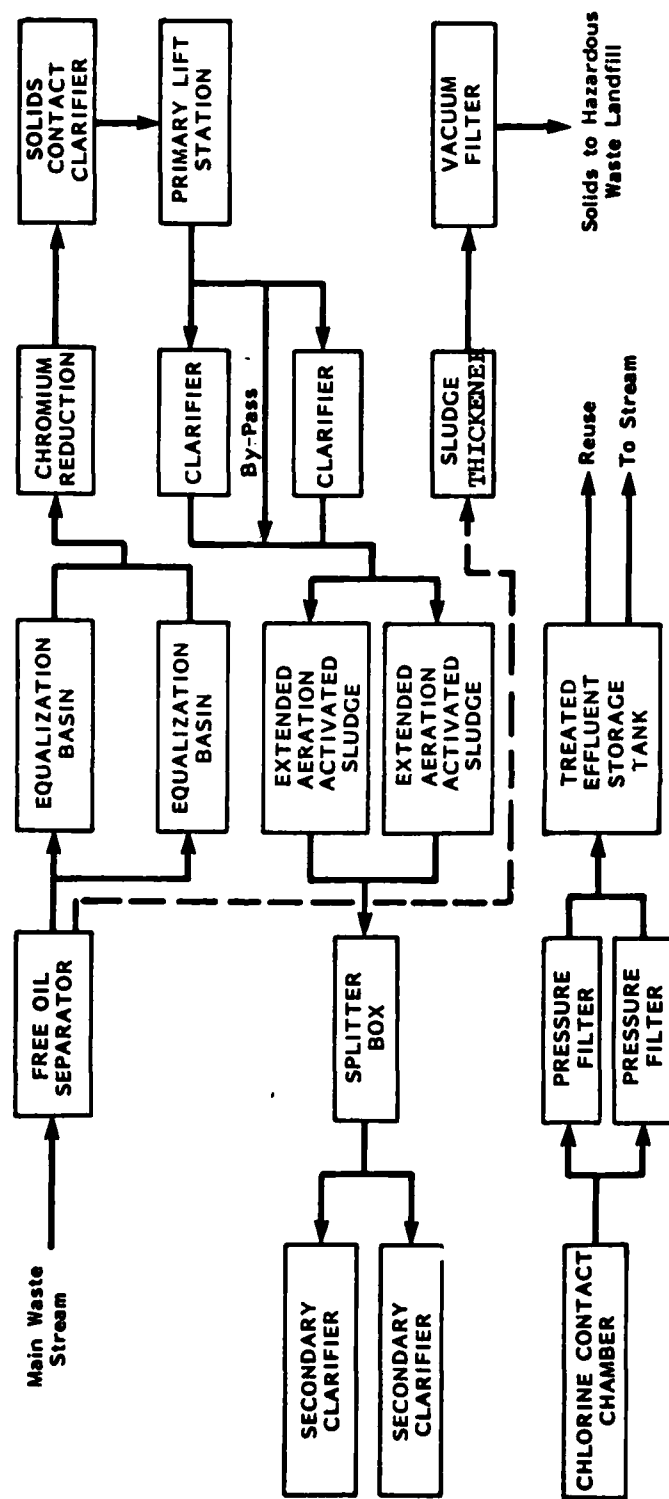


Figure 6. Industrial Wastewater Treatment Process at Tinker AFB

TABLE 12. RAW WASTE CHARACTERISTICS, SLUDGE PRODUCTION  
AND CHEMICAL CONSUMPTION AT TINKER AFB IWTP

Month	Flow gal x 10-3	Hex. Total				Lead mg/l	Nickel mg/l	Zinc mg/l	Cyanide mg/l	Total Sludge Hauled tons	SO <sub>2</sub> lbs	Cl <sub>2</sub> lbs	Lime lbs	Acid lbs	Sodium Chlorite lbs
		Cadmium mg/l	Copper mg/l	Chrom. mg/l											
1981															
Sept.	21.2	.52	.35	—	5.0	.86	3.6	.42	2.4	1117	10,000	4,000	49,740	164,220	2,200
Oct.	21.4	.38	.14	—	10.1	.38	5.8	.46	.16	176.0	20,000	4,000	48,800	47,080	5,000
Nov.	20.3	.39	.40	—	4.7	.35	1.8	.25	.11	83.3	16,000	4,000	47,880	50,190	2,300
Dec.						Not Available									
1982															
Jan.	24.2	.11	.37	—	12.0	.21	1.3	.17	.29	42.0	12,000	6,000	104,210	105,392	2,200
Feb.	24.0	.09	.33	—	5.4	.18	1.5	.14	.04	192	6,000	2,000	105,920	51,840	3,500
Mar.						Not Available									
April	25.5	.85	.35	—	5.7	.29	1.3	.21	.10	142.3	14,000	2,000	104,000	105,000	1,800
May	27.9	.12	.31	—	15.2	.22	1.8	.01	.20	101.7	14,000	4,000	91,110	105,200	1,400
June	24.6	.08	.25	—	4.9	.20	1.6	.24	ND	151.0	12,000	2,000	149,970	86,000	2,600
July	27.0	.10	.14	—	6.2	.06	1.0	—	0	181.0	10,000	2,000	102,780	151,000	2,900
Aug.	25.9	.01	.17	—	10.0	.25	1.4	.12	.16	141.9	10,000	2,000	NA	151,000	1,400
Sept.	25.2	.06	.07	—	6.5	.44	1.9	0.1	.38	41.0	10,000	6,000	98,000	15,141	2,200
Total	267.2	557	579	—	17,382	691	4680	446	958	1363.9	134,000	38,000	902,410	1,168,063	27,500
Avg.	24.29	.25	.26	—	7.8	.31	2.1	.20	.43	113.7	11,167	3,167	82,037	97,339	2,292

NA=Not available.

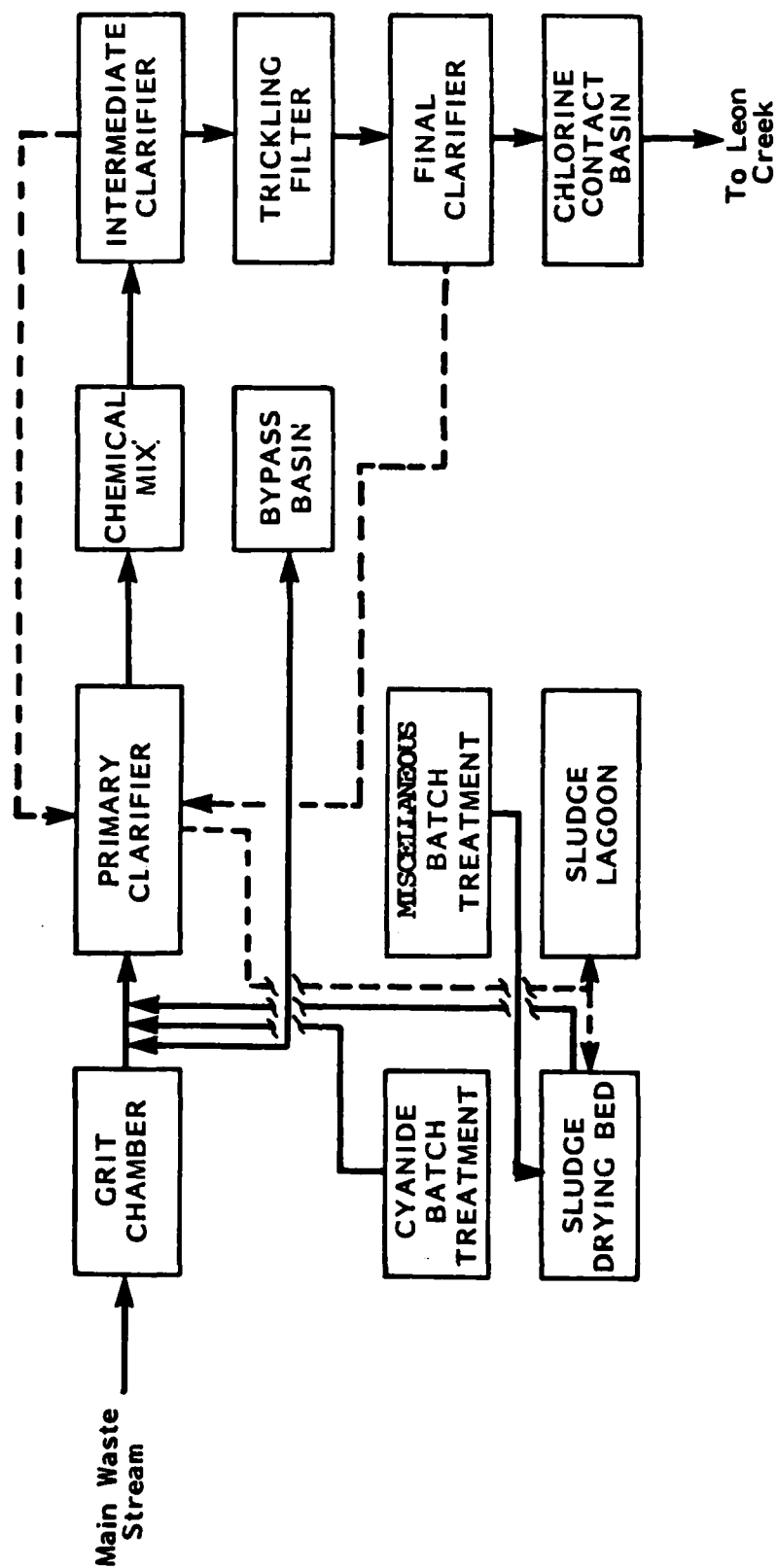


Figure 7. Industrial Wastewater Treatment Process at Kelly AFB

TABLE 13. RAW WASTE CHARACTERISTICS, SLUDGE PRODUCTION, AND  
CHEMICAL CONSUMPTION AT KELLY AFB TWP

Month	Flow gal x 10-3	Hex. Total				Lead mg/l	Nickel mg/l	Zinc mg/l	Cyanide mg/l	Total Sludge Hauled		Lime lbs	Alum lbs	FeSO <sub>4</sub> lbs <sup>4</sup>	NaHSO <sub>3</sub> lbs <sup>3</sup>
		Copper mg/l	Chrom. mg/l	Chrom. mg/l	Chrom. mg/l					gals	gals				
1981															
Oct.	41,893	.03	.09	.10	.14	ND	.15	.14	<.01	58,900	58,170	6,000	16,540		0
Nov.						No Data Available									
Dec.	35,123	.02	.05	.08	.09	ND	.02	.15	<.01	58,900	49,352	7,300	9,600		0
1982															
Jan.	46,048	.01	.05	.14	.20	ND	.17	.10	<.01	58,900	62,120	5,500	9,170		7,200
Feb.	48,800	.01	.05	.11	.06	ND	.15	.09	<.01	53,200	63,190	9,300	14,960		1,750
Mar.	49,264	.07	.04	.10	.09	ND	.25	.07	<.01	58,900	65,425	8,900	9,100		7,700
April	32,264	.01	.04	.09	.06	ND	.12	.08	<.01	57,000	43,770	10,400	10,100		0
May	29,615	.01	.04	.01	.08	ND	.11	.11	<.01	58,900	44,775	10,000	11,600		0
June	42,496	.01	.06	.43	.10	ND	.17	.10	<.01	55,170	57,660	6,000	10,850		0
July	33,662	.04	.08	.12	.35	ND	.11	.09	<.01	58,900	48,565	9,900	10,700		0
Aug.	53,879	.02	.27	.11	.13	ND	.06	.10	<.01	58,900	125,600	10,900	17,550		0
Sept.	45,888	.02	.04	.08	.07	ND	.17	.08	<.01	57,000	61,370	11,300	15,500		0
Total	420,296	—	—	—	—	—	—	—	—	634,600	678,987	95,500	135,700		15,950
Avg.	38,209	0.02	0.07	0.12	0.12	—	0.13	0.10	<.01	57,691	61,726	8,682	12,300		5,316

NA=Not available.

TABLE 14. BATCH TREATMENT DATA - KELLY AFB

Month	Chromium				Cyanide				Calcium Hypochl. lbs
	Vol. gal	Avg. Conc. mg/l	lbs Cr Removed	SO2 lbs	Sod. Bisulfite lbs	Vol.	Avg. Conc. mg/1 CN	lbs CN Destroyed	
1981									
Nov.									
Dec.	91,000	251	190	471	3,260	264,000	5.9	13	2,250
1982									
Jan.	87,000	602	437	244	9,805	252,000	8.4	18	1,650
Feb.	107,000	231	206	636	1,500	240,000	1.6	3.2	1,150
Mar.	121,000	298	300	1,077	875	252,000	0.8	1.7	1,000
April	121,000	538	543	1,885	2,200	336,000	2.4	6.7	390
May	99,000	73	60	518	0	132,000	2.6	2.9	950
June	133,000	155	172	463	2,300	120,000	3.5	3.5	1,000
July	81,000	157	106	246	670	108,000	1.4	1.3	775
Aug.	108,000	758	682	2,518	2,001	120,000	3.5	3.5	850
Sept.	94,000	798	625	3,544	0	156,000	1.4	1.8	1,020
Total	1,042,000	—	3,321	11,602	22,611	1,980,000	—	55.6	11,035
Avg.	104,200	320	332	1,160	2,261	198,000	3.2	5.6	1,104

<sup>1</sup>Data appeared to be estimated rather than measured and therefore is not reported on this table.



are reduced, using sulfur dioxide and after chromium reduction the pH of the wastewater is increased using caustic soda. This wastewater is then pumped to a drying bed to remove precipitated solids. The leachate filtering through the drying bed is pumped to the main waste stream. The main waste stream is treated with ferrous sulfate and sodium bisulfite for additional chromium reduction and lime, NaOH and alum for precipitation. The hydroxide sludge generated is then pumped from the intermediate clarifier to the primary clarifier. Solids are removed on an intermittent basis from the primary clarifier and dewatered on the drying beds. Sludge is removed from the drying beds at approximately 15 percent solids and hauled by contractor to a hazardous landfill located 150 miles from the base. Costs associated with wastewater treatment and sludge disposal at SA-ALC are presented in Table 10.

#### 5. Robbins AFB (WR-ALC)

The treatment process at Robbins AFB is similar to McClellan AFB in that both have separate treatment facilities for electroplating wastewaters. The plating wastes at Robbins are segregated into acid/alkali, chromium, and cyanide waste streams for preliminary treatment at IWTP Number 2 (Figure 8). Chromium is reduced using sodium bisulfite and cyanide wastes are treated with chlorine. These waste streams are then combined with the acid/alkali wastes and heavy metals are precipitated, using caustic soda and a polymer. The average daily flow rate of the combined waste streams is 89,000 gal/day (Reference 5).

The underflow from the IWTP Number 2 clarifier is sent to IWTP Number 1 (Figure 9), which treats wastewater from paint stripping, cleaning and washing, for dewatering. The IWTP Number 2 clarifier overflow is sent to the sewage treatment plant.

Sludge is dewatered at IWTP Number 1 using gravity thickening and a filter press to a solids content of 20 to 30 percent. The dewatered sludge is disposed of onbase in a building with an enclosed concrete basement. The sludge is being used to fill the basement, after which a concrete slab will be poured over the compacted sludge and the building will be used as a warehouse. Costs for wastewater treatment and sludge handling at WR-ALC were not available.

#### C. SLUDGE CHARACTERIZATION

To characterize the sludges generated at the IWTP, 5-day composite samples of sludges were analyzed from each of the five IWTPs. The sludge samples were taken from the clarifier underflow.

Portions of the composites were acid-digested and analyzed for total metal content. The total metal characterization included analysis for the EPA RCRA-regulated metals (As, BA, Cd,

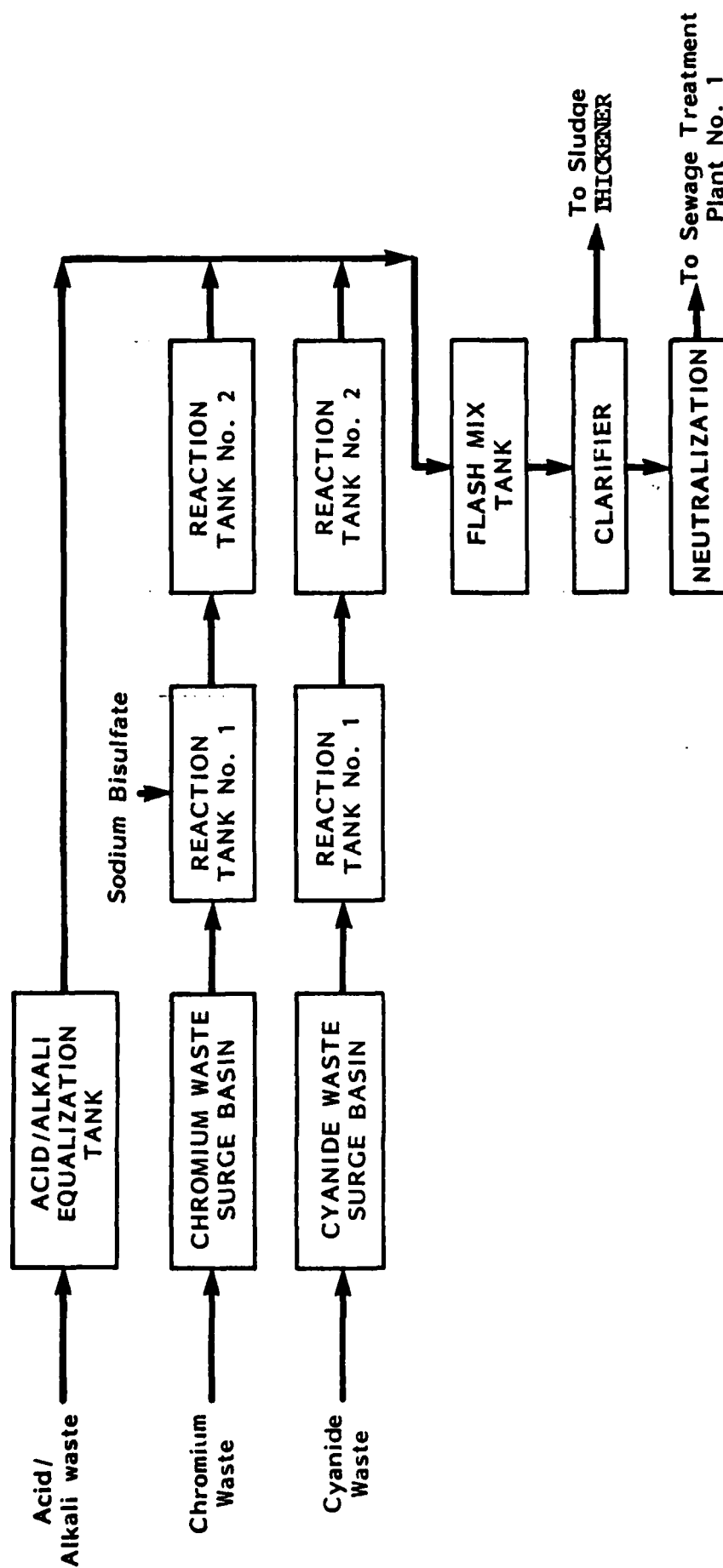


Figure 8. Process Flow Diagram, Robins AFB, IWTP No. 2.

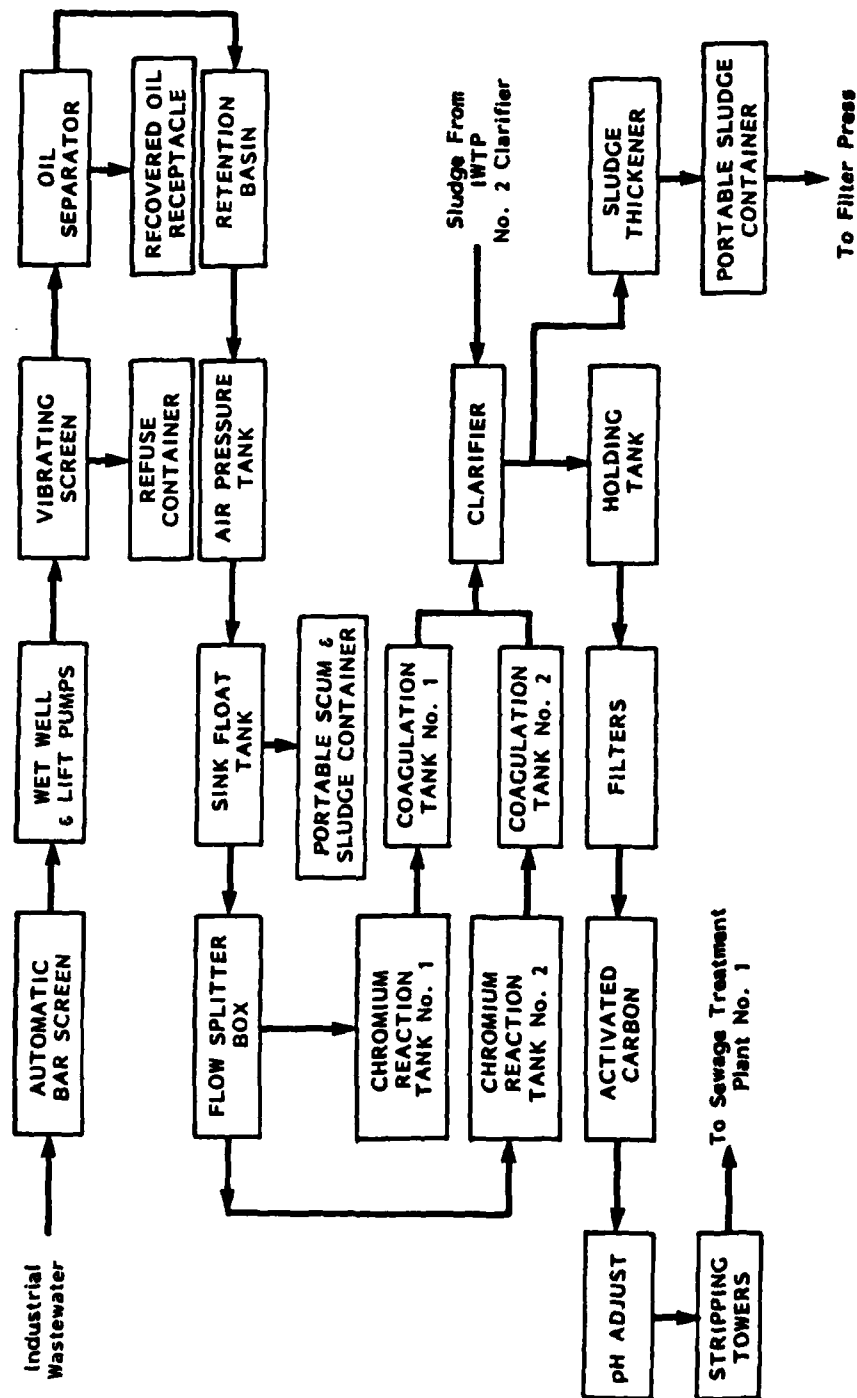


Figure 9. Process Flow Diagram, Robbins AFB, IWTP No. 1

Cr, Pb, Hg, Se and Ag); the Secondary Drinking Water Standard metals (Cu, Fe, Mn, and Zn); and other elements of interest (Al, Ca, Mg, Ni, K, Na and Sn). Separate portions of each composite sample were analyzed for pH, total solids (TS), total dissolved solids (TDS), cyanide ( $\text{CN}^-$ ), sulfide ( $\text{S}^{2-}$ ), chloride ( $\text{Cl}^-$ ), sulfate ( $\text{SO}_4^{2-}$ ), appearance and odor.

The characterization of the AF composite sludges also included an evaluation of their leaching characteristics when subjected to the EPA Extraction Procedure and the ASTM Method A extraction procedure (Appendix A). The performance of the sludge samples when subjected to leaching studies points out the problem metal constituents that will be targeted in subsequent tasks.

The ASTM Method A extraction is an extraction under mild conditions. During the test a portion of the whole sludge is extracted with four times its weight of deionized water and agitated for 48 hours. Following the extraction, the sample is filtered and the filtrate is analyzed for metals.

The EPA-EP is an extraction under harsher acidic conditions simulating an environment typical of co-disposal with organic wastes. First, a portion of the whole sludge is filtered and the filtrate is reserved for later recombination with the final extract. The solid material is extracted with 16 times its weight of deionized water. The pH is maintained at pH 5 by addition of 0.5N acetic acid up to four times the solids weight. If all the allotted acid is used, no further pH adjustment is performed. The extraction fluids are filtered after 24 hours and the extraction filtrate and original filtrate are recombined. The combined filtrate is analyzed for metals.

During the sludge characterization tests all analyses were performed with a minimum of 10 percent spiked and 10 percent duplicate samples. For statistical validation of the results, the compositing and analyses of one sludge sample, chosen at random, was run with complete replication.

The physical characteristics of the sludge samples are described in Table 15. Hill AFB sludges exhibited the most daily variability. Their sludges ranged most noticeably in odor, from a sweetly organic odor to strongly septic. Sludges collected from Robins AFB differ from the rest in that each set of five samples was collected from a different treatment facility. The electroplating waste sludge composite (No. 21473) exhibited no pronounced odor while the oils and greases waste sludge composite (No. 21474) was very strongly septic. The Kelly AFB sludges were mildly septic and varied between 1 and 70 percent settled solids. The first set of samples from Tinker AFB showed very little variability and appeared very much like a typical metal hydroxide sludge. The second set, however, was greatly variable and exhibited a septic odor. McClellan AFB samples showed little obvious variability and all were characterized as having black sludge and possessing a strong septic odor.

TABLE 15. PHYSICAL CHARACTERISTICS OF SLUDGE SAMPLES

Composite Sample	Air Force Base	Settled Solids (%)	Odor	Sludge Color	Variability
21384	Hill	10-50	strongly septic to mildly organic	light to dark brown	great
21475	Hill	50-80	strongly septic	dark brown to black	moderate
21474	Robins (Oils & Grease) Robins (Electroplating)	80	Strong septic	dark black	little
21473		20-50	no odor	brown	little
21575	Kelly Kelly	5-60	septic	dark	moderate
21575		1-70	septic	dark	moderate
21476	Tinker Tinker	60	no odor	grey	little
21721 (21722)		20-50	slight to moderately septic	green and brown	great
21723	McClellan McClellan	20-50	strong septic	black	little
21724		50-70	strong septic	black	little

The analytical results of the sludge characterizations are presented in Tables 16 through 21. The guidelines used by the EPA in association with the EP toxicity test are presented in Table 22.

The results of the EP toxicity test are summarized in Table 23 in terms of whether the sludge sample exceeded the limits defined for EP toxicity and for delisting of a particular sludge.

As indicated in Table 23, the Kelly sludge sample and the Robins oil and grease sludge sample were the only two to pass both the EP toxicity limits and the maximum allowable limits for delisting sludge. For these particular samples, cadmium and chromium are the only metals that would negate the potential for delisting. In one case (Tinker) nickel was relatively close to the delisting criteria.

Table 24 shows the percentages of metals that were leached from the various samples during the EP. The Tinker AFB sludge samples exhibited considerable variability in percentage of metal leaching. Both samples had similar levels of cadmium; however, nearly 84 percent of the available cadmium from one sample (No. 21476) was leached, and only 11 percent of the available cadmium leached from the other sample (Number 21721). The total cadmium contents of the Kelly and McClellan sludges were low, which may account for the sludge leaching less than the limits for this metal.

Chromium leaching exceeded the EP toxicity limit only with the McClellan sludge, although Hill and Tinker sludges present problems if delisting is desired. Although the total chromium content of the McClellan sludge samples was not unusually high, they leached considerably more chromium than samples from other bases.

The ASTM Method A extraction indicated high chromium leaching in one Tinker AFB sludge sample (Number 21722) and both McClellan sludge samples (Numbers 21723 and 21724). This indicates that there may be poor hexavalent chromium reduction treatment which usually results in high levels of  $\text{Cr}^{+6}$  in the sludges.

The other RCRA-regulated metals (Ag, As, Ba, Hg and Se) leached at levels well below the EP Toxicity limits.

The secondary drinking water metals (Fe, Cu, Mn and Zn) were leached at high levels in some sludges. Of these, only copper presented no apparent leaching problem. Iron leached 625 mg/l for the sludge obtained from the oil and grease treatment facility at Robins AFB, and, although the electroplating sludge had higher total Fe content, it leached only 7.1 mg/l. Manganese was found to be poorly stabilized in all of the sludges. However, even though greater than 60 percent of the manganese leached, the generally low total concentrations make it a

TABLE 16. HILL AIR FORCE BASE  
SLUDGE CHARACTERIZATION

Sample No.	pH	TS	TDS	Ag	As	Ba	Ca	Cd (mg/l)	Cr	Cu	Fe	Hg	Mg
21384													
TOTAL	7.70	15,900	2,170	1.08	0.275	14.0	560	35.0	760	21.0	620	0.005	570
EP				0.02	0.002	1.0		0.63	0.35	0.02	60.0	0.005	
ASTM				0.02	0.002	1.0		0.02	0.10	0.02	1.00	0.005	
21475													
TOTAL	8.81	26,000	2,500	0.04	0.335	20.0	3,600	42.0	1200	46.0	2100	0.005	920
EP				0.02	0.002	1.0		1.88	4.14	0.02	27.5	0.005	
ASTM				0.02	0.002	1.0		0.02	0.10	0.02	0.10	0.005	

Sample No.	Mn	Ni	Pb	Se	Zn	Al	Na	K (mg/l)	Sn	SO <sub>4</sub> <sup>2-</sup>	S <sup>2-</sup>	CN <sup>-</sup>	Cl <sup>-</sup>
21384													
TOTAL	12.4	32.2	10.3	0.010	47.0	600	730	21.4	2.0	432	0.5	0.1	16
EP	2.65	2.86	0.002	0.010	3.20								
ASTM	0.05	0.72	0.002	0.010	0.02								
21475													
TOTAL	26.0	100	13.6	0.010	82.0	204	260	11.5	2.0	330	0.5	0.1	29
EP	4.65	7.70	0.002	0.010	6.00								
ASTM	0.05	1.36	0.002	0.010	0.03								

TABLE 17. ROBBINS AIR FORCE BASE  
SLUDGE CHARACTERIZATION

Sample No.	pH	TS	TDS	Ag	As	Ba	Ca (mg/l)	Cd	Cr	Cu	Fe	Hg	Mg
21474													
TOTAL	6.90	29,700	600	0.04	0.120	27.6	84.0	7.30	500	11.0	8,200	0.006	45.9
EP				0.02	0.002	3.6		0.02	0.20	0.02	625	0.005	
ASTM				0.02	0.002	1.0		0.02	0.10	0.02	3.10	0.005	
21473													
TOTAL	8.48	22,700	2,400	0.24	0.067	1.60	111	94.0	660	20.0	10,000	0.005	47.1
EP				0.02	0.002	1.0		3.21	0.10	0.02	7.10	0.005	
ASTM				0.02	0.002	1.0		0.02	0.10	0.02	0.10	0.005	
Sample No.	Mn	Ni	Pb	Se	Zn	Al	Na	K (mg/l)	Sn	SO <sub>4</sub> <sup>2-</sup>	S <sup>2-</sup>	CN <sup>-</sup>	Cl <sup>-</sup>
21474													
TOTAL	21.0	2.80	5.00	0.010	96.0	98.0	58.8	3.00	2.0	5.8	0.5	0.1	14
EP	3.60	0.17	0.002	0.010	7.50								
ASTM	0.16	0.10	0.002	0.010	0.02								
21473													
TOTAL	27.0	27.00	4.3	0.010	48.0	122	118	2.00	2.0	180	0.5	0.1	10
EP	4.00	2.12	0.002	0.010	2.10								
ASTM	0.05	0.10	0.002	0.010	0.02								



TABLE 18. ROBINS AIR FORCE BASE  
SLUDGE CHARACTERIZATION

Sample No.	pH	TS	TDS	Ag	As	Ba	Ca	Cd (mg/l)	Cr	Cu	Fe	Hg	Mg
21574													
TOTAL	8.03	20,900	680	1.20	0.175	4.00	9,200	1.00	70.0	3.06	640	0.010	1,040
EP				0.02	0.002	1.0		0.02	0.10	0.05	0.10	0.005	
ASTM				0.02	0.002	1.0		0.02	0.10	0.03	0.53	0.005	
21575													
TOTAL	7.37	33,280	460	0.16	0.145	3.60	10,600	0.92	11.3	3.64	510	0.084	1,200
EP				0.02	0.002	1.0		0.02	0.10	0.03	0.10	0.005	
ASTM				0.02	0.002	1.0		0.02	0.10	0.02	0.10	0.005	
Sample No.	Mn	Ni	Pb	Se	Zn	Al	Na	K (mg/l)	Sn	SO <sub>4</sub> <sup>2-</sup>	S <sup>2-</sup>	CN <sup>-</sup>	Cl <sup>-</sup>
21574													
TOTAL	26.0	34.8	2.60	0.010	4.0	49.0	100	3.00	2.0	16	0.5	0.1	50
EP	1.10	0.80	0.002	0.010	0.03								
ASTM	0.21	0.10	0.002	0.010	0.02								
21575													
TOTAL	27.5	30.0	4.0	0.010	7.50	50.0	52.0	4.40	2.0	22	0.5	0.1	22
EP	1.36	0.48	0.002	0.010	0.02								
ASTM	0.10	0.10	0.002	0.010	0.01								

TABLE 19. TINKER AIR FORCE BASE  
SLUDGE CHARACTERIZATION

Sample No.	pH	TS	TDS	Ag	As	Ba	Ca	Cd (mg/l)	Cr	Cu	Fe	Hg	Mg
21476													
TOTAL	9.17	29,500	1,200	1.54	0.280	18.8	9,700	24.0	400	8.00	186	0.065	1,100
EP				0.02	0.010	1.0		3.20	2.00	0.22	0.50	0.005	
ASTM				0.02	0.002	1.0		0.02	0.10	0.04	0.32	0.005	
21721													
TOTAL	8.46	40,100	1,140	8.65	0.299	22.2	17,700	26.8	1130	8.19	145	0.094	890
EP				0.02	0.006	4.0		0.61	0.16	0.20	0.40	0.005	
ASTM				0.02	0.003	1.0		0.05	2.38	0.04	0.28	0.005	
Sample No.	Mn	Ni	Pb	Se	Zn	Al	Na	K (mg/l)	Sn	SO <sub>4</sub> <sup>2-</sup>	S <sup>2-</sup>	CN <sup>-</sup>	Cl <sup>-</sup>
21476													
TOTAL	500	330	8.00	0.011	34.0	96.0	70.8	4.00	2.0	470	0.5	0.1	10
EP	95.0	49.6	0.002	0.010	2.60								
ASTM	0.31	0.29	0.002	0.010	0.02								
21721													
TOTAL	473	339	6.37	0.072	31.30	77.0	96.7	9.19	2.0	365	0.5	0.1	28
EP	52.4	14.78	0.003	0.010	0.08								
ASTM	1.19	0.80	0.008	0.010	0.07								

TABLE 20. TINKER AIR FORCE BASE REPLICATE SAMPLE\*

Sample No.	pH	TS	TDS	Ag	As	Ba	Ca	Cd (mg/l)	Cr	Cu	Fe	Hg	Mg
21722													
TOTAL	8.48	39,400	1,160	4.29	0.258	19.6	14,900	22.0	952	7.33	125	0.078	730
EP				0.02	0.003	1.0		0.61	0.16	0.16	0.25	0.005	
ASTM				0.02	0.002	1.0		0.04	2.42	0.02	0.33	0.005	
TOTAL													
EP													
ASTM													

Sample No.	Mn	Ni	Pb	Se	Zn	Al	Na	K (mg/l)	Sn	SO <sub>4</sub> <sup>2-</sup>	S <sup>2-</sup>	CN <sup>-</sup>	Cl <sup>-</sup>
21722													
TOTAL	520	278	5.19	0.062	29.2	64.9	86.2	8.57	2.0	375	0.5	0.1	23
EP	49.8	13.4	0.002	0.010	0.09								
ASTM	1.18	0.80	0.008	0.010	0.10								
TOTAL													
EP													
ASTM													

TABLE 21. MCCLELLAN AIR FORCE BASE  
SLUDGE CHARACTERIZATION

Sample No.	pH	TS	TDS	Ag	As	Ba	Ca	Cd (mg/l)	Cr	Cu	Fe	Hg	Mg
21723													
TOTAL	8.07	38,400	1,170	0.17	0.782	4.11	10,900	4.21	802	6.52	140	0.019	778
EP				0.02	0.008	1.0		0.07	11.7	0.04	12.0	0.005	
ASTM				0.02	0.002	1.0		0.02	1.14	0.02	0.33	0.005	
21724													
TOTAL	7.74	37,400	1,150	0.32	0.750	5.08	11,500	3.42	766	15.1	189	0.024	564
EP				0.02	0.016	1.0		0.02	6.25	0.03	12.2	0.005	
ASTM				0.02	0.011	1.0		0.02	3.54	0.09	0.75	0.005	

Sample No.	Mn	Ni	Pb	Se	Zn	Al	Na	K (mg/l)	Sn	SO <sub>4</sub> <sup>2-</sup>	S <sup>2-</sup>	CN <sup>-</sup>	Cl <sup>-</sup>
21723													
TOTAL	4.42	5.65	5.19	0.070	20.2	502	161	21.0	2.0	242	0.5	0.1	55
EP	0.83	0.72	0.004	0.010	1.59								
ASTM	0.05	0.20	0.007	0.010	0.07								
21724													
TOTAL	5.50	4.97	6.14	0.150	23.7	1130	192	26.0	2.0	90	0.5	0.1	55
EP	0.67	0.51	0.002	0.010	0.71								
ASTM	0.05	0.10	0.014	0.010	0.22								

TABLE 22. HAZARDOUS WASTE DELISTING CRITERIA FOR METALS OF INTEREST

	Max. Conc. EP Toxicity (mg/l)*	Max. Conc. For Delisting (mg/l)†
Cd	1.0	0.3
Cr	5.0	1.5
Pb	5.0	1.5
Ni	--	20

\*Reference 6.

†Standards for delisting do not actually exist. As an informal standard for delisting, EPA requires that the material does not leach more than one-third of the limit used for classifying wastes as hazardous. In the case of nickel which does not have a published toxicity limit, the EPA considers a level of 20 mg/l to be allowable.

TABLE 23. SUMMARY OF AIR FORCE BASE SLUDGES IN PERFORMANCE IN EP TEST

Base	Cd		Cr		Pb		Ni	
	EP	Delist	EP	Delist	EP	Delist	EP	Delist
Hill	*	*	-	*	-	-	NA	-
Robins, Electroplating	*	*	-	-	-	-	NA	-
Robins, Oil and Grease	-	-	-	-	-	-	NA	-
Kelly	-	-	-	-	-	-	NA	-
Tinker	*	*	-	*	-	-	NA	-
McClellan	-	-	*	*	-	-	NA	-

Key: \* exceeds maximum limit  
 - below limit  
 NA not applicable

TABLE 24. METALS LEACHING DURING EP EXTRACTION  
AS A PERCENTAGE OF TOTAL METAL

Sample No.	Air Force Base	Percent						
		<u>Cd</u>	<u>Cr</u>	<u>Cu</u>	<u>Fe</u>	<u>Mn</u>	<u>Zn</u>	<u>Ni</u>
21384	Hill	6.8	0.2	0.4	36.7	81.1	25.8	33.7
21475		22.0	1.7	0.2	6.4	87.8	35.9	37.8
21474	Robins (Oils & Grease) (Electroplating)	0.2	0.3	1.3	56.1	126.1	57.5	44.7
21473		15.0	0.1	0.4	0.3	65.2	19.3	34.6
21574	Kelly	5.4	0.4	4.4	0.1	11.4	2.0	6.2
21575		6.4	2.6	2.4	0.1	14.7	0.8	4.7
21476	Tinker (Replicate of 21721)	84.3	3.2	17.4	1.7	120.2	48.4	89.3
21721		11.1	0.1	11.9	1.3	54.1	1.2	21.2
21722		13.6	0.1	10.9	1.0	58.2	1.5	23.6
21723	McClellan	8.0	7.1	3.0	41.5	90.9	38.1	61.7
21724		3.6	5.0	1.2	39.4	74.3	18.3	62.6

potential problem only in Tinker AFB sludges. Total zinc content in all the sludges was less than 100 mg/l and all EP extracts contained less than 10 mg/l zinc. High values of 7.5 mg/l and 6 mg/l zinc were found in EP extracts of Robins AFB oil and grease and Hill AFB sludges.

The less harsh ASTM Method A extraction showed low leachability of all metals investigated, with the notable exception of chromium.

Cyanide levels in all the sludges were found to be less than the detection limit providing evidence of proper treatment.

## SECTION V

### METAL REMOVAL STUDY

#### A. INTRODUCTION

Electroplating wastewaters generated at the ALCs are treated for metals removal by the conventional hydroxide precipitation with three of the five ALC using lime as the pH adjustment chemical. The preference for lime is due to several major reasons:

- Low cost
- Superior settling characteristics
- Superior dewatering characteristics

In spite of these advantages, lime produces three to six times more sludge volume than caustic soda. This high sludge volume results mainly from unreacted calcium hydroxide and insoluble compounds in the lime, such as sand and calcium by-products. Since lime is added in a slurry form, inefficient chemical feed systems, such as those observed at various ALCs (Reference 2), can easily overdose lime requirements and add to the sludge volume problem.

Another potential disadvantage of lime is that the effluent quality is limited by the solubility of metal hydroxides. Although the resultant effluent quality is usually adequate to meet the Federal metal finishing standards it may not be adequate to meet stringent local POTW standards or NPDES permit requirements.

The two ALCs that are not currently using lime are using caustic soda. Caustic soda (sodium hydroxide or NaOH) is fed as a liquid rather than a slurry, and therefore its dosage can be more accurately controlled. Caustic soda is widely used by U.S. industries for metals precipitation, but the precipitates formed during treatment exhibit poor settling and dewatering characteristics. Such problems have been observed at one of the ALCs that uses caustic soda. Effluents produced by caustic soda treatment have a quality similar to that of lime treatment.

One objective of this project was to investigate new and innovative processes that remove metals and reduce sludge volume as compared with lime treatment. At the same time, the removal efficiencies of the process were to meet Federal effluent limitations (Table 2) and approach the target effluent levels shown in Table 25. These target levels are beyond the



TABLE 25. EFFLUENT OBJECTIVES

<u>Parameter</u>	<u>Concentration (mg/l)</u>
Chromium (total)	0.25
Chromium (Hexavalent)	0.025
Cadmium	0.010
Copper	0.005
Nickel	0.10
Cyanide	0.002

effluent quality attainable using either lime or caustic soda treatment.

The first step during this task was to identify potential technologies for testing. Information collected during the literature review was used to aid in the selection process. A preliminary set of tests was then conducted to screen and identify the most promising technologies. The test results were evaluated and two technologies were selected for more comprehensive testing.

At several decision points during the metal removal study, a decision technique termed "worth assessment" was used to aid in the selection of technologies. With this method, a mathematical relationship is defined among decision criteria. Each criterion is given a relative weight from 0.0 to 1.0 with the sum of the weights equaling 1.0. Then, for each candidate technology, a worth assessment score is calculated by: (1) scoring on a scale of 0.0 to 1.0 how well each candidate technology satisfies each criterion, (2) multiplying the score for each criterion by its weighted value, and (3) summing the scores for each criterion.

#### B. INITIAL TECHNOLOGY SCREENING

The technologies identified in the literature survey were reviewed to identify potential candidates for testing. The metal removal technologies selected are presented in Table 26. Decision criteria were developed and the worth assessment model applied. A summary of the worth assessment results for chromium reduction, cyanide destruction and metal removal is presented in Table 27.

As indicated in Table 27, the use of sodium borohydride for precipitation was the highest ranking technology. Its major assets were considered to be the high-quality effluent produced

TABLE 26. POTENTIAL METAL REMOVAL TECHNOLOGIES  
IDENTIFIED FROM LITERATURE

1. Sodium borohydride precipitation
  2. Electrochemical removal of metals (end of pipe)
  3. Ion exchange plus batch treatment
  4. Water softening
  5. Oxide precipitation
  6. Hydroxide precipitation
  7. Sulfide precipitation
- 

by the process, the low solids generation, improved characteristics of solids, and the ability of the process to simultaneously reduce chromium and precipitate metals. Electrochemical removal of metals, as an end-of-pipe technology, was ranked second. Its major assets were considered to be its low operating cost (treatment chemicals are not required), reduced solids generation, potential for metals recovery, and simultaneous reduction of chromium and metals removal. Ion exchange plus batch treatment was ranked third. Its major assets were its commercialized development status, high-quality effluent, and low solids generation. The worth assessment score for ion exchange was reduced because of its high operating cost. Water softening was included in the worth assessment exercise although it was not identified in the literature search. The potential application for this process is to remove hardness compounds from the raw process water so that they will not be precipitated during waste treatment and add to the hazardous sludge volume. This technology's commercial development status and its potential for reducing solids generation are its major attributes. Since water softening would be applied in addition to waste treatment, it would increase capital and operating costs. The lowest scores of the selected technologies were hydroxide precipitation (i.e., using lime or caustic soda) and sulfide precipitation. Neither provides any significant advantage except that the performance of each has been demonstrated on a commercial scale.

A laboratory test plan was developed for conducting screening experiments with several of the identified technologies. The objectives of the screening were to establish a conventional treatment baseline and to investigate the most promising innovative technologies. The following experiments were included in the screening tests:

- Evaluating hydroxide precipitation with lime (baseline data)

TABLE 27. WORTH ASSESSMENT RESULTS - INITIAL SCREENING STEP

Chromium Reduction

<u>Technology</u>	<u>Worth Assessment Score</u>
Iron Anodes	0.776
Formalin	0.624
Sodium Borohydride	0.616
Sulfur Dioxide or Sodium Bisulfite	0.584
Cementation	0.524
Ferrous Sulfate	0.514
Sulfide	0.474
Activated Carbon	0.460

Metals Removal

<u>Technology</u>	<u>Worth Assessment Score</u>
Sodium Borohydride	0.746
Electrochemical Removal of Metals (end of pipe)	0.712
Ion Exchange plus Batch Treatment	0.642
Water Softening	0.608
Oxide Precipitation	0.586
Hydroxide Precipitation	0.560
Sulfide Precipitation	0.353

Cyanide Oxidation

<u>Technology</u>	<u>Worth Assessment Score</u>
Electrolytic	0.848
Electrolytic plus Sodium Chloride	0.840
Ozone	0.684
Chlorine	0.684
Sodium Hypochlorite	0.584

- Determining influence of neutralizing agent on sludge volume and solids content (baseline data)
- Determining influence of water hardness on sludge volume and solids content
- Determining influence of segregated treatment of chromium wastes on sludge volume and solids content
- Evaluating use of ferrous sulfate for chromium reduction
- Evaluating use of oxide precipitation for metal removal and cyanide oxidation
- Evaluating use of sodium borohydride precipitation process

Before conducting the tests, contrived wastewaters were formulated to have the metal composition shown in Table 28. Three wastewaters were prepared having various levels of hardness, synthesized by adding calcium and magnesium ions (or sodium carbonate in the case of softened water). Table 29 describes the hardness composition of the three contrived wastewaters used in the study. To produce background ion concentration, 100 mg/l sodium sulfate was added to each wastewater.

Detailed descriptions of the various experiments are as follows:

#### 1. Evaluation of Hydroxide Precipitation with Lime

In this test the optimum conditions were determined for chromate reduction using sodium bisulfite and the optimum pH for hydroxide precipitation using lime. The low hardness wastewater (WW1) was used in this study.

##### a. Chromium Reduction

A 10 percent solution of sodium bisulfite ( $\text{NaHSO}_3$ ) was prepared using sodium metabisulfite ( $\text{Na}_2\text{S}_2\text{O}_3$ ) and water. The wastewater sample was then adjusted to a pH of 2.5, using sulfuric acid ( $\text{H}_2\text{SO}_4$ ). The 10 percent sodium metabisulfite solution was then added to the wastewater sample, while maintaining a pH of 2.5 by addition of sulfuric acid and monitoring the oxidation-reduction potential (ORP). A final ORP reading of +220 mV indicated the completion of the reduction of hexavalent chromium ( $\text{Cr}^{+6}$ ) to trivalent chromium ( $\text{Cr}^{+3}$ ). This reaction was also monitored by visually observing a color change from the characteristic yellow of hexavalent chromium to the blue-green associated with trivalent chromium. Samples of the treated wastewater were collected at ORP readings of +220 mV and +230 mV. The sample collected from the solution at +230 mV showed a

TABLE 28. HEAVY METAL CONCENTRATIONS IN CONTRIVED WASTEWATERS

<u>Metal Ion</u>	<u>Concentration (mg/l)</u>	<u>Chemical Used</u>
Cr(+6)	15	CrO <sub>3</sub>
Cr(+3)	30	Cr(NO <sub>3</sub> ) <sub>3</sub> . 9H <sub>2</sub> O
Cd(+2)	1	Cd(NO <sub>3</sub> ) <sub>2</sub> . 4H <sub>2</sub> O
Cu(+2)	25	CuSO <sub>4</sub> . 5H <sub>2</sub> O
Ni(+2)	10	NiCl <sub>2</sub> . 6H <sub>2</sub> O
Fe(+2)	20	FeSO <sub>4</sub> . 7H <sub>2</sub> O

TABLE 29. WASTEWATER HARDNESS AND IONIC BACKGROUND

<u>Composition</u>	<u>Hardness (mg/l)</u>		
	<u>Low (WW#1)</u>	<u>High (WW#2)</u>	<u>Softened (WW#3)</u>
CaCO <sub>3</sub> (as CaCO <sub>3</sub> )	80	240	0
Mg(+2)(as CaCO <sub>3</sub> ) (added as MgCl <sub>2</sub> )	40	120	0
Na <sub>2</sub> CO <sub>3</sub> (as Na <sub>2</sub> CO <sub>3</sub> )	0	0	381
Na <sub>2</sub> SO <sub>4</sub> (as Na <sub>2</sub> SO <sub>4</sub> )	100	100	100

slight yellow tint that dissipated within a few hours. This indicates that the reduction reaction may be accelerated to completion by the addition of an excess amount of  $\text{NaHSO}_3$ . The reaction was driven to completion in 30 minutes with the addition of 20 percent excess  $\text{NaHSO}_3$ .

#### b. Hydroxide Precipitation

Tests to determine the optimum pH for hydroxide precipitation were performed using samples of WW1 that had been previously treated with  $\text{NaHSO}_3$  to reduce  $\text{Cr}^{+6}$  to  $\text{Cr}^{+3}$ . In this study, the wastewater samples were adjusted to pH values of 8.4, 8.8, and 9.2 by the addition of industrial grade hydrated lime. Screening tests were initially performed to identify the most effective flocculation agent and to determine its optimum dosage. The results of these screening tests indicated that the ionic polymer Magnifloc 836A used at a dosage of 2 mg/l would provide the best results.

The test procedure was designed to simulate the sequence of an industrial scale treatment process, using a pH adjustment time of 30 minutes, followed by a 30-minute settling time. Following the settling step, the amount of settleable solids (SS) was determined and a sample of the supernatant was collected and analyzed for total suspended solids (TSS), dissolved metals (following filtration through a 0.45 micron filter), and total metals. Results of these analyses are presented in Table 28.

In addition to the results detailed in Table 30, qualitative differences were noted in floc quality and settleability. Floc formed at pH 8.4 exhibited very poor settling characteristics. The floc formed at pH 8.8 settled well, although slowly, and the floc formed at pH 9.2 appeared very heavy and settled rapidly.

#### 2. Influence of Neutralizing Agent on Sludge Volume and Solids Content

In this study, caustic soda ( $\text{NaOH}$ ) and industrial grade lime ( $\text{Ca}(\text{OH})_2$ ) were compared in terms of their effect on the volume of sludge produced in treating wastewater and in terms of dry weight of solids produced. WW1 was first treated with sodium bisulfite for chromium reduction and then by the addition of either caustic soda or lime to achieve a final pH of 9.2. The results (Table 31) showed that treatment with caustic soda produced 6 times less solids in terms of dry weight. The floc formed by caustic soda treatment was, however, very light and settled poorly, yielding a greater sludge volume than lime treatment. The floc was very fragile and could be easily disturbed. Adjustment of the pH was achieved rapidly using caustic soda.

TABLE 30. HYDROXIDE PRECIPITATION STUDY

pH	SS (ml/l)	TSS (mg/l)	Metals Analysis*	Metals (mg/l)			
				Cr	Cd	Ni	Cu
8.4	19.0	720	Total	2.50	0.05	1.00	1.21
			Dissolved	0.10	0.02	0.20	0.02
			Dissolved	0.10	0.20	0.20	0.02
8.8	21.5	750	Total	1.38	0.02	0.20	0.73
			Dissolved	0.11	0.02	0.20	0.04
			Dissolved	0.10	0.02	0.20	0.02
9.2	37.2	1370	Total	1.55	0.02	0.20	0.85
			Dissolved	0.10	0.02	0.20	0.03

\*Total metals analysis was performed on the supernatant after 30 minutes settling time. Dissolved metals was performed by first filtering the supernatant through a 0.45 micron filter.

TABLE 31. COMPARISON OF NEUTRALIZING AGENTS

Neutralizing Agent	pH	SS (ml/l)	TSS (mg/l)
Ca(OH) <sub>2</sub>	9.2	37	1370
Ca(OH) <sub>2</sub>	9.2	39	--
Ca(OH) <sub>2</sub>	9.2	--	1145
Ca(OH) <sub>2</sub>	9.2	--	1215
NaOH	9.2	100	235
NaOH	9.2	92	220

The slow dissolution of lime necessitates very long pH adjustment times if the amount of solids generated is to be minimized. At a pH adjustment time of 30 minutes, overliming (addition of excess lime) is required to achieve the desired pH. As illustrated in Table 30, a much longer pH adjustment time, such as 120 minutes, significantly reduces the amount of overliming and hence reduces the solids generation. Such extended pH adjustment times may not be practical in field applications. However, neutralization efficiency may be increased by the practice of sludge recycle (Reference 2).

### 3. Influence of Water Hardness on Sludge Volume and Solids Content

Water hardness was evaluated as a factor in treatment processes. A low-hardness wastewater (WW1), a high-hardness wastewater (WW2), and a softened high-hardness wastewater (WW3) were each treated with sodium bisulfite to reduce  $\text{Cr}^{+6}$  to  $\text{Cr}^{+3}$ , then adjusted to a pH of 9.2 using lime to determine the effect of water hardness on the volume of sludge produced and the dry weight of solids generated. Flocculation was aided by addition of 2 mg/l Magnifloc® 836A. The results of this study are presented in Table 32.

TABLE 32. INFLUENCE OF WATER HARDNESS

Wastewater	pH Adjustment Time (Minutes)	SS (ml/l)	TSS (mg/l)
WW1	30	37	1370
	30	39	--
	30	--	1145
	30	--	1215
	120	13	265
WW2	30	17	845
	30	17	832
	120	9	250
WW3	30	13	835
	30	13	845
	120	10	295

The effect of overliming to adjust the pH to 9.2 within 30 minutes is illustrated by the vast reduction in solids when a 120-minute reaction time is allowed. As shown by the data, the low-hardness wastewater was observed to produce approximately 48 percent more sludge than the other two wastewaters at a 30-minute reaction time. At the longer reaction time (120 minutes), however, no difference was noted. This suggests that constituents in the low-hardness wastewater may



slow the dissolution of the lime, causing the need for over-liming at the 30-minute reaction time. The exact mechanism of this interference is not explained by the tests performed; however, its effect was determined to be of insignificant consequence to warrant further investigation considering the objectives of this project.

#### 4. Influence of Segregated Treatment of the Chromium Waste Stream

A segregated chromium waste stream was prepared, based on the composition of WW1 and the volume ratio of the chromium waste stream to the total waste streams at the Robins and Hill AFBs. The chromium waste stream consisted of the following weight percentages of each listed component from WW1:

Water	25%
Chromium	100%
Iron	25%
Magnesium	25%
Calcium	25%
Sodium Sulfate	25%

An acid/alkali (A/A) waste stream was prepared containing the balance of components of the WW1 composition in the remaining 75 percent of the water and the pH of this waste stream was adjusted to 6.5.

The segregated chromium waste stream was treated with sodium metabisulfite ( $\text{NaHSO}_3$ ) and sulfuric acid ( $\text{H}_2\text{SO}_4$ ) to reduce  $\text{Cr}^{+6}$  to  $\text{Cr}^{+3}$  then combined with the A/A waste stream. Precipitation was then carried out at pH 9.2 by the addition of lime. The results, presented in Table 33, indicate no appreciable reduction in the amount of sludge generated from segregated chromium reduction using sodium bisulfite.

#### 5. Evaluation of Ferrous Sulfate For Chromium Reduction

The purpose of this study was to evaluate the sludge volume and dry weight of solids produced by using ferrous sulfate ( $\text{FeSO}_4$ ) instead of sodium metabisulfite ( $\text{NaHSO}_3$ ) as a reducing agent. The evaluation was carried out using WW1 and using both segregated and combined chromium waste streams.

The waste streams for  $\text{FeSO}_4$  treatment were first adjusted to a pH of 3.3 because  $\text{FeSO}_4$  dissolves at or below pH 4. As indicated by ORP, reduction occurred at a much slower rate using  $\text{FeSO}_4$  as compared to sodium metabisulfite ( $\text{NaHSO}_3$ ). This slower reaction time could potentially lead to overuse of  $\text{FeSO}_4$  in industrial-scale processes, significantly increasing the sludge generation.

Results of these tests are presented in Table 34. They indicate that  $\text{FeSO}_4$  produces an average of 31 times more sludge, on a dry weight basis, than does  $\text{NaHSO}_3$ . In addition,

the  $\text{FeSO}_4$  process was more difficult to control through ORP and required a longer reaction time.

TABLE 33. EFFECTS OF SEGREGATED Cr(+6) TREATMENT

<u>Chromate Treatment</u>	<u>SS (ml/l)</u>	<u>TSS (mg/l)</u>
Combined	37	1370
	39	--
	--	1145
	--	1215
	100	235
Segregated	35	1210
	33	1190

TABLE 34. CHROMATE REDUCTION TESTS

<u>Wastewater</u>	<u>Treatment</u>	<u>SS (ml/l)</u>	<u>TSS (mg/l)</u>
1	Combined $\text{NaHSO}_3$ pH 2.5	37	1370
1	Combined $\text{NaHSO}_3$ pH 2.5	39	--
1	Combined $\text{NaHSO}_3$ pH 2.5	--	1145
1	Combined $\text{NaHSO}_3$ pH 2.5	--	1215
1	Combined $\text{FeSO}_4$ pH 3.3	160	29800
1	Combined $\text{FeSO}_4$ pH 3.3	133	25400
1	Combined $\text{NaHSO}_3$ pH 2.5	35	1210
1	Combined $\text{NaHSO}_3$ pH 2.5	33	1190
1	Combined $\text{FeSO}_4$ pH 3.3	290	38000
1	Combined $\text{FeSO}_4$ pH 3.3	250	29000
2	Combined $\text{NaHSO}_3$ pH 2.5	17	845
2	Combined $\text{NaHSO}_3$ pH 2.5	17	832
2	Combined $\text{FeSO}_4$ pH 3.3	135	42200
2	Combined $\text{FeSO}_4$ pH 3.3	152	43000

## 6. Oxide Precipitation and Cyanide Oxidation

Ozonation has been applied industrially for the disinfection and oxidation of organic waste and for the oxidation of cyanide. The literature also suggests that ozonation might be a viable means to simultaneously oxidize cyanides and produce metal precipitates superior to those from conventional lime treatment. Since the sludges generated by the ozonation process should be a mixture of oxides and hydroxides they would be

easier to dewater and handle. The preliminary oxide precipitation screening tests used hydrogen peroxide ( $H_2O_2$ ) as a substitute for ozone ( $O_3$ ) because  $O_3$  must be generated immediately prior to its use, and acquisition of an ozone generator was not necessary for screening tests.

During the test, WW1 was treated with sodium metabisulfite ( $NaHSO_3$ ) to reduce the  $Cr^{+6}$  to  $Cr^{+3}$ . The pH of the wastewater was then adjusted to 9.2 and maintained at that level, using caustic soda. Potassium cyanide was then added to the wastewater to achieve an initial cyanide concentration of 100 mg/l. A 30-percent solution of  $H_2O_2$  was then added to the wastewater while monitoring the oxidation reduction potential (ORP) of the wastewater. As the ORP dropped from an initial value of +170 mV to a final value of +130 mV, the suspended precipitate turned from light green to dark brown. The dry weight of sludge generated by this treatment method (Table 35) was comparable to the amount generated by caustic soda treatment; however, the solids generated by the  $H_2O_2$  treatment were easier to handle and lower in volume. However, due to hydrogen gas evolution, an extended settling time of 1.15 hours was required. Homogeneous samples of the sludge and the supernatant were collected, following settling for analysis. The  $H_2O_2$  treatment reduced the cyanide content, as shown in Table 33, from 100 mg/l to 0.18 mg/l. In addition, metal analyses of the unfiltered supernatant, following settling, showed metal levels roughly equivalent to those produced by conventional hydroxide precipitation.

TABLE 35. OXIDE PRECIPITATION

SS (ml/l)	TSS (mg/l)	Cyanide (mg/l)	Metals* (mg/l)			
			Cr (+6)	Cd	Cu	Ni
48	208	0.18	0.82	0.02	0.42	0.20

\*Metals determined in supernatant after 1.15 hours settling.

## 7. Sodium Borohydride Treatment

The purpose of this test was to evaluate sodium borohydride ( $NaBH_4$ ) as a treatment reagent for the simultaneous reduction of  $Cr^{+6}$  and precipitation of mixed heavy metals. A 12-percent solution of  $NaBH_4$  in 40-percent caustic soda ( $NaOH$ ) was added to WW1. Sulfuric acid ( $H_2SO_4$ ) was added to maintain the wastewater at a pH of 9.2. Hydrogen gas evolution occurred; however, a pH of 9.2 limited the duration to approximately 10 minutes after treatment. The  $NaBH_4$  treatment resulted in the formation of a heavy floc processing good settling characteristics. Analysis of the unfiltered supernatant, sampled following

a settling time of 30 minutes, showed complete chromium reduction and a favorable decrease in all metal constituents (Table 36). In addition, the dry weight of sludge formed was comparable to caustic soda precipitation.

TABLE 36. SODIUM BOROHYDRIDE REDUCTION

SS (ml/l)	TSS (mg/l)	Metals* (mg/l)				
		Total Cr	Cr (+6)	Cd	Cu	Ni
35	206	0.58	0.10	0.02	0.91	0.20

\*Metals determined in supernatant after 30 minutes settling.

#### 8. Summary of Technology Screening Tests

Lime treatment of the contrived wastewater produced on the order of 985 mg/l of sludge (dry weight). A portion of this sludge is attributed to the overliming required to achieve proper neutralization within a reasonable time frame.

Treatment using caustic soda (NaOH), hydrogen peroxide ( $H_2O_2$ ), and sodium borohydride ( $NaBH_4$ ) each produced approximately 220 mg/l of sludge for the contrived wastewater. Though dry weights sludge production by these three processes were comparable, significant qualitative differences were noted. In comparison with caustic soda treatment floc, the settling characteristics and quality of the floc produced by  $NaBH_4$  treatment were excellent, floc produced by oxide precipitation was good, and caustic soda treatment produced a floc of a delicate nature with poor settling characteristics. Hydrogen peroxide treatment produced a sludge closer to that characteristic of lime treatment.

Oxide precipitation and  $NaBH_4$  treatment were each observed to present an additional treatment advantage. The oxide precipitation process simultaneously precipitated a combination of metal oxides and hydroxides and effectively oxidized cyanide. Sodium borohydride, on the other hand, simultaneously reduced chromium and precipitated metals, which appeared to be partially precipitated as base metals.

Both  $NaBH_4$  treatment and oxide precipitation using  $H_2O_2$  resulted in gas evolution. This could cause problems with sludge settling in a continuous treatment process, necessitating varied treatment steps. Substitution of  $O_3$  for  $H_2O_2$  in the oxide precipitation process should preclude gas evolution in that process.

Ferrous sulfate ( $\text{FeSO}_4$ ) reduction produced very large quantities of sludge and was slower and more difficult to control by oxidation reduction potential than treatment by sodium metabisulfite ( $\text{NaHSO}_3$ ). Again, segregated chromium reduction had no significant impact on either sludge volume and solids generation.

### C. DETAILED TESTING

This phase of testing was designed to evaluate the treatment technologies found promising in the initial screening tests. Actual wastewaters obtained from Robins AFB and Hill AFB were used in this evaluation, in addition to the contrived wastewater. These two bases were selected for several reasons. First, the sludge characterization study indicated that toxic metals are present in sludges generated at these bases in significant amounts and the sludges failed the EP. Therefore, processes which rendered the sludge nontoxic could be evaluated. Secondly, the waste treatment systems at these locations include segregated cyanide, chromium, and acid/alkali waste streams. Therefore segregated wastewater samples could be collected and treatment variables independently examined during testing.

The technologies selected for this task were again chosen with the aid of the worth assessment model with the information generated during screening tests added to the previous data. The results of the worth assessment exercise are presented in Table 37. The decision criteria and details of the analysis are presented in Appendix B. Using the results of the worth assessment model, the sodium borohydride precipitation and oxide precipitation processes were the selected technologies.

TABLE 37. WORTH ASSESSMENT RESULTS - AFTER SCREENING

<u>Technology</u>	<u>Worth Assessment Score</u>
Sodium Borohydride	0.692
Oxide Precipitation	0.629
Caustic Soda Precipitation	0.526
Ion Exchange plus Batch Treatment	0.506
Lime Precipitation	0.411
Water Softening	0.391

#### 1. Analysis of Waste Streams

It was determined, after collection and analysis of the segregated waste streams from Hill AFB and Robins AFB (Table 38), that the chromium waste stream of Hill AFB was not segregated from the acid/alkali waste stream. This factor would adversely effect the results of this study since segregated

TABLE 38. ANALYSIS OF ACTUAL WASTESTREAMS FROM HILL AFB  
AND ROBINS AFB

			(mg/l)					
Waste Stream	pH		Cd	Cu	Ni	Cr	Cr(+6)	Cn
Hill AFB	Chromium	1.7	7.45	51.6	1.12	9760	8670	--
	Duplicate	-	7.29	53.7	1.12	7680	8790	--
	Cyanide	10.2	4.00	0.34	0.49	0.55	--	4.60
	Duplicate	-	4.00	0.35	0.53	0.27	--	4.30
	Acid/Alkali	7.8	0.21	0.14	0.20	8.97	6.22	--
	Duplicate	-	0.21	0.16	0.20	8.97	5.68	--
	Industrial	6.5	0.48	0.15	0.05	4.52	0.58	--
	Duplicate	-	0.47	0.15	0.05	4.21	0.52	--
	Chromium	3.6	0.14	0.30	0.10	61.2	57.5	--
	Duplicate	-	0.12	0.27	0.10	52.5	52.5	--
Robins AFB	Cyanide	7.7	1.74	0.15	0.10	0.05	--	4.80
	Duplicate	-	1.71	0.14	0.10	0.05	--	4.80
	Acid/Alkali	7.3	0.11	0.08	0.25	0.19	0.13	--
	Duplicate	-	0.12	0.08	0.21	0.18	0.11	--
	Industrial	6.5	0.01	0.34	0.10	0.99	0.06	--
	Duplicate	-	0.01	0.37	0.10	1.04	0.07	--

chromium reduction would not be possible. A contrived waste stream was therefore formulated to be used as a substitute for Hill AFB actual wastewater. The contrived wastewater was formulated with higher metal contents than Robins wastewater in order to subject the treatment methodologies to more vigorous investigation. The final wastewater compositions for the contrived and Robins AFB wastewater used in this study are shown in Table 39. The contrived wastewater was formulated having a hardness and ionic background of WW1. In addition, a background iron concentration of 20 mg/l was added to the contrived wastewater as ferrous sulfate ( $\text{FeSO}_4$ ).

## 2. Baseline Verification

In order to verify the results of the screening tests a baseline verification study was performed on both wastewaters using conventional treatment methodology. The baseline verification study consisted of wastewater treatment control set-points established in the initial studies. An aliquot of the treated waste stream was collected for determination of total suspended solids (TSS). After settling for 30 minutes, settleable solids (SS) were determined. Following clarification, a sample of the supernatant was collected for cyanide and metals analyses. The results are shown in Table 40.

TABLE 39. WASTE STREAM COMPOSITION

Composite	Nickel (mg/l)	Copper (mg/l)	Cadmium (mg/l)	Chromium (mg/l)	Chromium (+6) (mg/l)	Cyanide (mg/l)
Robins	0.10	0.17	0.13	7.56	7.14	0.17
Contrived	1.0	1.7	1.3	75.6	56.8	10.0

TABLE 40. BASELINE VERIFICATION STUDY

Composite	Nickel (mg/l)	Copper (mg/l)	Cadmium (mg/l)	Chromium (mg/l)	Cyanide (mg/l)	TSS (mg/l)	SS (ml/l)
Robins	0.10	0.04	0.01	0.05	0.02	172	9
Contrived	0.10	0.03	0.01	1.49	0.25	900	14

### 3. Determination of Ozone Dosage

During the screening tests, oxide precipitation was simulated with a 30-percent solution of hydrogen peroxide as the treatment reagent. In these detailed tests, a Welsbach Model T-816 Ozone Generator would be used. The ozone was introduced into a rapidly mixed sample through an aeration stone that produced very fine bubbles of the gas. The ozone production rate was determined by measuring the amount of iodine produced by passing the ozone through a 2-percent solution of potassium iodide for set times. The amount of iodine formed, measured by titration with standardized sodium thiosulfate solution, indicated 50 mg/min of ozone was produced.

The chromium waste stream was pretreated to reduce hexavalent chromium using sodium bisulfite ( $\text{NaHSO}_3$ ) prior to compositing with the other waste streams. The composited waste stream was adjusted to pH 9.2 using caustic soda ( $\text{NaOH}$ ). In separate experiments, the waste stream was dosed with the calibrated ozone gas stream for times of 1, 2, 5, 10, and 30 minutes. During ozonation the floc turned from a green-blue to brownish, suggesting oxide formation. In the contrived waste stream, which contained high concentrations of metals, the supernatant became visibly yellow, suggesting that the chromium was being reoxidized to the soluble  $\text{Cr}^{+6}$  form. This was confirmed by analysis (Table 39). Although the results of the ozone dosage study indicated that the reduction in solids observed in the screening tests (using hydrogen peroxide) was valid, the presence of  $\text{Cr}^{+6}$  in the effluent precluded use of this process. The use of ozone did not result in any gas evolution during clarification, such as that which occurred when hydrogen peroxide was used.

In order to investigate the factors involved in chromium oxidation during ozonation an additional experiment was performed. Rapid chromium oxidation is evidently due to the greater redox potential of ozone (compared to peroxide). During ozonation, the pH decreased from its original value of 9.2 to approximately 7. Since the chromium oxidation may be pH-related, the 500 mg/l ozone dosage was repeated while maintaining pH at 9.2, using caustic soda addition (see footnote in Table 41). A reduction was noted in the amount of hexavalent chromium formed.

TABLE 41. OZONE DOSAGE STUDY

Composite	Ozone Dosage (mg/l)	TSS (mg/l)	Nickel (mg/l)	Copper (mg/l)	Cadmium (mg/l)	Chromium (mg/l)
Contrived	50	352	0.10	0.01	0.03	4.81
	100	202	0.10	0.01	0.04	6.95
	250	166	0.10	0.01	0.04	12.8
	500	170	0.10	0.01	0.01	27.8
	1500	196	0.45	1.10	0.94	14.2
	500*	172	0.10	0.01	0.01	12.2
Robins	50	18.2	-	-	-	-
	100	15.1	-	-	-	-
	250	15.3	-	-	-	-
	500	16.4	-	-	-	1.51
	1500	18.7	-	-	-	-

\*pH maintained at 9.2 using NaOH.

The ozonation process was further investigated to determine if ozonation at elevated pH would retard chromium oxidation yet still favor metal oxide formation. Prior to compositing, the contrived chromium waste stream was pretreated with sodium bisulfite at pH 2 to reduce hexavalent chromium. The pH of the composited wastewater was then increased and maintained at pH 10 with caustic soda addition. In separate batches, the wastewater was dosed with various quantities of ozone and total suspended solids (TSS) and metals were determined at each ozone dosage (Table 42). The first visual evidence of oxide formation (color change) occurred at a dosage of 150 mg O<sub>3</sub>/l dosage, but at this point, considerable Cr<sup>+6</sup> formation had occurred as evidenced by high chromium levels in the supernatant. The best effluent quality was found at the 60 mg O<sub>3</sub>/l dosage and the metal levels were comparable to the hydroxide treatment in the screening tests (Table 38). The improvement in TSS concentration is due to the use of caustic soda in this test rather than lime used in the screening test.



TABLE 42. OZONE DOSAGE STUDY CONTRIVED WASTEWATER, pH 10

Ozone Dosage (mg/l)	TSS (mg/l)	Nickel (mg/l)	Copper (mg/l)	Cadmium (mg/l)	Chromium (mg/l)
0	185	0.60	0.91	0.04	4.98
60	126	0.10	0.03	0.01	0.90
60	171	0.10	0.01	0.01	0.66
80	182	0.10	0.13	0.02	4.74
80	148	0.10	0.12	0.01	4.84
150	154	0.10	0.01	0.01	6.47
150	131	0.10	0.02	0.01	6.28
310	160	0.10	0.27	0.07	16.0
310	167	0.10	0.23	0.06	13.64

It was concluded that reoxidation presents a serious disadvantage when applied to chromium bearing waste streams. Ozone simultaneously converts chromium to its soluble hexavalent form while causing the formation of oxides of the other metals present. The widespread presence of chromium in metal finishing wastewater precludes use of this process. Since in the screening tests, hydrogen peroxide treatment showed no evidence of chromium oxidation it was used in the remainder of the oxide precipitation study.

#### 4. Oxide Precipitation

The new test consisted of seven individual runs on each wastewater. Three liters of contrived wastewater per run produced sufficient quantities of sludge for the study. However, the Robins AFB wastewater produced limited quantities of sludge due to low metals concentrations. Hence, 6 liters of this wastewater per run were used.

In each run, the chromium wastestream was pretreated with sodium bisulfite to reduce chromium. The pH of the composed wastewater was increased and maintained at 9.2 using caustic soda. Thirty percent hydrogen peroxide ( $H_2O_2$ ) solution was added while monitoring pH and oxidation reduction potential (ORP). The end point was signaled by an ORP reading of +130 mV. The addition of the  $H_2O_2$  was made over a period of 30 minutes with mixing and pH adjustment. The reaction appeared to lag behind the addition of treatment chemicals. Formation of dark brown precipitate occurred as the ORP approached +130 mV. The dosages required were 3 ml  $H_2O_2$  for the contrived wastewater and 1 ml for the Robins AFB wastewater. Following hydrogen peroxide addition, Magnifloc® 836-A was added at a concentration of 2 mg/l to aid flocculation. Settling was hindered for approximately 30 minutes after treatment due to gas evolution.

The treated wastewater was then filtered under pressure in a 1-liter capacity Millipore pressure filtration system using commercial filter media. A screening study using

several filter medias with the contrived, treated wastewater indicated a polypropylene fabric supplied by P & S Textiles of Skaneateles Falls, N.Y. provided reasonable flow rates and visibly good filtrate quality and this media was used throughout the remainder of the study. Filtration was performed at 20, 30, and 35 psig and the results are shown in Table 43. In the contrived wastewater experiments, the filter cake was removed after each run, weighed, and its moisture content determined. The cake was not easily removed and had to be scraped from the filter. Between runs, the filter cloth was cleaned with dilute nitric acid and rinsed extensively with deionized water. The amount of sludge produced from the actual Robins AFB wastewater was too small to collect from each run, so the filter cake was allowed to build during the six runs.

TABLE 43. FILTRATION STUDY ON ROBINS AFB AND CONTRIVED WASTEWATERS (HYDROGEN PEROXIDE)

Wastewater	Run	Pressure (PSIG)	Filtration Volume (ml)	Filtration Time (sec)	Wet Sludge* Weight (g)
Contrived	15	20	2800	750	2.1
	16	20	2800	715	1.7
	17	30	2800	730	2.3
	18	30	2800	705	2.2
	19	35	2800	680	2.0
	20	35	2800	640	2.1
Robins AFB	22	20	5800	195	1.8**
	23	20	5800	175	"
	24	30	5800	220	"
	25	30	5800	210	"
	26	35	5800	185	"
	27	35	5800	170	"

\*Weight of sludge scraped from filter cloth at percent solids listed in Table 42.

\*\*Weight of sludge from runs 22-27 combined.

A sample of the filtrate from each run was collected for analysis. Results of total dissolved solids (TDS), cyanide (CN), and metals analyses are presented in Table 44. The level of chromium (total) in the treated effluent was determined to fall within the range of 0.18 mg/l to 0.32 mg/l for the actual Robins wastewater and 0.59 mg/l to 1.23 mg/l for the contrived wastewater (within a 95-percent confidence limit). Exceeding the stipulated effluent regulations is therefore unlikely when the oxide precipitation process is employed. The dry weight of sludge produced by the oxide precipitation process was determined to fall within the following ranges with 95-percent confidence limits:

Contrived wastewater	295.9 - 345.4 mg/l
Actual Robins wastewater	73.7 - 101.3 mg/l

The contrived wastewater is used for comparative purposes with the other treatment methods, primarily, due to the larger original metal concentrations and hence greater accuracy of measurement. The average value for dry weight of sludge produced by the oxide precipitation process is 321 mg/l. The difference in dry weight of sludge produced by this process, as compared with the dry weight of sludge produced by lime treatment, averaging 985 mg/l, was determined to be significant with nearly 100 percent confidence.

TABLE 44. ANALYSIS OF HYDROGEN PEROXIDE TREATED AND FILTERED WASTEWATER

Wastewater	Run	TSS (mg/l)	TDS (mg/l)	Cyanide (mg/l)	Ni (mg/l)	Cu (mg/l)	Cd (mg/l)	Cr (mg/l)
Contrived	15	322	2630	0.05	0.2	0.02	0.02	0.85
	16	345	2210	0.05	0.2	0.02	0.02	0.81
	17	320	2150	0.05	0.2	0.02	0.02	0.78
	18	290	2840	0.05	0.2	0.02	0.02	0.78
	19	295	2610	0.05	0.2	0.02	0.02	0.79
	20	342	2370	0.05	0.2	0.02	0.02	1.46
Robins AFB	22	88	5150	0.05	0.2	0.02	0.02	0.19
	23	71	5240	0.05	0.2	0.02	0.02	0.21
	24	78	5320	0.05	0.2	0.02	0.02	0.23
	25	96	4960	0.05	0.2	0.02	0.02	0.21
	26	84	5420	0.05	0.2	0.02	0.02	0.35
	27	108	4210	0.05	0.2	0.02	0.02	0.31

The filter cake collected for each run was subjected to leachability studies using the EPA EP. For this purpose, filter cakes from the contrived wastewater were combined in pairs (Runs 15 - 16, 17 - 18, and 19 - 20). Due to the small quantity of sludge from the Robins AFB wastewater, Runs 22-27 were combined for a single leachability study. Solids contents of the contrived wastewater filter cakes were ranged from 11.8 percent to 10.9 percent. The Robins AFB filter cake had a solids content of 16.0 percent. Results of the leachability studies presented in Table 45, indicate that sludges produced by hydrogen peroxide treatment (oxide precipitation) will be hazardous due to leaching of cadmium and chromium. Calculations indicate that approximately 4 percent of the cadmium and less than 0.5 percent of the chromium is leached during the EP test.

A sample of wastewater containing sludge, treated by the oxide precipitation process, was allowed to stand overnight, after which it was observed to exhibit the yellow color characteristic of  $\text{Cr}^{+6}$ . This indicates the potential instability of the sludge produced by this treatment process.

TABLE 45. ANALYSIS OF SLUDGE PRODUCED BY HYDROGEN PEROXIDE TREATMENT MOISTURE CONTENT AND LEACHABILITY STUDY

Wastewater	Run	Solids %	EP Toxicity (mg/l)			
			Ni	Cu	Cd	Cr
Contrived	15, 16	10.9	6.73	0.81	3.15	19.7
	17, 18	11.8	8.96	0.37	2.74	18.5
	19, 20	11.7	5.14	0.44	5.40	22.7
Robins AFB	22-27	15.4	5.98	0.56	8.15	13.4

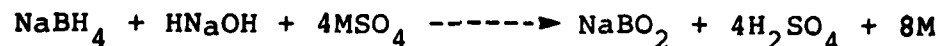
### 5. Sodium Borohydride Treatment

The investigation of sodium borohydride ( $\text{NaBH}_4$ ) treatment was performed in a manner analogous to that for the oxide precipitation process. Sodium borohydride treatment simultaneously reduces hexavalent chromium while precipitating metals rather than simultaneously oxidizing cyanide as was the case for the oxide precipitation process. While most common plating metals are precipitated as base metals by  $\text{NaBH}_4$  treatment, chromium is a notable exception. Although  $\text{NaBH}_4$  treatment reduces  $\text{Cr}^{+6}$ ,  $\text{NaBH}_4$  does not convert it to the base metal. Chromium is most likely precipitated in the alkaline environment as  $\text{Cr}(\text{OH})_3$ . In light of this, sodium borohydride precipitation was performed at pH 8.6, the optimum pH for hydroxide precipitation of  $\text{Cr}^{+3}$ .

Both the contrived wastewater and actual wastewater obtained from Robins AFB were used in this study. The composition of the contrived wastewater is shown in Table 39. This study consisted of seven individual runs on each wastewater. Three liters of contrived wastewater per run produced sufficient quantities of sludge for this study. However, the Robins AFB wastewater again produced very small quantities of sludge so 6 liters per run was used.

The cyanide wastestream was pretreated by alkaline chlorination prior to compositing with the other wastestreams. Sodium borohydride was added as a 12-percent solution stabilized in 40 percent caustic soda ( $\text{NaOH}$ ). During the addition of the  $\text{NaBH}_4$  reagent, the pH was maintained at  $8.6 \pm 0.5$  by sulfuric acid ( $\text{H}_2\text{SO}_4$ ) additions. The reaction was carried out at room temperature with 30 minutes mixing time.

The amount of sodium borohydride used was determined by adding approximately three times the theoretical amount necessary to reduce each heavy metal constituent to its elemental form. Each sodium borohydride molecule provides eight electrons, as shown below:



Based on this premise, 4 milliliters of the 12 percent  $\text{NaBH}_4$  reagent were added to the 3 liters of contrived wastewater and 1 ml was added to the 6 liters of Robins AFB wastewater.

During  $\text{NaBH}_4$  addition, the wastewater was observed to rapidly darken, forming a brown precipitate. Hydrogen gas formation accompanied the metal reduction and settling was hindered for approximately 1 hour. The formation of large heavy floc was aided by addition of 2 mg/l Magnifloc® 836-A. Small dense particles, in addition to large heavy floc, were observed in the settled sludge providing qualitative evidence of base metal formation.

The treated wastewater was then filtered under pressure in the Millipore pressure filtration apparatus. In the contrived wastewater tests, the filter cake was removed after each run. The cake was weighed and its moisture content determined. Most of the filter cake was readily loosened with a spatula. Between runs, the filter was cleaned with dilute nitric acid and rinsed extensively with deionized water. The amount of sludge produced from the actual wastewater from Robins AFB was too small to collect from each run and so the filter cake was allowed to build during the six runs (8-13). During filtration, there was no evidence of clogging, although the initial filtration rate was much higher than subsequent rates. Filtration was performed at pressures of 20, 30, and 35 lb/in<sup>2</sup>g (Table 46).

TABLE 46. FILTRATION STUDY ON ROBINS AFB AND CONTRIVED WASTEWATERS (SODIUM BOROHYDRIDE)

Wastewater	Run	Pressure (PSIG)	Filtration Volume (ml)	Filtration Time (sec)	Sludge* Weight(g)
Contrived	1	20	2800	880	1.9
	2	20	2800	865	2.0
	3	30	2800	605	2.0
	4	30	2800	630	2.0
	5	35	2800	520	1.8
	6	35	2800	515	1.9
Robins AFB	8	20	5800	245	1.9**
	9	20	5800	310	"
	10	30	5800	215	"
	11	30	5800	230	"
	12	35	5800	195	"
	13	35	5800	195	"

\*Weight of sludge scraped from filter cloth at percent solids listed in Table 48.

\*\*Weight of sludge from runs 8-13 combined.

A sample of the filtrate from each run was collected for analysis. Results of total dissolved solids (TDS), cyanide (CN) and metals analyses are presented in Table 47. In addition, total suspended solids (TSS) of the mixed unfiltered sludge is shown in this table.

TABLE 47. ANALYSIS OF SODIUM BOROHYDRIDE TREATED AND FILTERED WASTEWATER

Run	TSS (mg/l)	TDS (mg/l)	Cyanide (mg/l)	Nickel (mg/l)	Copper (mg/l)	Cadmium (mg/l)	Chromium (mg/l)	Cr(+6) (mg/l)
1	314	2930	0.05	0.1	0.01	0.01	0.05	0.05
2	310	2370	0.05	0.1	0.01	0.01	0.05	0.05
3	286	2930	0.05	0.1	0.01	0.01	0.05	0.05
4	330	2380	0.05	0.1	0.01	0.01	0.05	0.05
5	306	2220	0.05	0.1	0.01	0.01	0.05	0.05
6	306	2670	0.05	0.1	0.01	0.01	0.05	0.05
8	84	5900	0.05	0.1	0.02	0.01	0.05	0.05
9	76	6220	0.05	0.1	0.01	0.01	0.05	0.05
10	81	5890	0.05	0.1	0.01	0.01	0.05	0.05
11	75	3900	0.05	0.1	0.02	0.01	0.05	0.05
12	66	6180	0.05	0.1	0.01	0.01	0.05	0.05
13	78	5660	0.05	0.1	0.01	0.01	0.05	0.05

The pollutant levels were very low in the filtered effluent for both the Robins wastewaters and the contrived wastewaters. Samples from the contrived wastewaters (Run 7) and Robins wastewaters (Run 14) were allowed to settle after the gas evolution ceased. A sample of the unfiltered supernatant was analyzed (Table 48). The pollutant metal levels were similar to the filtered values for nickel, cadmium and copper. The chromium levels were somewhat higher.

TABLE 48. ANALYSIS OF SODIUM BOROHYDRIDE TREATED AND UNFILTERED WASTEWATER

Wastewater	Run	SS (ml/l)	Nickel (mg/l)	Copper (mg/l)	Cadmium (mg/l)	Chromium (mg/l)
Contrived	7	110	0.01	0.02	0.01	0.44
Robins AFB	14	10	0.01	0.01	0.01	0.09

The low levels of Cd, Cu, and Ni are consistent with the premise that  $\text{NaBH}_4$  treatment precipitates these as base metals. The higher levels of chromium reflect that this metal

is precipitated as a lighter hydroxide floc. Close visual inspection of the supernatant revealed small quantities of suspended floc, even after several hours of settling.

The dry weight of sludge produced by the  $\text{NaBH}_4$  treatment process was determined to fall within the following ranges with 95 percent confidence:

Contrived wastewater	293.7 mg/l - 323.6 mg/l
Actual Robins wastewater	70.2 mg/l - 83.2 mg/l

The results of the  $\text{NaBH}_4$  treatment (runs 1-6 Table 47) compared with lime treatment (WW1, 30 min Table 32) show the  $\text{NaBH}_4$  produced almost 75 percent less sludge on a dry weight basis.

The filter cake collected for each run was analyzed for moisture content and then subjected to leachability studies using the EP test. For this purpose, filter cakes from the contrived wastewater were combined in pairs (Runs 1, 2, 3, 4, 5 and 6). Due to the small quantity of sludge from the Robins AFB wastewater, Runs 8-13 were combined for a single leachability study. Solids contents of the contrived wastewater filter cakes ranged from 14.2 to 14.7 percent. The filter cake produced from the combined filtration of 36 liters of Robins wastewater had a solids content of approximately 32 percent.

Results of the leachability study, presented in Table 49, indicate that sludges produced by  $\text{NaBH}_4$  precipitation are hazardous due to the leaching of cadmium and chromium during the EP test. Calculations indicate that less than 0.5 percent of the chromium available in the sludge leaches during the EP test. However, approximately 12 percent of the precipitated cadmium becomes soluble at a pH of 5.

TABLE 49. ANALYSIS OF SLUDGE PRODUCED BY SODIUM BOROHYDRIDE TREATMENT

Moisture Content and Leachability Study						
Wastewater	Run	Solids %	EP Toxicity (mg/l)			
			Nickel	Copper	Cadmium	Chromium
Contrived	1, 2	14.7	13.2	0.74	12.4	28.3
	3, 4	14.6	14.5	1.20	12.5	16.7
	5, 6	14.2	9.46	1.21	9.84	10.3
Robins AFB	8-13	31.6	8.56	2.03	20.3	13.7

## 6. Summary of Detailed Testing

The evaluation of oxide precipitation using ozone revealed a serious disadvantage to this treatment methodology. Ozone rapidly oxidizes chromium to its soluble hexavalent form.

This results in unacceptably high chromium levels in the effluent. Hydrogen peroxide ( $H_2O_2$ ) treatment was, therefore, further evaluated as a method to accomplish oxide precipitation. While the preliminary screening test did not show evidence of chromium oxidation, it did occur at a much reduced rate. Large excesses of  $H_2O_2$  produced yellow supernatants indicative of high levels of hexavalent chromium ( $Cr^{+6}$ ). Also allowing the unfiltered  $H_2O_2$  treated wastewater to stand overnight produced higher  $Cr^{+6}$  levels. This indicates that the sludge produced by the  $H_2O_2$  treatment may be unstable posing potentially serious problems. The dry weight of sludge produced by oxide precipitation, averaging 321 mg/l, was approximately one-third the amount produced by conventional lime treatment and was of better handling quality. The difference in dry weight of sludge produced was determined to be significant with nearly 100 percent confidence. The sludge failed the EP test, leaching hazardous quantities of both cadmium and chromium by RCRA definition. The effluent produced by the oxide precipitation process using  $H_2O_2$  was found to meet federal effluent guidelines with a 95-percent confidence level. This effluent, however, did not meet the AF lower objective levels defined in Table 25.

Sodium borohydride treatment of the wastewaters was demonstrated to be a viable treatment methodology for mixed plating and metal finishing wastewaters. Many common metals are simultaneously precipitated as base metals and hexavalent chromium is reduced and precipitated as a hydroxide. The mixed hydroxide/base metal sludge filtered well and a very high quality effluent was produced. The dry weight of sludge generated by  $NaBH_4$  treatment, averaging 309 mg/l, approximately one-third that produced by lime treatment, was of superior handling quality. The difference in dry weight of sludge was determined to be significant with 100 percent confidence. Additional treatment steps may be required since hydrogen evolution hampers sludge settling. The sludge produced by this treatment process failed the EP test, leaching hazardous quantities of both cadmium and chromium. The effluent produced by the  $NaBH_4$  treatment process was determined to meet federal effluent guidelines with a 95-percent confidence level. In most cases, the concentration of metals was below detection limits. The sodium borohydride treatment was the only process which approached the AF's lower objective levels (Table 25).

The oxide precipitation and sodium borohydride treatments were determined to reduce the dry weight of sludge produced in comparison with lime treatment with close to 100 percent confidence. However, the difference in average values of dry weight of sludge produced by these two experimental processes does not display statistical significance. Thus, on the basis of the data obtained, there is no meaningful difference between the amounts of sludge, on a dry weight basis, produced by oxide precipitation and sodium borohydride treatment.



## SECTION VI

### INVESTIGATING SLUDGE TREATMENT TECHNOLOGIES

#### A. INTRODUCTION

The objective of this phase was to investigate methods of reducing costs associated with the disposal of treatment sludges. Disposal costs are a function of the sludge volume, hauling distance, and disposal fee, hence the overall cost could be reduced by either reducing the sludge volume or detoxifying the waste. The latter method would allow for delisting of the waste (see Section II) and its disposal in sanitary landfills with relatively low disposal fees. Sludges used during this phase of the project were generated by using sodium borohydride and the two chemicals currently used at ALCs, lime and caustic soda to treat the contrived wastewater.

The technologies selected for investigation were identified from the literature or developed by project personnel. Initial screening tests were performed to determine the applicability of the technologies to AF sludges.

After the screening tests were complete, the results were evaluated and several technologies were selected for additional testing. More detailed tests were then performed to develop design criteria and cost data. The results of the screening tests and detailed tests are contained in this section.

#### B. SCREENING TESTS

The following technologies were identified as potential sludge treatment techniques:

- Heat treatment
- Barium compound addition
- Solidification
- Sludge aging
- Leaching plus segregated treatment or recovery
- Sludge washing

To evaluate the potential applicability of these technologies, sludge was generated using the sodium borohydride precipitation

process and the contrived wastewater used in the metal removal study (Table 50). The cyanide wastestream was pretreated by alkaline chlorination prior to mixing with the other wastestream components. The sludge produced from individual batches was filtered, mixed, and analyzed for percent moisture, total metals and EP toxicity. Approximately 350 grams of sludge was produced with a moisture content of 86.0 percent. The total metals in the sludge are shown in Table 51. EP extraction results are shown in Table 52.

TABLE 50. COMPOSITION OF CONTRIVED WASTEWATER FOR TASK III COMPREHENSIVE STUDIES AND TASK IV

<u>Constituent</u>	<u>Concentration, mg/l</u>	<u>Chemical Used</u>
Cr <sup>+6</sup>	56.8	CrO <sub>3</sub>
Cr <sup>+3</sup>	18.8	Cr(NO <sub>3</sub> ) <sub>3</sub> · 9H <sub>2</sub> O
Cd <sup>+2</sup>	1.3	Cd(NO <sub>3</sub> ) <sub>2</sub> · 4H <sub>2</sub> O
Cu <sup>+2</sup>	1.7	CuSO <sub>4</sub> · 5H <sub>2</sub> O
Ni <sup>+2</sup>	1.0	NiCl <sub>2</sub> · 6H <sub>2</sub> O
Fe <sup>+2</sup>	20.0	FeSO <sub>4</sub> · 7H <sub>2</sub> O
CN	10.0	KCN
CaCO <sub>3</sub>	80	CaCO <sub>3</sub>
Mg <sup>+2</sup>	40	MgCL <sub>2</sub>
Na <sub>2</sub> CO <sub>3</sub>	0	Na <sub>2</sub> CO <sub>3</sub>
Na <sub>2</sub> CO <sub>4</sub>	100	Na <sub>2</sub> SO <sub>4</sub>

TABLE 51. TOTAL METALS ANALYSIS RESULTS SODIUM BOROHYDRIDE TREATMENT SLUDGE

<u>Metal</u>	<u>mg/kg Wet Sludge (86% Moisture)</u>
Cr <sup>+6</sup>	33.5
Cr, total	33700
Cd	880
Ni	410
Cu	534

TABLE 52. EP EXTRACTION RESULTS

Description	Cr <sup>+6</sup>	Cr, total	Cd	Ni	Cu
	mg/l				
Sludge Characterization-Baseline	0.25	26.0	11.9	6.09	1.20
Solidification	0.36	0.53	0.06	0.10	0.05
Heat Treatment at 120°C (250°C)	0.26	0.83	0.32	0.54	0.04
Heat Treatment at 160°C (500°C)	2230	2520	16.3	74.3	0.85
Leaching at pH 3.5	0.25	16.4	10.9	4.76	0.55
Leaching at pH 7.0	0.25	18.1	11.3	4.61	0.80
Leaching at pH 10.5	0.25	13.9	10.1	4.52	0.38
Barium Compound Addition	0.25	17.6	10.05	5.90	0.60
Sludge Aging	0.25	28.0	13.8	6.12	0.72
EP Toxicity	--	5.0	1.0	--	--
Maximum Conc. for Delisting	--	1.5	0.3	20.0	--

Information from the literature and the results of the screening tests for each of the identified technologies are as follows:

#### 1. Solidification

The use of solidification for rendering wastes non-hazardous has been widely investigated. For the treatment of inorganic sludges, the most effective systems involve the use of Portland cements, lime based mortars, lime-pozzolan cements such as lime and fly ash, and some mixed inorganic-organic materials (Reference 7).

Portland cement, the most common material, is prepared by sintering fixed portions of calcium carbonate and aluminosilicate in a kiln at a very high temperature. This process produces a powder which is primarily made up of calcium silicates. The silicates give the cement its property of hardening in the presence of water (Reference 8).

The composition of commercial Portland cement is a mixed system of three oxides--calcium, silicon and aluminum--as well as various impurities such as iron oxide and lime. Hydration of silicate compounds is largely responsible for the hardening or "setting" of Portland cement/water mixtures. The hydration products form a colloidal calcium-silicate-hydrate gel. In the hardened cement this gel comprises about 70 percent by volume of the material and thus forms the main bonding between unreacted cement and other crystalline products of hydration (Reference 8). These hydration products are of most interest in treating persistent inorganic wastes.

Another material which has been utilized for solidifying industrial wastes is fly ash, a byproduct of pulverized-coal-burning power plants. Fly ash is typically used as an additive to a cement/waste mixture to improve its bonding characteristics. Fly ash has also been used with lime/waste mixtures in a commercial application (Reference 9).

The physical and chemical phenomena associated with solidification of wastes have been well investigated (Reference 7). As reported in the literature, the colloidal metal hydroxides present in sludge become members of the cement matrix. As water is added or the available moisture is utilized the cement particles begin to hydrate and form the calcium-silicate-hydrate gel. Along with this gel formation comes the formation of various crystalline hydration products such as calcium hydroxide and various heavy metal hydroxides. These products form in the interstices of the cement matrix. During the final stages of hydration the gel swells to the point where particle overlap occurs and silica fibrils develop. Eventually, all of the hydration byproduct crystals grow to their maximum size and are either overlapped by fibrils or grow into the particle gel itself. The interlocking of the fibrils and the formation of various hydration products binds the cement and other components of the mix into a rigid mass (Reference 7).

Unreactive materials that are blended with the cement prior to gel formation and setting can become encased in the solid matrix. These materials are not, in fact, chemically bound to the solid but their mobility is restricted because of physical entrapment (Reference 7).

Portland cements and lime-based materials have been used to immobilize radioactive and military wastes (Reference 10), heavy metal industry waste sludges from plating operations (Reference 9), toxic industrial wastes such as arsenic-bearing sludges, and for stabilizing silts and solids for land reclamation (Reference 7).

A problem encountered in achieving stabilization is that each waste has its own particular set of chemical requirements. Slight alterations in chemical additives to the unreacted cement may be required to achieve the most stable product. Avenues for approaching this problem must be addressed on a case-by-case basis.

After passage of the RCRA hazardous waste regulations the status of solidification technologies with respect to delisting was unclear, since EPA indicated that there was some concern over the long-range stability of solidified hazardous wastes. More recently, however, the EPA's "multiple"-extraction procedure allows a waste generator to test for delisting a solidified material. This multiple procedure was not developed at the start of this project so to determine the effectiveness of solidification on AF sludges, the following test was performed: Ten grams of wet (14 percent solids) sludge was mixed with 50 grams Portland cement and 60 grams fly ash. Sixty grams of water was added and the sample was well mixed. This mixture was poured into a cylindrical paper mold, positioned on a watch glass, and cured in an oven at 65°C (150°F) for 48 hours. The tube was slowly cooled, keeping the paper mold moistened.

This curing produced a solid weighing 119.4 grams. This entire sample was then subjected to the Structural Integrity Procedure as specified by RCRA test procedures. The sample broke into three large pieces and a small amount of fragmented material. One hundred grams of the sample was then tested using the EP toxicity procedure.

The results of the extraction (Table 52) revealed that the sludge is nonhazardous. During the extraction, the particles remained intact. Although the sludge was nonhazardous the mass of sludge produced was increased about 10-fold.

## 2. Gel Destruction

The hydroxide precipitation process yields a gelatinous precipitate that absorbs water and holds it tenaciously making these precipitates difficult to dewater. Experiments conducted previously (References 1,11) showed evidence that when a freshly formed inorganic gel is allowed to stand (or age) at

room temperature and humidity, changes occur in the solid masses which are chemical and physical in nature. The gel becomes less hydrous; its solubility, peptizability, and absorption capacity decreases. It appears that, with time, the metal hydroxides, typical of fresh sludge, are converted to metal oxides. The oxides of chromium, cadmium, nickel, copper and zinc have low water solubility, less than 0.1 mg/l, and could be rendered nontoxic. Therefore, three methods of gel destruction were investigated: sludge aging, heat treatment and chemical destruction using ammonium chloride.

#### a. Sludge Aging

Results of previous work indicated that sludge aging could detoxify plating sludges in 90 days. Aging also proved to be a reasonably good method of sludge volume reduction since the majority of interstitial water evaporated during the process. Using similar test procedures, a sodium borohydride sludge sample was aged for 30 days at ambient temperature and humidity conditions.

The EP test results, presented in Table 52, do not indicate that any significant reduction in leachability occurred during the 30-day test period.

#### b. Heat Treatment

Heat treatment at low or moderate temperatures was investigated as a means of accelerating the "aging" process. Twenty grams of sludge (wet weight) were heated for an 8-hour period at temperatures of 120°C (250°F) and 260°C (500°F). The final weight of the 120°C sample was reduced to 2.6 grams and the 260°C sample was reduced to 2.3 grams. The samples were then extracted by the EP toxicity procedure (based on their final weights). The 260°C treated sludge showed immediate evidence of leaching. The 16-fold extraction water turned dark yellow indicating large amounts of hexavalent chromium. The 120°C heat treatment resulted in a nonhazardous sludge. The leachability of all metals was dramatically reduced. In addition, the quantity of sludge was reduced eightfold. The results of the heat treatment studies are presented in Table 52.

#### c. Sludge Washing

It was hypothesized that sludge gels could be destroyed chemically by changing the ionic environment, thereby disrupting the attractive forces present in the colloids of the gel. To accomplish this goal ammonium chloride, a relatively inexpensive salt was selected as the washing compound.

The screening test was conducted by combining equal weights of dewatered sodium borohydride or lime sludge with a 0.1 percent ammonium chloride solution in plastic containers and mixing vigorously for 30 seconds. The mixtures were

then dewatered under conditions identical to the initial dewatering step and the sludge was weighed. The results (Table 53) showed 20-25 percent sludge weight decreases. The effect of washing was most noticeable with the sodium borohydride sludge which lost most of its gelatinous appearance. The EP test (Table 53) indicated that washing increased leaching in the sodium borohydride sludge and had little effect on the leaching characteristics of the lime sludge.

A combined test was performed during the screening phase to determine if heat treatment of a washed sludge had any additional effect on sludge leaching. The results show combining these processes (Table 53) increased the leaching of copper and a decreased leaching of cadmium and chromium as compared with sludge that was only washed.

### 3. Leaching Study

Twenty-gram quantities of sludge were subjected to leaching with three equal consecutive aliquots of pH adjusted water totalling a ten-fold water to sludge ratio. Three pH values were tested (pH 3.5, 7.0, and 10.5). Acidic adjustments of deionized water were performed using  $H_2SO_4$ . Basic adjustments were made with NaOH.

The sludge was mixed with an aliquot of pH adjusted water for approximately 10 minutes, centrifuged and decanted. This procedure was repeated with each aliquot. The extracts were analyzed for metals (Table 54) and the sludge subjected to EP extraction. The EP results are shown in Table 52. The level of chromium leachability was significantly reduced, but still exceeded the RCRA limits for toxicity. The level of Cd leaching remained essentially unchanged. Ni and Cu showed moderate reductions.

### 4. Barium Compound Addition

This experiment used barium acetate to aid in heavy metal precipitation. Barium acetate was added at a ratio of 2.6 parts to 1 part Cr during  $NaBH_4$  treatment at pH 8.6. The resulting sludge was filtered with the filtrate analyzed for metals, and the sludge extracted by the EP toxicity procedure. The results, presented in Tables 52 and 54, indicate a significant decrease in Cr leaching. However, the sludge is still classified as hazardous due to levels of Cr and Cd leaching.

## C. DETAILED TESTING

The results of the screening tests showed that several promising technologies exist for reducing sludge volumes and/or reducing the leaching of hazardous contaminants. The following technologies were selected for further testing:

- Solidification

TABLE 53. SLUDGE WASHING - SCREENING TESTS

Effect on Sludge Weight

<u>Sludge</u>	<u>Initial Weight (g)</u>	<u>Volume of NH<sub>4</sub>Cl Added<sup>1</sup> (ml)</u>	<u>Weight of Sludge After Dewatering (g)</u>	<u>% Change in Sludge Weight</u>
NaBH <sub>4</sub> (dewatered)	40	40	30	25%
Lime (dewatered)	22	22	14.5	21%

<sup>1</sup>0.1% NH<sub>4</sub>Cl solution.

EP Results

<u>Sludge</u>	<u>Cr<sub>T</sub> mg/l</u>	<u>Cd mg/l</u>	<u>Ni mg/l</u>	<u>Cu mg/l</u>
NaBH <sub>4</sub> (no treatment)	4.02	4.73	1.87	0.10
NaBH <sub>4</sub> (washed)	11.18	5.71	2.15	0.23
Lime (no treatment)	< 0.10	0.04	< 0.20	0.10
Lime (washed)	< 0.10	< 0.02	< 0.20	0.09
NaBH <sub>4</sub> (washed & heat treatment)	3.55	1.39	3.48	4.11



TABLE 54. LEACHATE AND FILTRATE ANALYSIS

<u>Task</u>	<u>Description</u>	<u>mg/l</u>			
		Cr +6	Cr, total	Cd	Ni
					Cu
4.1.4	Leaching at pH 3.5	0.25	16.4	10.9	4.76
4.1.4	Leaching at pH 7.0	0.25	18.1	11.3	4.61
4.1.4	Leaching at pH 10.5	0.25	13.9	10.1	4.52
4.1.5	Barium Compound Addition	0.05	0.05	0.01	0.10
					0.55
					0.80
					0.33
					0.01

- Heat treatment
- Barium compound addition
- Sludge washing
- Sludge aging\*

Laboratory experiments under this detailed testing phase were conducted over a period of several months with each new set of tests based on results of the prior tests. The five technologies were applied to sludges generated by sodium borohydride, sodium hydroxide, and lime precipitation.

Prior to each set of tests, a sufficient volume of sludge was generated from contrived wastewater, with the exception of the barium compound addition test which is done in conjunction with the precipitation process. The sludges were filtered and an EP Extraction was performed on each to provide baseline data on the leaching characteristics of the sludges.

#### 1. Solidification

During the screening tests, sludge solidification using Portland cement and fly ash was investigated. A 10-gram sample of dewatered sodium borohydride sludge (14 percent solids) was mixed with 50 grams cement, 60 grams fly ash and 60 grams water. The mixture (1.3 percent sludge on a dry weight basis) was placed into a cylindrical paper mold and cured in an oven at 65°C (150°F) for 48 hours. The resultant material was well solidified and resisted breaking when subjected to the integrity test. The results of an EP showed that the material leached less than 1 mg/l of each metal; thereby meeting the delisting criteria.

One objective of the Phase 2 tests was to determine the maximum percentage of sludge that could be added without making a hazardous solid or one that easily crumbled or powdered. Another objective was to determine if the solidification process was applicable to lime and sodium hydroxide sludges. Further, since the energy intensiveness of oven curing would add to the operating costs, air curing would also be investigated in the detailed testing phase.

The first test in this detailed testing phase was a composition study where various ratios of sodium borohydride sludge, fly ash, and cement were mixed and cured in an oven at 65°C for 48 hours. Data and observations from the initial

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\*The screening results for sludge aging were not impressive; however, it was selected for detailed testing because a previous project showed some success with this technique.

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AN INVESTIGATION OF TECHNOLOGIES FOR HAZARDOUS SLUDGE  
REDUCTION AT AFL (C) (U) CENTEC CORP RESTON VA  
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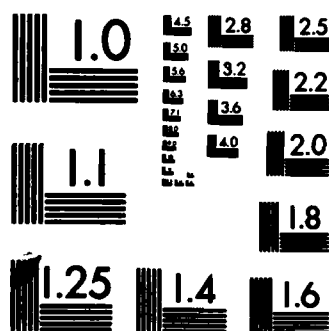
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MICROCOPY RESOLUTION TEST CHART  
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composition study are presented in Table 55. After curing, the samples were analyzed using the EP. During the EP each of the samples used the maximum amount of acetic acid with the final extract pH ranging from 9.8 to 10.9. The EP results are presented in Table 56. The material tested nonhazardous up to 15.3 percent, the maximum used in the testing.

TABLE 55. SOLIDIFICATION - COMPOSITION STUDY OBSERVATIONS

Sludge (g)	Fly Ash (g)	Cement (g)	Water (g)	% Sludge	Integrity*
10	60	50	60	1.6	Very good
20	50	50	60	3.5	Very good
30	40	50	60	5.7	Good
40	30	50	60	8.3	Acceptable
50	20	50	60	11.4	Poor
60	10	50	60	15.3	Very good

\*Integrity is a relative term which describes the ability of the solidified material to hold together under pressure. Samples with very good integrity are not easily broken and do not powder, very poor samples tend to crumble easily.

TABLE 56. SOLIDIFICATION - COMPOSITION STUDY EP RESULTS

(mg/l)					
% Sludge	Cr <sup>+6</sup>	Cr <sub>T</sub>	Cd	Ni	Cu
1.6	0.14	0.46	0.06	<0.20	0.06
3.5	0.62	0.48	<0.02	<0.20	<0.05
5.7	0.40	0.51	<0.02	<0.20	0.05
8.3	0.84	0.62	<0.02	<0.20	<0.05
11.4	0.40	0.35	<0.02	<0.20	<0.05
15.3	0.78	0.55	<0.02	<0.20	<0.05

Note: Oven temperature set at 65°C, NaBH<sub>4</sub> sludge used in testing.

Additional tests were performed during Phase 2 to further investigate the solidification technology. First, the sodium borohydride sludges were again used in a composition study in an attempt to maximize the percentage of sludge in the mixture. During this test, a minimal amount of water was used in making the mixtures. The percentage of sludge in the samples ranged from 4.5 to 18.2 percent. The samples were cured in an oven (65°C) for 8 hours. All samples cured to an acceptable integrity. An EP was performed on the sample with the highest percentage of sludge. The results of the test are presented in Table 57, showed the material tested nonhazardous.

TABLE 57. SOLIDIFICATION - COMPOSITION STUDY (II)

Wet Sludge (g)	Dry Sludge (%)	Fly Ash (g)	Cement (g)	Water (g)	Integrity
10	4.5	21	21	19.5	Very good
20	9.0	20	20	11.5	Very good
30	13.6	19	19	3.5	Very good
40	18.2	18	18	0	Good

Dry Sludge (%)	EP Results				
	Cr <sup>+6</sup>	Cr	Cd	Ni	Cu
18.2		0.42	0.02	0.20	0.05

A curing time study was also performed during Phase 2. For this test, 10 grams of sodium borohydride sludge was solidified with 60 grams fly ash, 50 grams cement and 60 grams water. The mixtures were cured in the same manner as the composition study samples except for varying curing times (8 hr, 24 hr, 48 hr). After curing, each sample was inspected and all appeared adequately cured and were classified as "very hard." The EP test was applied to each sample and again all available acetic acid was used with final extract pH ranging from 9.8 to 10.7. The EP results for the curing time study are presented in Table 58. Again, all samples tested nonhazardous.

TABLE 58. SOLIDIFICATION - CURING TIME STUDY EP RESULTS

Curing Time (hr) <sup>a</sup>	% Sludge	Cr <sup>+6</sup>	Cr <sub>T</sub>	Cd	Ni	Cu
8	1.6	0.24	0.35	0.02	0.20	0.05
24	1.6	0.22	0.40	0.02	0.20	0.05
48	1.6	0.14	0.46	0.06	0.20	0.06

<sup>a</sup>Oven temperature set at 65°C.

To determine if solidification was applicable to sludges currently produced at the ALCs, the methodology was applied to a lime sludge. As a screening test, one sample was mixed containing 50 grams sludge (42 percent solids), 50 grams cement, 20 grams fly ash and 60 grams water. The sample was cured at 65°C for 48 hours. After curing, the leaching properties of the sample were tested, using the EP. The results are presented in Table 59.

A second lime sludge test (Sets 2 and 3) was conducted to determine (1) if the mixtures could be cured under atmospheric conditions rather than oven curing and (2) the approximate time for curing. Initially (Set 2), four samples were mixed with the same composition (80 grams wet sludge at 42 percent solids, 36 grams cement, 36 grams fly ash, 40 grams water)\* and put into cylindrical molds. The samples were cured in air at room temperature, and every 24 hours a sample was examined to determine if curing was complete. The results of the test, presented in Table 59, showed curing complete after 2 days.

A combined lime solidification study was then performed (Set 3) to further evaluate the effect of composition and curing methods. In the combined study, four different compositions were used with the percent sludge varying from 31.8 percent to 79.5 percent (dry weight basis). Two samples were prepared for each mixture (eight samples total) and placed into cylindrical molds. For each mixture, one sample was cured at atmospheric conditions and one was placed in a closed 100 ml plastic container. The closed container was used to determine if the mixtures could "set-up" without drying. The conditions in the closed container approximate the conditions in a large mold which would be required on a full-scale application. In such a situation, the sludge mixture in the center of the mold would not be exposed to the atmosphere and drying would therefore be relatively slow. The samples were observed on a daily basis to determine when the sample cured. After curing, the samples were examined for integrity. The results of the combined study presented in Table 59 showed no detrimental effect of enclosing the sample on curing, although curing took longer. The maximum percentage of sludge that could be mixed with the solidifying materials was 48 percent.

Various materials and processes are being marketed for the solidification and detoxification of hazardous wastes. One such product\*\* was tested to determine if some potential exists for its use. This product was selected because it did not contain cement or fly ash and therefore was distinctly different

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\*Equivalent to 32 percent sludge solids on a dry weight basis.

\*\*Anschutz Absorbent for hazardous liquid waste solidification.

TABLE 59. SOLIDIFICATION--LIME SLUDGE

Set 1 - Composition Study  
35% Solids

## Composition

<u>Sludge (g)</u> <u>wet/dry</u>	<u>% Solids</u> <u>dry</u>	<u>Cement</u> <u>(g)</u>	<u>Fly Ash</u> <u>(g)</u>	<u>Water</u> <u>(g)</u>	<u>Integrity</u>
50/17.5	20	50	20	60	Very good

## EP Results (mg/l)

<u>Material</u>	<u>Cr</u>	<u>Cd</u>	<u>Ni</u>	<u>Cu</u>
Sludge only	.15	.02	.54	.15
Solidified material	.37	.03	.2	.2

## Set 2 - Air-Curing Study

<u>% Sludge (Dry)</u>	<u>Curing Time</u> <u>Days</u>	<u>Integrity</u>
32	1	good
32	2	Very good
32	3	Very good
32	4	Very good

## Set 3 - Combined Study

	<u>Sludge (g)</u> <u>Wet/Dry</u>	<u>% Sludge</u> <u>(Dry Wt.)</u>	<u>Cement</u> <u>(g)</u>	<u>Fly</u> <u>Ash (g)</u>	<u>Water</u> <u>(g)</u>	<u>Required</u> <u>Curing</u> <u>Time-days</u> <u>(Open/Closed)</u>	<u>Integrity</u> <u>(Open/Closed)</u>
1	40/16.8	31.8	18	18	10	1.5/3	very good/very good
2	60/25.2	47.7	13.8	13.8	5	1.5/3	good/good
3	80/33.6	63.6	9.6	9.6	0	1.5/-	poor/poor
4	100/42.0	79.5	5.4	5.4	0	1.5/-	very poor/very poor



from other solidification mixtures tested previously under this project. This material is characterized by its manufacturers as a mineral absorbent.

The material was tested with lime, sodium borohydride and sodium hydroxide sludges. The mixtures selected were approximately equal to the optimal sludge solids/total solids ratios found for each sludge using the cement fly ash mixture (no directions for using the material were supplied by the manufacturer). Lower ratios were not considered since they would increase the total sludge volume above volumes achievable with the cement/fly ash mixtures.

The mixtures were prepared, placed into cylindrical tubes and set out under room conditions in open containers and checked periodically. It was observed after several days that the mixtures had dried; however, the material failed to solidify the sludges (Table 60).

TABLE 60. SOLIDIFICATION - CLAY MATERIAL

<u>Sludge Type</u>	<u>Sludge g Wet/Dry</u>	<u>% Sludge Dry</u>	<u>Clay Dry g</u>	<u>Water g</u>	<u>Results*</u>
Lime (50% solids)	40/20	50	20	21	Did not solidify
Sodium Borohydride (10% solids)	50/5	25	15	0	Did not solidify
Sodium Hydroxide (10% solids)	55.6/5	25	15	0	Did not solidify

\*Observations during 30-day period.

## 2. Barium Compound Addition

During the screening tests, barium acetate was added during sodium borohydride treatment and while the sludge remained hazardous, there was a significant decrease in chromium leaching (Table 61). For the detailed testing, barium carbonate was used in place of barium acetate in an attempt to improve the results. The barium carbonate was added at the same ratio, 2.6 parts to 1 part chromium, but the method for adding the barium carbonate was varied in Phase 2. First (Case 1), the chemical was added immediately following sodium borohydride precipitation (pH 8.6) and the solution was mixed for 30 minutes. Secondly (Case 2), the barium carbonate was added prior to the addition of sodium borohydride. Directly after the addition of the barium carbonate, the pH was measured at 4.8. The pH was then adjusted and precipitation with sodium borohydride was performed.

TABLE 61. BARIUM COMPOUND ADDITION

TEST	Cr <sup>+6</sup>	Cr <sub>T</sub>	Cd	Ni	Cu
Screening: EP Test on Sludge without Barium Compound Addition	—	57.8	2.45	11.4	0.84
Screening: EP Test on Barium Acetate Sludge	0.25	17.6	10.5	5.90	0.60
Detailed Test: EP Test on Sludge without Barium Compound Addition	0.25	26.0	11.9	6.09	1.20
Detailed Test: EP Test on Barium Carbonate Sludge (Case 1)	0.05	49.8	16.0	5.39	9.33
Detailed Test: Barium Carbonate Filtrate (Case 1)	0.06	0.05	0.02	0.05	0.05
Detailed Test: EP Test on Barium Carbonate Sludge (Case 2)	0.23	145	7.84	5.01	4.92
Detailed Test: Barium Carbonate Filtrate (Case 2)	0.52	0.40	0.02	0.05	0.20
EP Toxicity Limits	—	5.0	1.0	—	—

In Case 1 it appeared that the barium carbonate only slightly dissolved while in Case 2, the barium carbonate dissolved completely. In each case the sludge produced was filtered, the filtrate was analyzed for metals, and an EP was performed on the sludge. The analytical results, presented in Table 61, indicate that the barium carbonate causes the sludges to leach greater amounts of metals, especially chromium. Case 1 was increased 192 percent and Case 2, 558 percent.

### 3. Heat Treatment

During the screening tests, EP results from the sodium borohydride sludges subjected to heating showed a dramatic temperature variance. The sludge treated at the lower temperature leached less than 1 mg/l for each of the metals while the sludge treated at the higher temperature leached over 2,520 mg/l total chromium and hazardous amounts of both cadmium (16.3 mg/l) and nickel (74.3 mg/l).

This phase of testing concentrated on determining the optimal temperature and time for sludge drying. For the time study, 20-gram quantities of sludge were subjected to continuous heat treatment at 120°C with times varied from 1 to 8 hours. An EP was run on each of the samples and the results are contained in Table 62. Although heat treatment reduced the metal leachability, all the sludge samples still tested hazardous.

TABLE 62. HEAT TREATMENT - TIME STUDY EP RESULTS

Treatment Time (hr)*	Final Wt (g)	(mg/l)				
		Cr <sup>+6</sup>	Cr <sub>T</sub>	Cd	Ni	Cu
0	15.4**	0.10	57.8	2.45	11.4	0.84
1	7.0	0.05	1.53	2.96	1.40	0.75
2	3.8	0.05	3.59	6.09	3.03	1.05
4	2.6	1.25	4.04	3.44	2.57	0.83
6	3.4	0.29	5.25	4.07	2.96	0.98
8	3.2	0.28	3.48	4.08	2.70	1.30
EP Toxicity Limits	—	—	5.0	1.0	—	—

\*All samples were subjected to a temperature of 120°C for the specified time.

\*\*The original weight of all samples was 20 grams. This sample was subjected to air drying for 8 hours during which some weight loss occurred.

The heat treatment time study results indicate that the time required for complete drying at 120°C is approximately 2 hours and the leaching of metals was not greatly affected by increasing the drying time. In fact, the lowest leaching levels of treated samples are found in the sample that was heated for only 1 hour. That sample contained approximately 50 percent solids after the 1-hour drying period.

The temperature study was performed on two different batches of sodium borohydride sludge. The first set of samples was taken from the same sludge batch as was used for the time study. All samples started with a weight of 20 grams. The results for the two sets are presented in Table 63.

The temperature study results indicate that the temperature has a very significant effect on the leaching of some metals, especially chromium and nickel. By increasing the temperature, leaching slowly decreases to a point (approximately 100°C) and then increases rapidly. The EP results for chromium (Set 1), displayed graphically in Figure 10, further illustrate this observation.

The two sets of data show an inconsistency. Set 1, although showing a reduced leachability, still leached at hazardous levels, but Set 2, which was a more limited test, showed leachate metal concentration below the EP toxicity limit. The Set 2 results were similar to the screening test results. No explanation for the variability of the results was found.

TABLE 63. HEAT TREATMENT - TEMPERATURE STUDY EP RESULTS

Treatment Temperature* (°C)	(mg/l)					
	Final Wt (g)	Cr <sup>+6</sup>	Cr <sub>T</sub>	Cd	Ni	Cu
Set 1						
20	15.4	0.10	57.8	16.65	11.4	0.84
40	13.0	0.10	62.9	15.6	11.4	0.73
60	4.8	0.05	4.00	4.83	2.83	1.46
80	3.0	0.05	3.59	4.23	2.44	0.63
100	3.4	0.11	3.32	4.50	2.96	0.75
120	3.2	0.28	3.48	4.08	2.70	1.30
160	2.8	23.7	24.9	4.36	9.28	1.07
200	3.0	373	199	5.97	21.6	1.59
Set 2						
80	—	—	0.10	0.04	0.20	0.11
100	—	—	1.21	0.21	0.39	0.05
EP Toxicity Limits	—	—	5.0	1.0	—	—

\*All samples were subjected to the specified temperature for 8 hr.

#### 4. Sludge Washing

The screening tests indicated that sludge weights could be reduced by 20 to 25 percent by washing. A series of tests was run during this phase to confirm the screening results, investigate the effects of varying process parameters, such as the optimal concentration of ammonium chloride, and investigate the effects of washing on various sludge types.

First the screening test was repeated using 40 grams of dewatered lime, caustic soda, and sodium borohydride sludges. The sludges were mixed with equal weights (40 grams) of 0.1 percent ammonium chloride solution in plastic lab containers and vigorously agitated for 30 seconds. The sludge slurries were then dewatered, using Millipore filtering apparatus, the solids measured, and an EP analysis was performed. The results of the tests (Table 64) indicated that the caustic soda and sodium borohydride sludges improved considerably; the weights of the two sludges were reduced by 39 percent. However, the weight of the lime sludge increased 5 percent. The leachability of all three sludges was not significantly affected by the washing process.

A second test was performed on the caustic soda sludge to investigate the effect of varying the concentration of ammonium chloride in the wash water. The sludge was precipitated

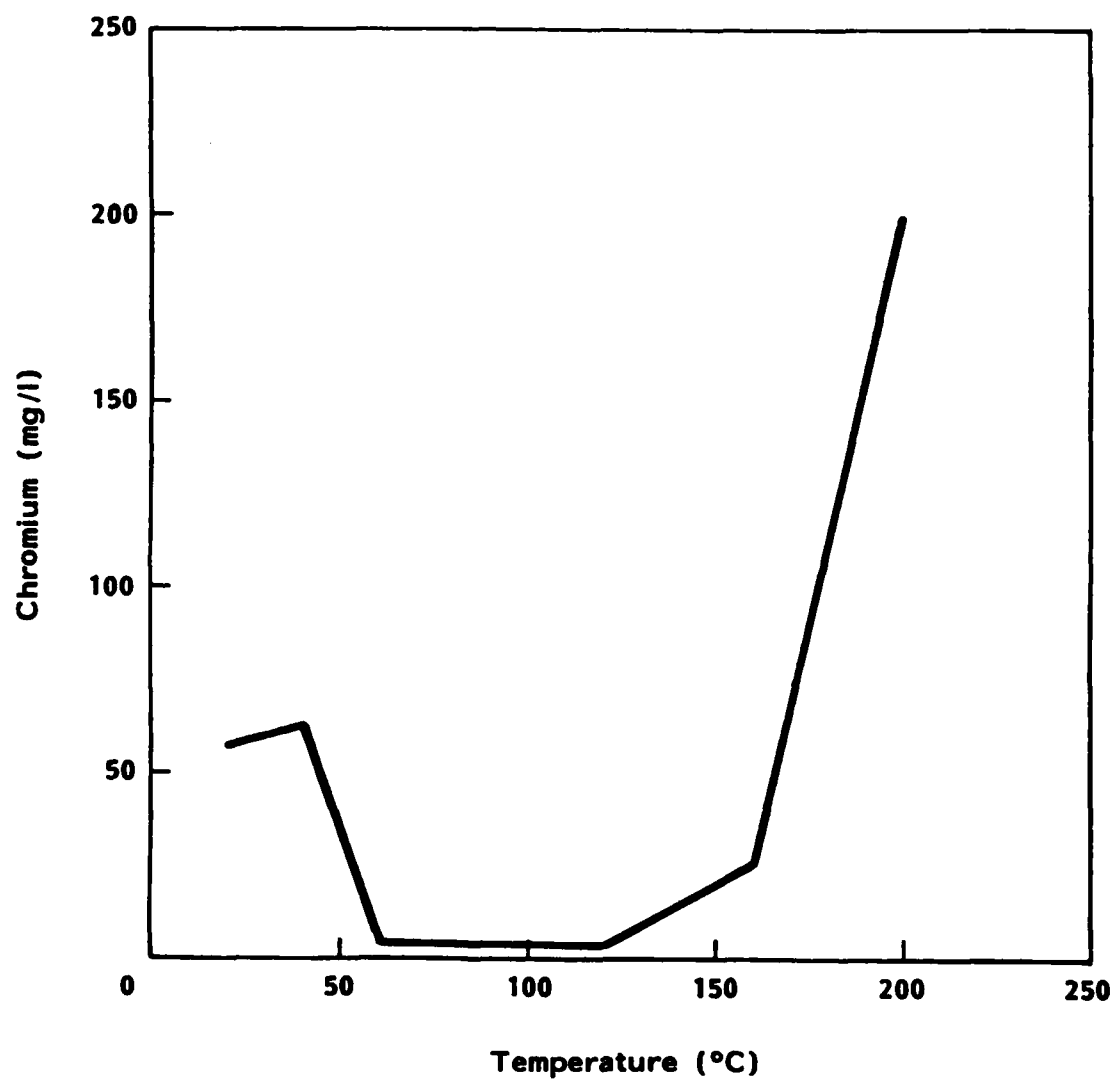


Figure 10. Heat Treatment Temperature Study--EP Results for Chromium

TABLE 64. SLUDGE WASHING

Effect on Sludge Weight

<u>Sludge</u>	<u>Before Washing</u>		<u>After Washing</u>	
	<u>Weight (g)</u>	<u>% Solids</u>	<u>Weight (g)</u>	<u>% Solids</u>
Lime	40.0	42.0	42.0	40.0
Caustic Soda	40.0	9.0	25.7	14.0
Sodium Borohydride	40.0	10.0	25.0	16.0

EP Results

<u>Sludge</u>	<u>Cr<sub>T</sub> mg/l</u>	<u>Cd mg/l</u>	<u>Ni mg/l</u>	<u>Cu mg/l</u>
Lime Before Washing	0.50	.10	0.20	0.20
Lime After Washing	0.60	.10	.20	0.10
Caustic Before Washing	33.0	12.2	3.90	0.20
Caustic After Washing	29.5	16.2	5.20	0.25
NaBH <sub>4</sub> Before Washing	5.0	18.5	10.0	1.70
NaBH <sub>4</sub> After Washing	4.5	22.4	13.0	1.60

from the contrived wastewater, dewatered, divided into four batches and washed with the following ammonium chloride solutions:

- 0 percent (dionized water)
- 0.1 percent NH<sub>4</sub>Cl
- 1 percent NH<sub>4</sub>Cl
- 5 percent NH<sub>4</sub>Cl

The results of the test (see Case 1, Table 65) indicate that the concentration of ammonium chloride had little effect on the ability of the washing process to increase dewaterability.

After completion of the above test, some concern was raised on the appropriateness of comparing the final solids content of the individual sludges to the solids content of the initial dewatered sludge, which was dewatered in one large batch. The nature of the dewatering device may cause the individual sludges which are of smaller volume to dewater at a different rate than the original batch, thereby affecting the results. The test procedure was, therefore, adjusted. After precipitation, the dilute solids were removed from the treatment vessel, divided into five batches and dewatered separately. The dewatered sludges were then washed with varying concentrations of ammonium chloride solution. The results (see Case 2, Table 65) indicated that washing improved the dewaterability of the sludge as did higher concentrations of ammonium chloride. An EP analysis was performed on the 5-percent and 10-percent washed sludges which showed a moderate decrease in chromium leaching but an overall insignificant effect.

TABLE 65. SLUDGE WASHING - VARYING WASH SOLUTIONS

CASE 1

<u>Wash Solution Concentration (% NH<sub>4</sub>Cl)</u>	<u>Solids Concentration Before Washing</u>	<u>Solids Concentration After Washing</u>
0%	10%	16%
0.1%	10%	15%
1.0%	10%	14%
5.0%	10%	15%

CASE 2Effect on Sludge Weight

<u>Wash Solution Concentration (% NH<sub>4</sub>Cl)</u>	<u>Solids Concentration Before Washing</u>	<u>Solids Concentration After Washing</u>
0 %	11%	13%
0.1%	9%	13%
1.0%	11%	13%
5.0%	10%	18%
10 %	9%	22%

EP Results

<u>Sludge</u>	<u>Cr<sub>T</sub> mg/l</u>	<u>Cd mg/l</u>	<u>Ni mg/l</u>	<u>Cu mg/l</u>
Washed with 5%	9.38	39.8	12.8	2.39
Washed with 10%	15.3	32.0	11.2	2.29
Unwashed	17.5	31.8	11.1	1.25

The procedure used throughout the testing consisted of two dewatering steps, one after precipitation/settling and one after washing. Since this second dewatering step may significantly increase the load on a dewatering device, a test was performed to determine the effect of directly washing the dilute settled solids from the precipitation process. During this test the settled solids were removed and divided into six batches. One batch was dewatered and the others were washed with varying concentrations of ammonium chloride solution (0 percent, 0.5 percent, 1.0 percent, 5.0 percent, 10.0 percent). After washing, the sludges were then dewatered. The results of solids concentration analysis (Table 66) indicate that direct washing does not increase sludge dewaterability. The unwashed sludge which was simply dewatered actually showed the highest solids concentration.

## 5. Sludge Aging

Although the screening test for the sludge aging process did not generate a sludge that tested nontoxic, work performed under an independent study has generated a nontoxic

sludge after aging for a longer period of time. Based on these findings, it was decided to include sludge aging in the detailed test program.

TABLE 66. SLUDGE WASHING - EFFECTS OF DIRECT WASHING

<u>Wash Solution Concentration (% NH<sub>4</sub>Cl)</u>	<u>Solids Concentration Before Washing</u>	<u>Solids Concentration After Washing</u>
Unwashed	12.9%	--
0%	--	10.0%
0.5%	--	11.0%
1.0%	--	12.2%
5.0%	--	10.7%
10.0%	--	11.9%

An EP extraction was performed on a sodium borohydride sludge after aging for 50 and 80 days ( a 30-day aging period used in the screening tests). The results of the EP are shown in Table 67. The additional aging resulted in chromium and cadmium levels in the extract below EP toxicity limits. All metals, with the exception of nickel, leached in lower concentrations after 80 days of aging; compared to 50 days of aging.

TABLE 67. SLUDGE AGING - EFFECT OF AGING PERIOD

<u>EP Results</u>	<u>Cr (mg/l)</u>	<u>Cd (mg/l)</u>	<u>Cu (mg/l)</u>	<u>Fe (mg/l)</u>	<u>Ni (mg/l)</u>
Aged 50 days	3.50	0.84	0.35	2.85	0.45
Aged 80 days	2.60	0.63	0.25	1.07	0.67
EP Toxicity Limits	5.0	1.0	--	--	--



## SECTION VII

### PROTOTYPE DESIGNS

#### A. INTRODUCTION

The results of the metal removal and sludge volume reduction studies show several technologies that could reduce costs of treating Air Force electroplating wastewaters by either reducing the volume of sludge requiring disposal or rendering the sludge nonhazardous. Prototype systems have been designed and capital and operating costs have been estimated.

Based on the results of the laboratory tests the following technologies were selected for this design phase:

- Heat treatment
- Sludge washing
- Sludge aging
- Solidification
- Sodium borohydride precipitation

#### B. HEAT TREATMENT PROCESS

The sludge will be maintained at a temperature between 60°C and 125°C for 1 hour in a rotary dryer to maintain the time/temperature requirements specified by the lab results. To use a rotary dryer, however, the sludge must be essentially solid in nature. In the proposed process, this is done by first dewatering and then mixing with an appropriate amount of dried sludge.

Sizing of process equipment was based on the 2,010 cubic yards of sludge disposed of annually by the 00-ALC (solids content of 10 percent by weight) (Reference 10). This amounts to 365,000 lb/yr of dry solids. The heat treatment process is fed by underflow from the existing clarifier. It is assumed that the underflow has a solids content of 1 percent. Assuming 2000 hours of operation per year, the feed rate to the system is 2200 gallons per hour of dilute (1 percent solids) sludge.

##### 1. Process Description

The process flow diagram in Figure 11 shows the equipment associated with the heat treatment process. The clarifier underflow gravity drains to an in-ground filter feed

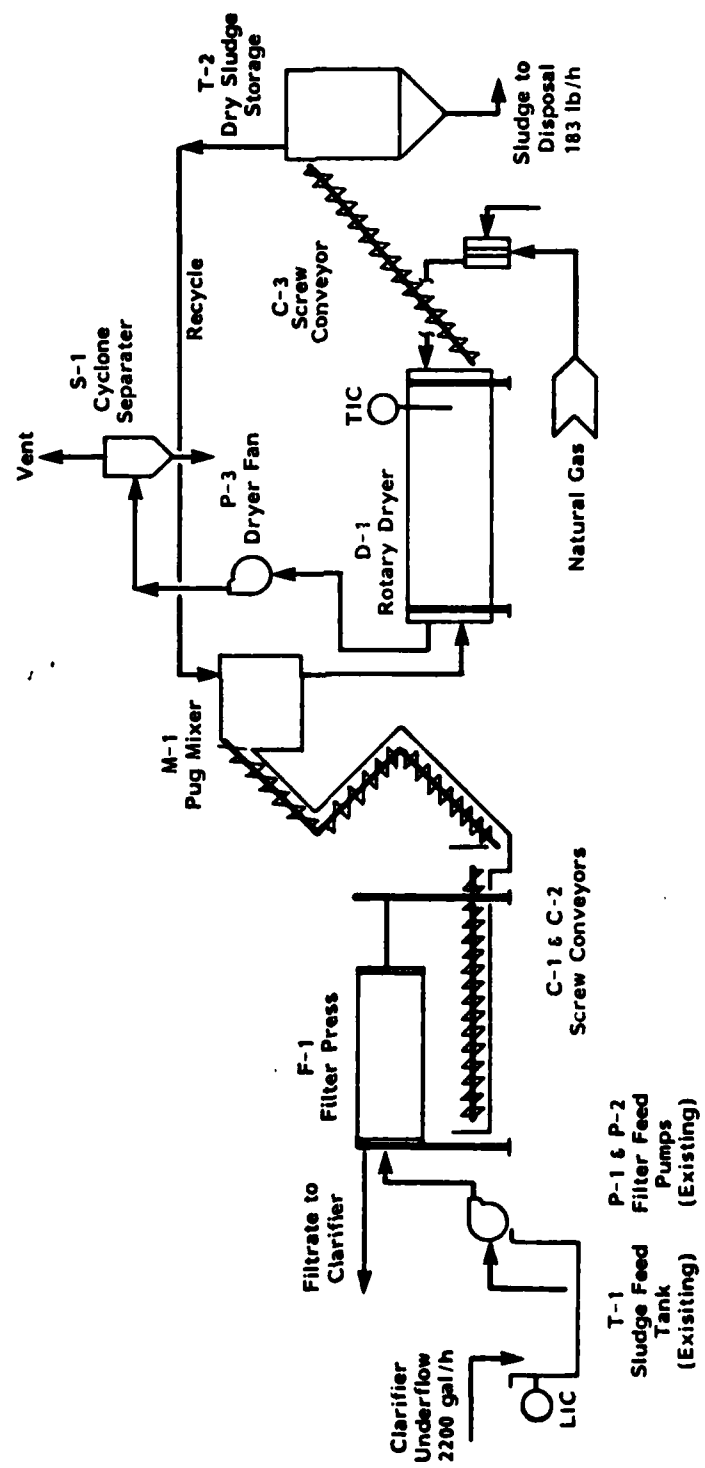


Figure 11. Heat Treatment Process

tank (T-1). The tank volume represents approximately 5 hours of retention capacity. The tank is equipped with level control instrumentation to automatically start the filter feed pumps (P1 and 2) when the tank level exceeds the high-level set point and stop the pumps when it goes below the low-level set point.

Air-operated diaphragm pumps are specified for the filter press feed pumps. These pumps are reliable for sludge handling, are able to pass debris up to 1 inch in diameter and have a performance curve well suited for filter press operation. They should be valved to provide the option of simultaneous or individual service. They require an air supply of 100 psig to achieve the pressure necessary to give reasonable cake dryness. If air is not available at this pressure, consideration should be given to a centrifugal pump designed to handle slurries.

The filter press (F-1) is a recessed plate type, using polypropylene plates on a carbon steel frame with a cake-holding capacity of 65 cubic feet. Assuming a cake solids concentration of 20 percent by weight, the press was sized for two cycles per day with a 25-percent capacity safety factor. Presses of this size are typically equipped with a hydraulic ram for press closure and a mechanical plate-shifting mechanism.

The cake discharges from the press into a trough below containing a triple-screw conveyor (C-1). The conveyor will break up the cake and transport it to a single-screw conveyor (C-2) which will carry the cake to a solids mixer (M-1). The mixer will blend the dewatered sludge with dried sludge that has already been processed through the dryer. The ratio of recycled sludge necessary to achieve a nonsticking mixture must be determined by testing. Possibly, this piece of equipment is not required. The mixer was sized based on the assumption that one part dewatered sludge is blended with one part dried sludge.

The dryer (D-1), burner, and air handling system are part of a package unit including a 4-foot diameter by 24 foot long free-standing rotary dryer, a blower with a rated capacity of 6,200 scfm of air at 50°C, a burner capable of heating that volume of air to 125°C and a cyclonic dust separator to remove entrained particles from the dryer exhaust. At that air flow, the dryer could evaporate 800 pounds of water per hour. The burner fuel consumption would be approximately 1 million Btu/hr of natural gas. Residence time in the dryer is a function of dryer pitch (i.e., degrees off horizontal), rotation speed and velocity of the countercurrent air flow. With a dryer of this size and an average feed rate of 370 pounds per hour of solids (this includes 185 pounds of recycle), the dryer will easily provide the needed retention time. The natural gas burner can be controlled either on inlet air temperature or dry solids temperature.

The dried solids exit the dryer and are conveyed (C-3) to a 10,000-gallon elevated storage tank (T-2) to inventory the material prior to final disposal. The original sludge volume

will be reduced from 2,200 gallons per hour of clarifier underflow to 180 pounds per hour of dry solids. The storage volume should provide enough capacity to store the solids generated for a 100-day period.

## 2. Capital and Operating Costs

The cost of the equipment components are presented in Table 68. The costs for major components are based on vendor quotes. The total installed cost for the system is \$460,200 which includes estimates for contingency (20 percent) and engineering (20 percent).

The annual operating costs for the sludge heat treatment process are presented in Table 69. It is assumed that the system will require 8 hours of labor per day. Fuel costs for the dryer are based on the equipment vendor's estimate. The sludge hauling and disposal costs are based on the assumption that the heat-treated sludge can be disposed locally at a nonhazardous site. The total annual operating cost is \$30,620.

Comparing the Hill AFB current hauling and disposal costs (\$120,600)\* to the heat-treatment process costs indicates that an annual savings of approximately \$90,000 is expected. This savings would represent a return on the \$460,000 investment of 20 percent and a simple payback period of 5.1 years.

## C. SLUDGE-WASHING PROCESS

During laboratory tests the ammonium chloride ( $\text{NH}_4\text{Cl}$ ) sludge-washing process proved to be an effective method for decreasing the water content and volume of sludge. The tests indicated that the solids content of sludge could be effectively doubled; using a 5 percent or 10 percent  $\text{NH}_4\text{Cl}$  wash solution.

The selected process design operates on a batch basis and involves dewatering the clarifier underflow using a filter press, reslurrying the dewatered sludge from the filter press by mixing the sludge with an equal weight of 10 percent ammonium chloride solution, then dewatering this mixture a second time. Filtrate from the first press cycle is returned to the treatment process. Filtrate from the second press cycle is recycled for the reslurrying operation or discharged to the treatment process on alternate batches, providing one-time reuse of the  $\text{NH}_4\text{Cl}$  solution.

Process equipment was again sized for OO-ALC. The sludge-washing process is also fed by underflow from the existing clarifier. Assuming 2000 hours of operation per year, the feed rate to the system is 2200 gallons per hour of dilute (1 percent solids) sludge.

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\*2,010  $\text{yd}^3/\text{yr}$  x 60  $\$/\text{yd}^3$ .

TABLE 68. SLUDGE HEAT TREATMENT--EQUIPMENT  
DESCRIPTION AND COST

Item	Description	Equip. Cost n/a	Install. Cost existing*
T-1	Sludge Filter Feed Tank - 10,000 gal in-ground, concrete lined tank		
P-1 & 2	Sludge Filter Feed Pumps - air operated diaphragm pumps; max flow: 100 gpm each; max TDH: 100 psig	existing*	existing*
F-1	Recessed Plate Filter Press - polypropylene plates on carbon steel frame with cake capacity of 65 ft <sup>3</sup> and a plate recess to provide 1 1/4 in thick cakes. Hydraulic ram for closure and mechanical plate shifting device	\$ 65,000	\$ 85,000
C-1	Triple Screw Conveyor and Trough - carbon steel, 12 in. triple screw conveyor, 32 ft long wi/5 hp drive and trough	22,000	32,000
C-2	Single Screw Conveyor - 12 in. carbon steel screw conveyor, 45 ft long wi/1.5 hp drive and trough	9,000	12,000
M-1	Pug Mixer - carbon steel construction to provide homogenous mixing in one to one ratio of filter cake and dried sludge	20,000	30,000
D-1, P-1, S-1	Rotary Dryer and Exhaust Fan - carbon steel freestanding dryer at 4 ft diameter by 24 ft long including burner, air heater, dryer, feed and discharge seals, feed and discharge breeching, cyclonic dust collector and associated ductwork (manf. by Edw. Renneburg & Sons, Baltimore, MD)	80,000	110,000
C-3	Single-Screw Conveyor - 12 in. carbon steel screw conveyor, 30 ft long wi/1 hp drive and trough	6,000	9,000
T-2	Dried Sludge Storage Tank - 10,000 gal above ground, conical bottom storage tank	16,000	26,000
Instru- mentation Process Piping & Ductwork	Miscellaneous	10,000	20,000
	Miscellaneous	15,000	30,000
	Total Equipment Cost	\$243,000	\$354,000
	Contingency (at 20%)		70,800
	Engineering (at 10%)		35,400
	Total Cost		\$460,200

n/a - not applicable

\* It is assumed that an equivalent piece of equipment exists at Hill AFB IWT.

TABLE 69. HEAT TREATMENT ANNUAL OPERATING COSTS AND SAVINGS

<u>Annual Operating Costs</u>	
Labor at \$8/hr (1 operator/shift)	\$16,000
Chemicals	N.R.
Utilities	
Natural Gas at \$5/MM Btu	10,000
Electricity at \$.07/kWh	3,000
Sludge Hauling and Disposal (108 yd <sup>3</sup> /yr)	
Hauling at \$5/yd <sup>3</sup>	540
Disposal at \$10/yd <sup>3</sup>	<u>1,080</u>
Total annual cost	\$30,620
<u>Annual Savings</u>	
Current cost for hauling and disposal	\$120,600
Projected cost for heat treatment	<u>30,620</u>
Savings	\$ 89,980

#### 1. Process Description

The process flow diagram in Figure 12 shows the equipment associated with the sludge-washing process. The clarifier underflow gravity drains to an in-ground filter feed tank (T-1). The tank volume represents approximately 4 hours of retention capacity. The tank is equipped with level control instrumentation to automatically start the filter feed pumps (P1 and 2) when the tank level exceeds the high-level set point and stop the pumps when it goes below the low-level set point.

Air-operated diaphragm pumps are specified for the filter press feed pumps. These pumps are reliable for sludge handling, are able to pass debris up to 1 inch in diameter and have a performance curve well suited for filter press operation. They should be valved to provide the option of simultaneous or individual service. They require an air supply of 100 psig to achieve the pressure necessary to give reasonable cake dryness. If air is not available at this pressure, consideration should be given to a centrifugal pump designed to handle slurries.

The 1-percent sludge slurry is fed to the filter press (F-1), a recessed plate type utilizing polypropylene plates on a carbon steel frame with a cake-holding capacity of 100 cubic feet. Assuming a cake solids concentration of 20 percent by weight, the press was sized for four cycles per day with a 25-percent capacity safety factor. Presses of this size are typically equipped with hydraulic ram for press closure and a mechanical plate shifting mechanism.

The filtrate from F-1 is returned to treatment and the filter cake at 20 percent solids is dropped through a chute into a reslurry tank (T-2) directly below the filter press. A 5-percent solution of ammonium chloride is then gravity fed from

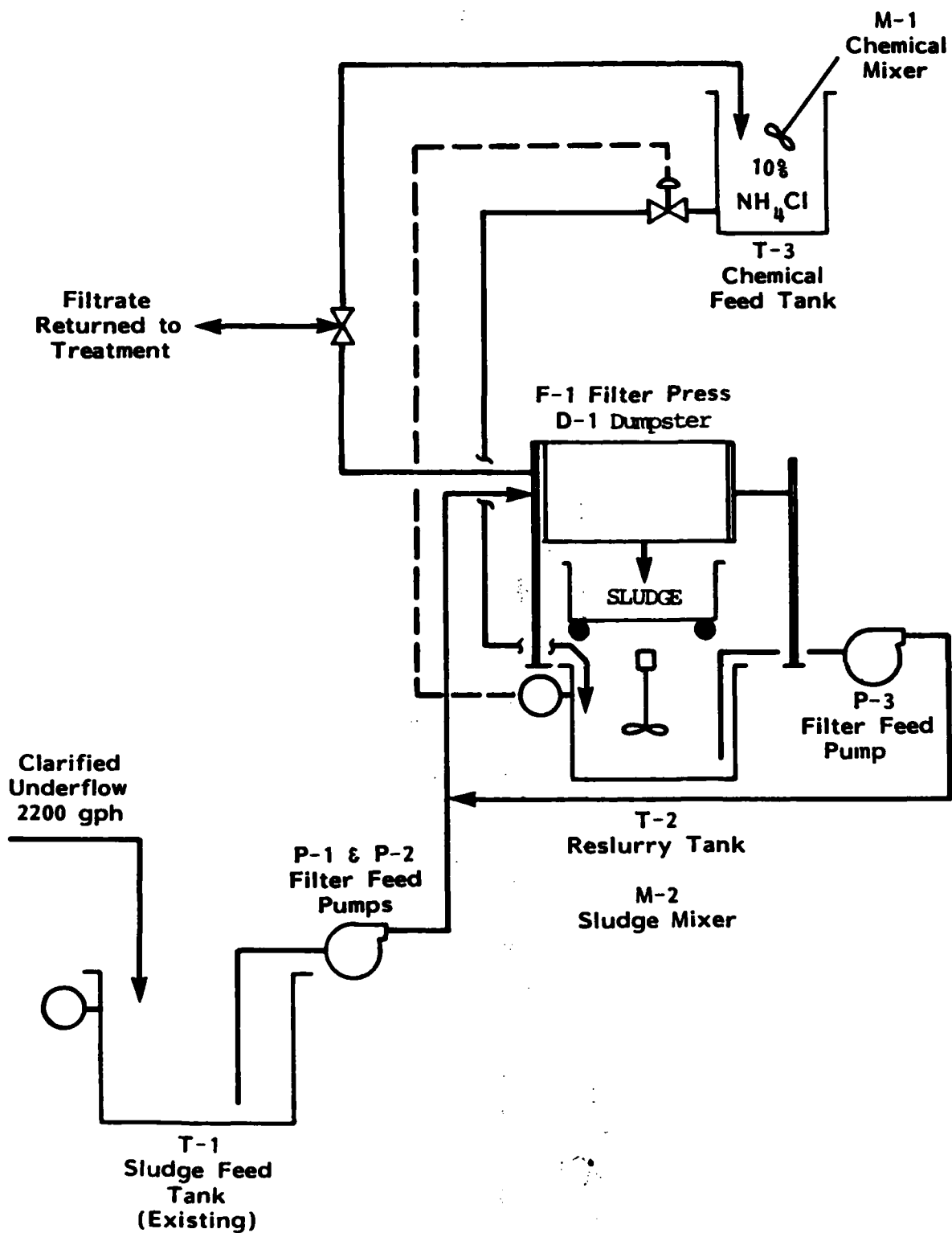


Figure 12. Sludge-Washing Process

the chemical feed tank (T-3) to the reslurry tank. A level controller on the reslurry tank closes the valve on the line from the chemical feed tank when the level in the reslurry tank reaches the set point. The mixture in the reslurry tank is agitated for 15 minutes then returned by pump to the filter press.

Filtrate from the second filter press cycle is recycled to the chemical feed tank or discharged to the wastewater treatment system on alternating cycles allowing a one-time reuse of the  $\text{NH}_4\text{Cl}$  wash solution. The filter cake from the second press is discharged to a small dumpster (D-1) which is rolled over rails directly beneath the filter press. After filling, the dumpster is rolled away from the filter press and the sludge is removed.

## 2. Capital and Operating Costs

The costs of the equipment components are presented in Table 70. The costs for major components are based on vendor quotes. The total installed cost for the sludge washing system is \$160,400. The major portion of this cost is for a filter press (\$100,000 installed).

The annual operating costs for the sludge-washing process are presented in Table 71. It is assumed that the system will require 8 hours of labor per day. The chemical requirements are based on a 1:1 addition of 5 percent  $\text{NH}_4\text{Cl}$  solution to dewatered sludge (weight basis) assuming that the sludge is initially dewatered to 30 percent solids. The sludge-hauling and disposal costs are based on the following assumptions: (1) the sludge will dewater to 50 percent solids after washing, (2) the sludge will be hazardous and must be hauled to a secure site. Using the latter assumption, the current costs incurred by Hill AFB for hauling and disposal of hazardous sludge were used (\$60/yd<sup>3</sup>). The total annual operating cost for the sludge-washing system is \$47,570.

Comparing the Hill AFB current hauling and disposal costs (\$120,600) to the sludge-washing process costs indicates that an annual savings of approximately \$73,000 is expected. This saving would represent a return on the \$160,000 investment of approximately 46 percent; the simple payback period is 2.2 years.

## D. SLUDGE-AGING PROCESS

Sludge aging was demonstrated as a means of rendering the sludge nonhazardous during the laboratory testing stage of the project. By allowing the sludge to age for 2 to 3 months, the material was able to pass the EPA EP toxicity test. The effect of aging is presumed to be a result of contact with air which both oxidizes and dries the sludge. The aging process is a simple one; it basically requires dewatering the sludge and then aging it in a dry environment for 3 months. The dewatering is required to assure that the sludge is not masked from contact



TABLE 70. SLUDGE-WASHING PROCESS--EQUIPMENT DESCRIPTION AND COST

<u>Item</u>	<u>Description</u>	<u>Equipment Cost</u>	<u>Installed Cost</u>
T-1	Sludge Feed Tank - 10,000 gal in-ground, concrete construction	existing*	existing*
T-2	Reslurry Tank - 1,800 gallon; in-ground concrete construction	n/a	\$ 5,000
T-3	Chemical Feed Tank - 1,200 gallon; heavy duty polyethylene w/ welded steel support	\$12,100	\$ 2,800
P-1, 2 & 3	Filter Feed Pumps - air-operated diaphragm pumps, max. flow 100 gpm each; max TDH: 100 psig	existing*	existing*
P-3	Filter Feed Pump - same as P-1 & 2	4,000	6,000
M-1	Chemical Mixer	600	1,000
M-2	Sludge Mixer at 350 RPM	5,000	8,000
F-1	Filter Press - polypropylene plates on carbon steel frame, cake capacity 100 cu. ft. at 1 1/4 inch thick cake; hydraulic ram closure; mechanical plate shifter; chute to direct cake to hopper or reslurry tank	80,000	100,000
D-1	Dumpster - steel box 200 ft <sup>3</sup> on rails	400	600
	Total Equipment Cost	\$92,100	\$123,400
	Contingency (at 20%)		24,700
	Engineering (at 10%)		12,300
	Total Cost		\$160,400

n/a - not applicable

\* It is assumed that an equivalent piece of equipment exists at Hill AFB IWTP.

TABLE 71. SLUDGE-WASHING ANNUAL OPERATING COSTS AND SAVINGS

<u>Annual Operating Costs</u>	
Labor at \$8/hr (1 operator/shift)	\$16,000
Chemicals (NH <sub>4</sub> Cl at \$0.18/lb)	5,500
Utilities	
Electricity at \$.07/kWh	4,410
Sludge Hauling and Disposal (361 yd <sup>3</sup> /yr) at \$60/yd <sup>3</sup>	<u>21,660</u>
Total annual cost	\$47,570
<u>Annual Savings</u>	
Current cost for hauling and disposal	\$120,600
Projected cost for sludge washing	<u>47,570</u>
Savings	\$ 73,030

with air due to water blinding. While aging, it is also necessary to turn the sludge on a regular basis so that the aging occurs through the sludge bed.

The sludge-aging technology was also sized to process the sludge generated by Hill Air Force Base. This amounts to 2,200 gallons per hour of dilute (1 percent solids) sludge in the clarifier underflow.

#### 1. Process Description

The process to accomplish the aging is the same as the heat treatment process up to the point the sludge is dewatered in the filter process (F-1, refer to Figure 11). The clarifier underflow gravity drains to an in-ground filter feed tank (T-1). The tank volume represents approximately 5 hours of retention capacity. The tank is equipped with level control instrumentation to automatically start the filter feed pumps (P1 and 2) when the tank level exceeds the high-level set point and stop the pumps when the level falls below the low-level set point.

Air-operated diaphragm pumps are specified for the filter press feed pumps. These pumps are reliable for sludge handling, are able to pass debris up to 1 inch in diameter and have a performance curve well suited for filter press operation. They should be valved to provide the option of simultaneous or individual service. They require an air supply of 100 psig to achieve the pressure necessary to give reasonable cake dryness. If air is not available at this pressure, consideration should be given to a centrifugal pump designed to handle slurries.

The filter press (F-1) is a recessed plate type utilizing polypropylene plates on a carbon steel frame with a cake-holding capacity of 65 cubic feet. Assuming a cake solids concentration of 20 percent by weight, the press was sized for

two cycles per day with a 25-percent capacity safety factor. Presses of this size are typically equipped with a hydraulic ram for press closure and a mechanical plate shifting mechanism.

The best method of handling the sludge filter cakes discharged from the filter depends upon the proximity of the aging beds to the filter. If the beds are close by, use of screw conveyors to deliver the sludge to the beds is feasible. However, the best approach is to discharge the cakes into a hopper and have the hopper towed or carried and emptied onto the aging beds.

The aging process consists of three beds sized to store the volume of sludge generated over a 3-month period. While one bed is being filled, the second bed is aging the sludge for the required 3 months and the third is being emptied of the aged sludge and readied to accept the next charge.

To accommodate 3 months of sludge at a solids content of 20 percent by weight, the required bed volume is 330 cubic yards. Assuming an average bed depth of 1.25 feet, the dimensions of each bed would be approximately 40 feet by 20 feet.

Design considerations that must be addressed in constructing the aging beds include:

- Protection of the beds from precipitation and freezing conditions
- The sludge must be allowed to drain to remove any free water
- Heavy earth-moving equipment may frequently enter the bed during charging and emptying the bed
- The sludge must be turned during the aging process to allow homogeneous contact with the air.

Protection from the elements would probably require an indoor system; therefore, a pre-engineered metal building has been included in the design. To provide drainage, the beds should be sloped and have a bottom layer of gravel for drainage. The beds would drain into a common sump which would pump any liquor back to the treatment system. A clay liner base and concrete sidewalls will seal the bed and provide the necessary foundation support. The sludge in the bed could be turned by an appropriately modified piece of earth-moving equipment. A schematic of the proposed bed design is presented in Figure 13. The floor space requirements for a three-bed system with 10-foot wide access to a long side of each bed would be an area of 80 feet by 60 feet.

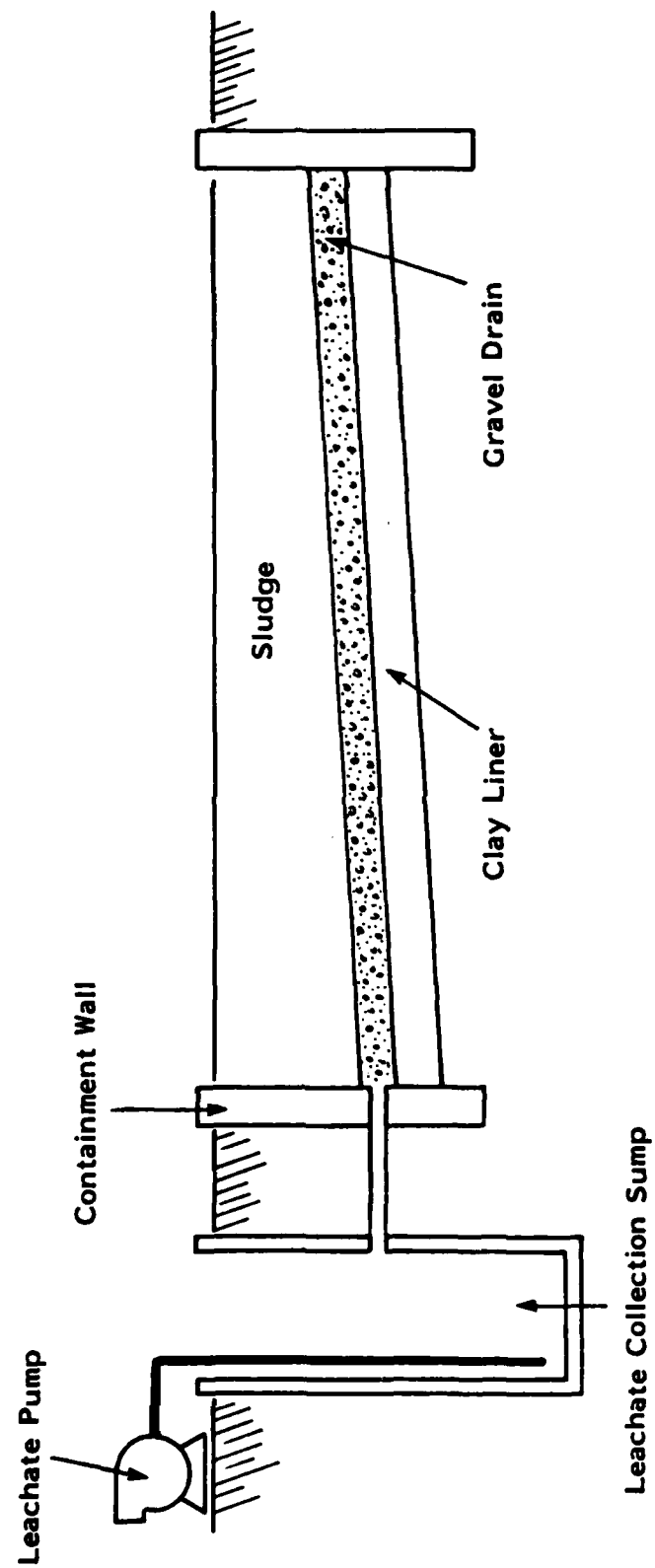


Figure 13. Sludge Aging Bed

## 2. Capital and Operating Costs

The capital cost of the aging process is presented in Table 72. The cost includes the necessary process equipment and construction of the drying beds.

The cost for constructing the aging bed only covers the labor, materials and leasing of the necessary equipment. Two hundred feet of gravel-bed access roadway is also included. No land cost is included.

The operating costs for the sludge-aging process are presented in Table 73. The sludge-hauling and disposal costs are based on the generation of 274 yd<sup>3</sup> of aged sludge per year at 60 percent solids content. It is assumed that the sludge will be nonhazardous and that it can be disposed of locally in a sanitary landfill. The total annual operating cost for the sludge aging process at Hill AFB is \$33,620.

Comparing the Hill AFB current hauling and disposal costs (\$120,600)\* to the sludge-aging process costs indicates that an annual savings of approximately \$98,000 is expected. This saving would represent a return on the \$289,000 investment of 34 percent; the simple payback period is 2.9 years.

### E. SOLIDIFICATION

Solidification of sludge using cement and fly ash was demonstrated to be an effective means of producing a nonhazardous material. The process was especially effective using lime-precipitated sludge where a cement-to-fly ash-to-sludge solids ratio of 1:1:2 could be used to produce a very hard and non-hazardous product.

To investigate the economics of solidification, a process was designed for McClellan AFB. The IWTP at McClellan currently uses a lime precipitation process. Sludge is presently dewatered to 20 percent solids using a centrifuge. Approximately 63 yd<sup>3</sup>/wk of dewatered sludge are generated. In formulating the design it was assumed that the solidification process would be operated 250 days per year, 8 hrs per day.

#### 1. Process Description

The process flow diagram presented in Figure 14 indicates the equipment requirements of the solidification process. The sludge from the centrifuge is stored in a concrete, in-ground storage tank. It is then transferred to a conical-bottom bin with a capacity of 12 cubic yards in preparation for mixing. Sludge is introduced into the mixer on a batch basis. Portland cement and fly ash from storage bins are added on a ratio 1:1:2 (cement: fly ash:sludge on dry basis). Water is

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\* 2,010 yd<sup>3</sup>/yr x \$60/yd<sup>3</sup>.

TABLE 72. SLUDGE AGING--EQUIPMENT DESCRIPTION AND COST

<u>Item</u>	<u>Description</u>	<u>Equipment Cost</u>	<u>Installed Cost</u>
T-1	Sludge Filter Feed Tank - 10,000 gal in-ground, concrete lined tank	n/a	existing <sup>1</sup>
P-1 & 2	Sludge Filter Feed Pumps - air operated diaphragm pumps; max flow: 100 gpm each; max TDH: 100 psig	existing <sup>1</sup>	existing <sup>1</sup>
F-1	Recessed Plate Filter Press - polypropylene plates on carbon steel frame with cake capacity of 65 ft <sup>3</sup> and a plate recess to provide 1 1/4 in thick cakes. Hydraulic ram for closure and mechanical plate shifting device	\$ 65,000	\$ 85,000
T-2	Dumpster, carbon still, rubber lined; 4 feet x 10 feet x 4 feet deep, on wheels	400	400
V-1	Light duty earth moving equipment and accessories for turning sludge	25,000	25,000
B-1, 2 & 3	Aging beds, excavation, installation of liner and gravel drain, disposal of fill, gravel bed access road	--	50,000
T-3	Leachate Collection Tank - 2,000 gal, in-ground, concrete lined tank	--	8,000
P-3	Leachate Return Pump - Centrifugal, max flow: 20 gpm; max TDH: 25 psig	1,000	3,000
B-1	Pre-engineered metal building (erected), 5,000 ft <sup>2</sup> , eave height 14 feet	n/a	25,000
Instru- mentation		8,000	16,000
Process Piping		5,000	10,000
Total Equipment Cost		<u>\$104,400</u>	<u>\$222,400</u>
Contingency (at 20%)			44,400
Engineering (at 10%)			22,200
Total Cost			<u>\$289,000</u>

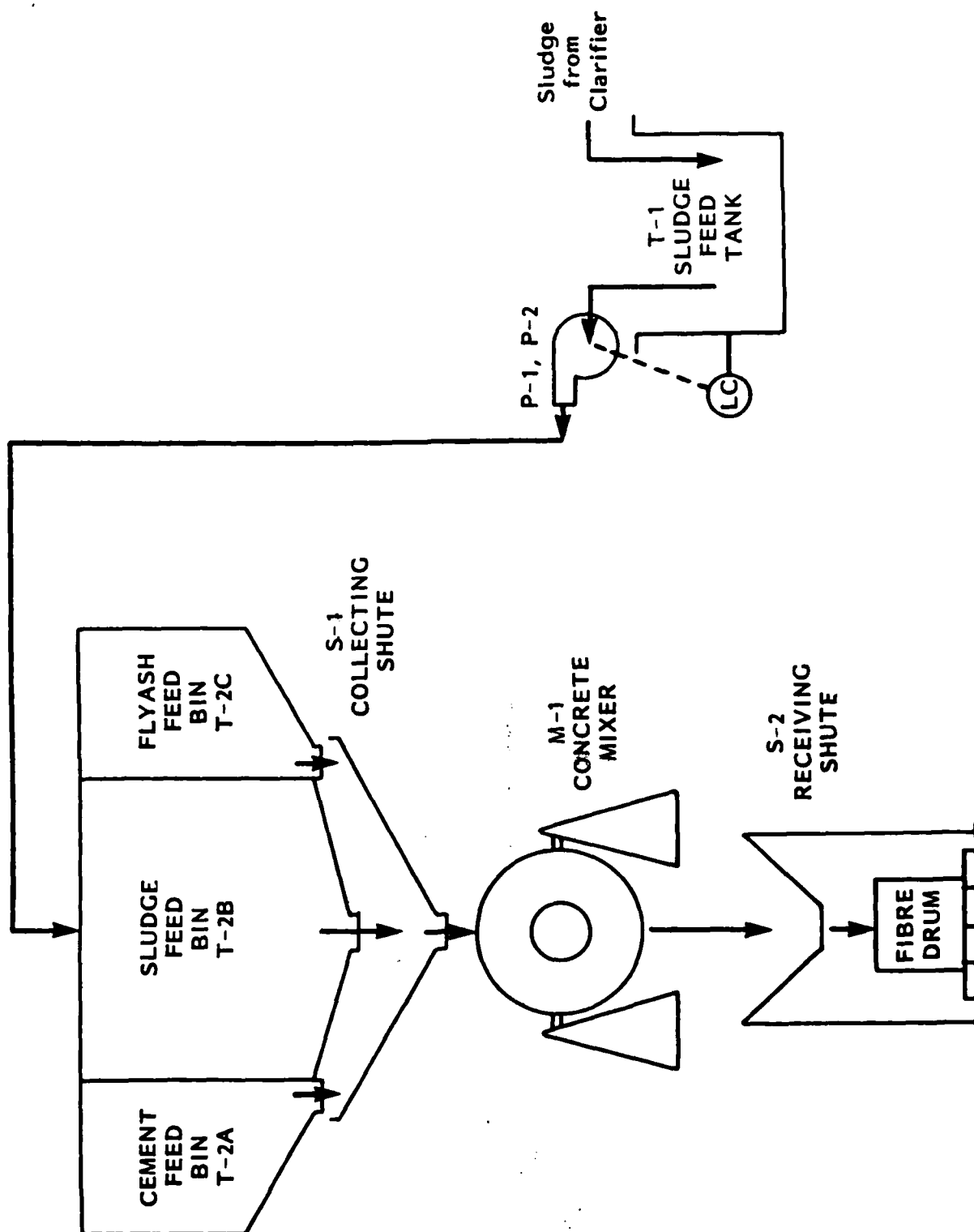


Figure 14. Solidification Process

TABLE 73. SLUDGE AGING--ANNUAL OPERATING COSTS AND SAVINGS

Annual Operating Costs

Labor at \$8/hr (1 operator/shift)	\$16,000
Chemicals	0
Utilities	
Diesel fuel at \$1/MM Btu	10,000
Electricity at \$.07/kWh	3,000
Sludge Hauling and Disposal (108 yd <sup>3</sup> /yr)	
Hauling at \$5/yd <sup>3</sup>	540
Disposal at \$10/yd <sup>3</sup>	<u>1,080</u>
Total annual cost	\$30,620

Annual Savings

Current cost for hauling and disposal	\$120,600
Projected cost for heat treatment	<u>30,620</u>
Savings	\$ 89,980

then added as required to produce an easily mixed consistency. The mixer is a commercially available unit, normally used for mixing concrete.

After mixing, the material is poured into a 55-gallon plastic-lined fiber drum mold for curing. The drums are filled on pallets to facilitate handling with fork trucks. Curing time has not yet been established, however, it is expected to be less than 30 days.

## 2. Capital and Operating Costs

The costs of equipment components are presented in Table 74. The major equipment costs were obtained from vendor quotes. The vendors also provided rough estimates for typical installation costs. No cost for building space is included in the estimate. The installed cost was estimated at \$110,630.

Operating costs are presented in Table 75. It is anticipated that 13,234 drums will be filled per year. If the process is operated 250 days per year, 53 drums will be filled per day. It is anticipated that this process will require two men per shift. The resultant material is expected to be nonhazardous and can therefore be disposed in a local nonhazardous landfill. The total annual operating cost is \$181,314.

Comparing the McClellan AFB current hauling and disposal costs (\$216,380) to the solidification process costs indicates that an annual savings of \$35,000 is expected. This saving would represent a return on the 111,000 investment of 32 percent; the simple payback period is 3.2 years.



TABLE 74. SOLIDIFICATION TREATMENT--EQUIPMENT DESCRIPTION  
AND COST

Item	Description	Equipment Cost	Installed Cost
<u>T-1</u>	<u>Sludge Filter Feed Tank - 5,000 gal in-ground, concrete lined tank</u>	<u>n/a</u>	<u>\$ 3,000</u>
P-1 & 2	Sludge Feed Pumps - air operated diaphragm pumps; max flow: 25 gpm each; max TDH: psig	\$ 3,500	5,200
M-1	Concrete Mixer, 3 cu yd batch capacity, electric drive, 15 h.p.	32,000	38,400
T-2A,-2B, -2C	Feed bin, steel, field erected with reinforcements and supports	15,000	22,500
S-1, S-2	Diverting shutes, steel, with reinforcement and supports	3,000	4,500
Instru- mentation	Miscellaneous	1,000	1,500
Process Piping & Ductwork	Miscellaneous	<u>5,000</u>	<u>10,000</u>
	Total Equipment Cost	\$59,500	\$ 85,100
	Contingency (at 20%)		17,020
	Engineering (at 10%)		8,510
	Total Cost		<u>\$110,630</u>

n/a - not applicable

TABLE 75. SOLIDIFICATION PROCESS ANNUAL OPERATING COSTS AND SAVINGS

<u>Annual Operating Costs</u>	
Labor at \$8/hr (2 operator/shift)	\$ 32,000
Chemicals	
Portland Cement at \$.03/lb	18,856
Fly ash at \$.01/lb	6,285
Utilities	
Electricity at \$.07/kwh	3,675
Sludge Hauling and Disposal (3,604 yd <sup>3</sup> )	
Hauling at \$5/yd <sup>3</sup>	18,018
Disposal at \$10/yd <sup>3</sup>	36,040
Fiberdrums at \$5/drum (13,234 drums)	<u>66,170</u>
Total annual cost	\$181,314
<u>Annual Savings</u>	
Current cost for hauling and disposal	\$216,380
(3,276 yd <sup>3</sup> ) at \$66.05/yd <sup>3</sup> *	
Projected cost for solidification process	<u>181,314</u>
Savings	\$ 35,066

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\* \$13.72/yd<sup>3</sup> collect and transport \$52.33/yd<sup>3</sup> disposal.

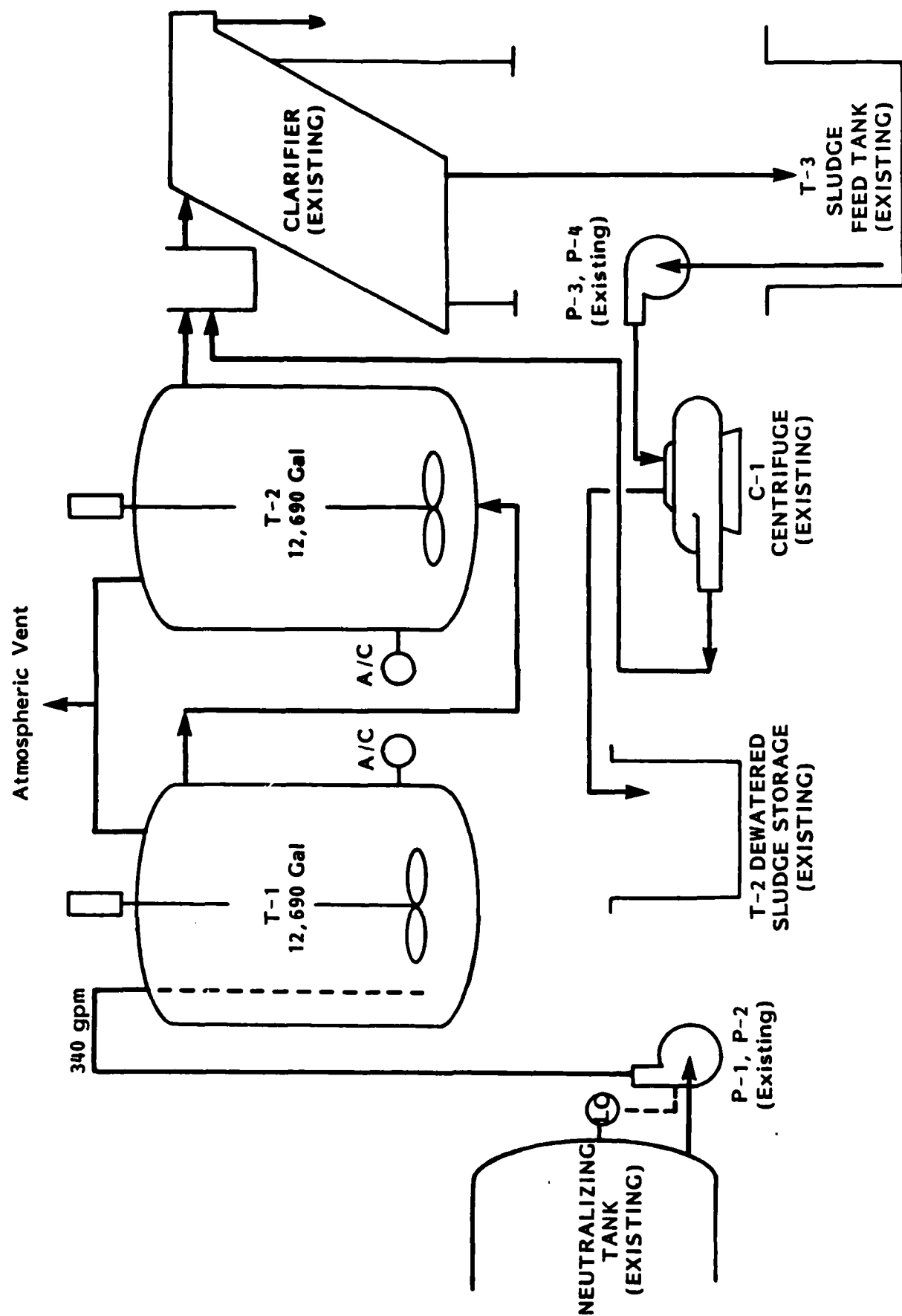
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#### F. SODIUM BOROHYDRIDE PRECIPITATION PROCESS

Laboratory tests demonstrated the ability of the sodium borohydride (NaBH<sub>4</sub>) precipitation process to produce an effluent quality superior to the processes using either lime or caustic soda. It may be necessary to use such a process at a particular location where local standards are more stringent than the federal requirements. The high cost of sodium borohydride makes it uneconomical for cases where stringent regulations do not exist. The process produces a smaller volume of sludge which helps to offset the high chemical costs.

The McClellan AFB (SM-ALC) IWTP was selected as the design site for the sodium borohydride process. SM-ALC currently uses lime for pH adjustment/precipitation. The use of lime presents a problem at SM-ALC since that facility is reusing the IWTP effluent for cooling water and the calcium carbonate carryover causes scaling. Further, the SM-ALC has relatively stringent effluent standards which provide additional justification for considering the use of sodium borohydride.

For design purposes an average effluent flow rate of 495,000 gal/day based upon 24-hour operation and a wastewater composition of 0.20 mg/l copper, 1.8 mg/l chromium (+3), and 20.0 mg/l iron (+3) was assumed. The design incorporates the existing precipitation system equipment (Figure 15).



Sodium borohydride is capable of simultaneous chromium reduction and metals precipitation. However, it is assumed that the current practice of hexavalent chromium reduction with sulfur dioxide at SM-ALC will be continued because of the lower cost compared with  $\text{NaBH}_4$  reduction. The subsequent  $\text{NaBH}_4$  treatment will reduce any residual chromate contained in the wastewater.

## 1. Process Description

The treated effluent from the existing neutralizing tank (Figure 15) is pumped through a dip tube to an enclosed stainless steel reactor where sodium borohydride is added, based upon the wastewater feed rate.

A free space of 10 percent of the reactor volume is provided to allow for the evolution of hydrogen. The reactor is vented to the atmosphere through a vent pipe. Agitation is provided to ensure that thorough mixing is achieved. An overflow nozzle from the reaction tank provides the feed to the degassing tank. The degassing tank is similar in design to the reaction tank. Evolved Hydrogen is released through the vent line common to the reaction tank.

The overflow from the degassing tank is fed to the existing clarifier where the solids are separated in the manner currently practiced. No change is planned for the sludge-dewatering and handling operations.

## 2. Capital and Operating Costs

The costs of the equipment components are presented in Table 76. Note that the sodium borohydride process fully utilizes the existing treatment system. The total installed cost for the additional equipment is estimated to be \$162,500.

The annual operating costs for the sodium borohydride process are presented in Table 77. Details of the chemical costs are presented in Table 78. It is assumed that the system will not require any additional labor above the current labor needs. The chemical requirements are based on a  $\text{NaBH}_4$  dosage 2 times the theoretical requirement. The sludge-hauling and disposal cost was calculated assuming that  $\text{NaBH}_4$  would reduce the sludge volume by a factor of only one-third. It was assumed that the sludge would be hazardous and that the current rates for hauling and disposal were applicable.

Comparing the current annual treatment and sludge-hauling/disposal cost at McClellan AFB (\$279,884) to the annual cost for the sodium borohydride process (\$198,870) indicates an expected savings of \$80,000, representing a 49 percent return on the \$162,000 investment and a simple payback of 2 years.

TABLE 76. SODIUM BOROHYDRIDE--EQUIPMENT DESCRIPTION AND COST

<u>Item</u>	<u>Description</u>	<u>Equipment Cost</u>	<u>Installed Cost</u>
T-1,T-2	Reaction Vessels - 13,000 gal. 304 stainless steel reactors with agitators	\$ 50,000	\$ 75,000
P-1 & 2	Centrifugal Transfer Pumps, 400 gpm, 240V, 60 Hz. TEFC motors	existing*	existing*
C-1	Centrifuge		
T-3	Sludge Filter Feed Tank - 10,000 gal in-ground, concrete lined tank	existing*	existing*
P-3 & 4	Sludge Filter Feed Pumps - air operated diaphragm pumps; max flow: 100 gpm each; max TDH: 100 psig	existing*	existing*
T-2	Dewatered Sludge Storage Tank - 10,000 gal above-ground, conical-bottom storage tank	existing*	existing*
Instru- mentation	Miscellaneous	10,000	20,000
Process Piping & Duckwork	Miscellaneous	15,000	30,000
Total Equipment Cost		\$ 75,000	\$125,000
Contingency (at 20%)			25,000
Engineering (at 10%)			12,500
Total Cost			<u>\$162,500</u>

\* It is assumed that an equivalent piece of equipment exists at McClellan AFB.

TABLE 77. ANNUAL OPERATING COSTS AND SAVINGS FOR THE  
SODIUM BOROHYDRIDE PRECIPITATION PROCESS

Annual Operating Costs

Labor*	\$ 0
Chemicals NaBH <sub>4</sub> at \$0.70/1000 gal treated (171,500 m gal/yr)	125,244
Utilities	
Electricity at \$.07/kWh	
Sludge Hauling and Disposal (1,092 yd <sup>3</sup> /yr)	2,500
Hauling at \$13.72/yd <sup>3</sup>	14,982
Disposal at \$52.33/yd <sup>3</sup>	<u>57,144</u>
Total annual cost	\$199,870

Annual Savings

Current cost for precipitation†	\$ 63,504
Current cost for sludge hauling and disposal†† (3,276 yd <sup>3</sup> /yr)	<u>216,380</u>
Subtotal	\$279,884
Projected cost for NaBH <sub>4</sub> process	199,870
Savings	\$ <u>80,014</u>

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\*No additional labor needs expected.

†Precipitation costs based on 176,400 m gal/yr treated at  
\$0.36 m gal (see Table 10).

††\$13.72/yd<sup>3</sup> collection and transport, \$52.33/yd<sup>3</sup> disposal.

TABLE 78. CALCULATION OF SODIUM BOROHYDRIDE CHEMICAL COSTS\*  
FOR McCLELLAN AFB

<u>Pollutant</u>	<u>Concentration of Pollutant (mg/l)</u>	<u>NaBH<sub>4</sub> Required at 2 time Stoichiometric mg/l</u>	<u>NaBH<sub>4</sub> Cost to Treat 1000 gal at \$14.00/lb</u>
Cd	-	-	-
Cu	0.3	0.09	.01
Cr <sup>+6</sup>	1.3	-	-
Cr	1.8	0.97	0.11
Pb	-	-	-
Ni	-	-	-
Zn	-	-	-
Fe	5.0	<u>1.67</u>	<u>0.19</u>
Total		2.73	0.31

\*Sodium Borohydride will replace the use of lime and alum for precipitation. It is assumed that the use of other reagents at the IWTP (see Table 9 ) will continue. Caustic soda which is not currently used will be added to adjust the pH. The additional cost of this chemical would be approximately +0.17/1000 gal assuming 1.0 lb NaOH/1000 gal.

## SECTION VIII

### CONCLUSIONS

The analytical and engineering effort associated with the project has established the following conclusions regarding sludge generated at ALC industrial wastewater treatment plants. Sludge generated at the ALC wastewater treatment plants generally proved hazardous when tested for toxicity as defined by the EPA EP Toxicity test. At three facilities, cadmium leached at toxic levels. Chromium leaching was in excess of delisting criteria in the sludge from two ALCs. The sludge from Kelly ALC was low in cadmium content and tested nontoxic when subjected to the EP. The other RCRA-related metals (Ag, As, Ba, Hg, and Se) leached at levels well below the EP toxicity limits in all sludge samples tested.

Screening tests were performed on contrived wastewater to investigate the influence of different factors on the volume and characteristics of the resultant sludge generated. These tests indicated:

- Maintaining a pH of 9.2 in the neutralization/precipitation reaction using lime as the reagent gave optimum results in terms of metal removal and sludge settling.
- A comparison between caustic soda and lime as neutralizing reagents indicated that caustic soda generated approximately 20 percent of the dry-solids associated with lime neutralization. However, the volume of sludge generated by the caustic soda precipitation, due to its poor settling characteristics was three times that associated with lime precipitation after 30 minutes settling.
- The influence of water hardness on sludge volume was investigated, using lime neutralization. The test compared solids generated in treatment of a low hardness, high hardness and sodium ion exchange softened water. No significant difference in sludge volume was observed.
- Segregation and pretreatment of chromate-bearing wastewater was compared to treatment of all noncyanide wastewater for chromate reduction and subsequent neutralization. No significant difference existed with respect to sludge generation between the two variables.



- Reduction of chromates with  $\text{FeSO}_4$  was compared to reduction using  $\text{NaHSO}_3$ .  $\text{FeSO}_4$ , on the average, generated 30 times the amount of sludge on a dry weight basis, than  $\text{NaHSO}_3$  treatment.
- Treatment of wastewater with hydrogen peroxide at neutral pH achieved simultaneous cyanide oxidation and metal precipitation. The dry weight of sludge generated in this process scheme was equivalent to that associated with  $\text{NaOH}$  precipitation, but the solids exhibited superior settling and handling properties. Observation of color changes during treatment suggest many of the metals are precipitating as the oxide instead of the hydroxide. Wastewater quality was equivalent to that produced by conventional treatment.
- Treatment of wastewater with sodium borohydride ( $\text{NaBH}_4$ ) achieved simultaneous chromate reduction and metal removal at a slightly alkaline pH. This process exhibited superior metal removal compared to conventional treatment. The dry weight of solids generated by this process was equivalent to that associated with  $\text{NaOH}$  precipitation; however, the floc formed was of a much sturdier nature. After allowing gas evolution from the treated solution, the solids settled to a dense precipitate. Observation of the process supported the contention that most metals present were reduced and precipitated as the base metal.

Two technologies, ozone precipitation and sodium borohydride precipitation, were selected for detailed testing on the basis of the screening tests. These tests were performed on both actual wastewater from ALC and on contrived wastewater formulated to simulate wastewater generated at the AFLCs.

Ozone precipitation was evaluated after hydrogen peroxide precipitation showed promising results in terms of simultaneous metal precipitation and cyanide oxidation and that the process generated less sludge than lime precipitation. Ozone was substituted because it is a cheaper source of oxidizing reagent. The use of ozone, however, resulted in an oxidation of trivalent chromium to the hexavalent state. The high level of chromate in the treated wastewater precluded use of ozone in this process. Testing was resumed, using hydrogen peroxide as the oxidizing agent. The tests confirmed the reduced solids generation rate. Solids generation was reduced from the baseline value of 985 mg/l associated with lime neutralization to 321 mg/l. The resultant sludge was tested by the EPA EP and found hazardous due to leaching of chromium and cadmium. A further problem was observed if the sludge was allowed to sit overnight--trivalent chromium was slowly oxidized to the hexavalent form. This

indicates that chromium-containing sludge produced by  $H_2O_2$  is unstable and may pose a serious disposal problem. The effluent produced by the oxide precipitation process was determined to meet federal effluent guidelines with a 95-percent confidence level. The effluent did not meet the AF lower level objectives shown in Table 79.

TABLE 79. EFFLUENT OBJECTIVES

<u>Parameter</u>	<u>Concentration (mg/l)</u>
Chromium (Total)	0.25
Chromium (Hexavalent)	0.025
Cadmium	0.010
Copper	0.005
Nickel	0.10
Cyanide	0.002

Sodium borohydride was evaluated after promising results during the screening tests in terms of lower solids generation and superior effluent quality. The detailed testing confirmed that the process reduced chromates and precipitated many metals as the base metal with a low residual concentration in the effluent. The dry weight of sludge generated by the process when treating the contrived wastewater was 309 mg/l, approximately 1/3 the amount generated by lime treatment. The sludge produced by  $NaBH_4$  precipitation failed the EP test due to leaching of high levels of cadmium and chromium. The sludge did form dense flocs, however, which settled rapidly after residual hydrogen gas evolution ceased.

At this point in the project, it was concluded that no alternative treatment process could guarantee generation of non-hazardous waste when applied to treating wastewater typical of that generated at ALC. The next stage performed screening evaluations of sludge treatment techniques that would either reduce the volume of sludge generated by a given treatment process or render the sludge nonhazardous. The tests concluded:

- Solidification of the sludge with a mixture of Portland cement, fly ash and water produced a monolithic sample, which when subjected to a structural integrity test and the EP, proved nonhazardous.
- Sludge aging was investigated as a method of volume reduction (by water evaporation) and detoxification by conversion to metal oxides when exposed to air. After 30 days aging, however, no significant reduction in leachability occurred.

- Heat treatment was investigated as a means of accelerating the aging process. Heat treatment at 260°C was dismissed because it reoxidized hexavalent chromium and caused it to leach at high concentrations. Heat treatment at 120°C, however, resulted in a nonhazardous sludge and reduced the sludge volume eightfold.
- Sludge washing with ammonium chloride was investigated as a means of breaking the bonds of hydration that bind water to sludge solids. Both lime and borohydride sludges were washed with equal volumes of 1% ammonium chloride. The washing reduced the sludge volumes after dewatering by 25 percent. After washing, the borohydride sludge leached higher concentrations of metals in the EP test. The lime sludge-leaching properties were not affected by the washing; it still tested hazardous.
- Leaching of the sludge with pH adjusted deionized water at pH levels of 3.5, 7.0, and 10.5 reduced the EP leaching of the sludge but not to a level sufficient to make the sludge nonhazardous.
- Barium acetate was added to the wastewater during sodium borohydride precipitation. This test decreased the chromium leaching during the extraction procedure, but not sufficiently to make the sludge test nonhazardous.

The results of the screening tests pointed to four techniques which might prove effective in making the wastewater sludge nonhazardous: solidification, heat treatment, washing, and barium compounds. In addition, sludge aging was evaluated because an earlier independent project showed success with this technique.

The objectives of the detailed testing of the solidification process were to determine the maximum percentage of sludge that could be used in the mixture, whether the process was also effective with lime sludges, and whether air curing could be substituted for oven curing. The tests found that up to 15 and 40 percent of sodium borohydride and lime sludge solids, respectively, could be used in the mixture and have the solidified material retain its structural integrity and nonhazardous properties. Further, air-curing was as effective as oven-curing but, naturally, required a longer period. Also, enclosing the sample in an airtight container did not significantly retard the ambient-temperature curing process.

Detailed testing of barium compound addition focused on varying the point of addition of barium in the wastewater treatment process. The tests revealed the barium dissolved better into the wastewater if mixed prior to pH adjustment than if added after metal precipitation. In both cases, however, barium addition increased the level of chromium leaching in the EP.

The detailed testing of the heat treatment process focused on determining the optimum duration of heat treatment and the temperature range that would render the sludge nonhazardous. Optimum drying time in terms of volume reduction and metal leachability reduction was between 1 and 2 hours. The optimum temperature was between 80 and 120°C. The EP results on the heat-treated sludge left some doubt as to whether the process was a reliable method for rendering a sludge nonhazardous.

Testing on the sludge washing with ammonium chloride was expanded to include lime and sodium hydroxide sludges in addition to the sodium borohydride sludge. The results indicated that after washing and subsequent dewatering, the volume of the sodium hydroxide and sodium borohydride sludges were reduced approximately 40 percent. The lime sludge dewaterability was not affected by the washing, nor did the washing affect the EP toxicity of any of the sludges tested. Further testing indicated that increasing the concentration of ammonium chloride in the wash improved the dewaterability; optimum dewaterability was realized with a 10-percent solution of ammonium chloride.

Prototype designs were developed for the following processes as a means of determining equipment costs and economic benefits. Table 80 presents a summary of the factors that were considered in assessing the various systems.

TABLE 80. SUMMARY OF PROTOTYPE SYSTEMS

Process	Design Basis	Installed Cost (\$)	Operating Cost (\$/yr)	Annual Savings (\$/yr)	Sludge Hazardous
Heat treatment	Hill AFB	460,000	31,000	89,000	No
Sludge washing	Hill AFB	160,000	48,000	73,000	Yes
Sludge aging	Hill AFB	289,000	30,000	90,000	No
Solidification	McClellan AFB	111,000	181,000	35,000	No
Sodium borohydride precipitation	McClellan AFB	162,000	199,000	80,000	Yes

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APPENDIX A

EXTRACTION PROCEDURES

EP Toxicity Test is reprinted from Federal Register,  
Monday, May 19, 1980.

# Appendix II— EP Toxicity Test Procedure

## A. Extraction Procedure (EP)

1. A representative sample of the waste to be tested (minimum size 100 grams) should be obtained using the methods specified in Appendix I or any other methods capable of yielding a representative sample within the meaning of Part 260. [For detailed guidance on conducting the various aspects of the EP see "Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods," SW-846, U.S. Environmental Protection Agency Office of Solid Waste, Washington, D.C. 20460.]<sup>1</sup>

2. The sample should be separated into its component liquid and solid phases using the method described in "Separation Procedure" below. If the solid residue<sup>2</sup> obtained using this method totals less than 0.5% of the original weight of the waste, the residue can be discarded and the operator should treat the liquid phase as the extract and proceed immediately to Step 8.

3. The solid material obtained from the Separation Procedure should be evaluated for its particle size. If the solid material has a surface area per gram of material equal to, or greater than, 3.1 cm<sup>2</sup> or passes through a 9.5 mm (0.375 inch) standard sieve, the operator should proceed to Step 4. If the surface area is smaller or the particle size larger than specified above, the solid material should be prepared for extraction by crushing, cutting or grinding the material so that it passes through a 9.5 mm (0.375 inch) sieve or, if the material is in a single piece, by subjecting the material to the "Structural Integrity Procedure" described below.

4. The solid material obtained in Step 3 should be weighed and placed in an extractor with 16 times its weight of deionized water. Do not allow the material to dry prior to weighing. For purposes of this test, an acceptable extractor is one which will impart sufficient agitation to the mixture to not only prevent stratification of the sample and extraction fluid but also insure that all sample surfaces are continuously

brought into contact with well mixed extraction fluid.

5. After the solid material and deionized water are placed in the extractor, the operator should begin agitation and measure the pH of the solution in the extractor. If the pH is greater than 5.0, the pH of the solution should be decreased to  $5.0 \pm 0.2$  by adding 0.5 N acetic acid. If the pH is equal to or less than 5.0, no acetic acid should be added. The pH of the solution should be monitored, as described below, during the course of the extraction and if the pH rises above 5.2, 0.5N acetic acid should be added to bring the pH down to  $5.0 \pm 0.2$ . However, in no event shall the aggregate amount of acid added to the solution exceed 4 ml of acid per gram of solid. The mixture should be agitated for 24 hours and maintained at 20°–40° C (68°–104° F) during this time. It is recommended that the operator monitor and adjust the pH during the course of the extraction with a device such as the Type 45-A pH Controller manufactured by Chemtrix, Inc., Hillsboro, Oregon 97123 or its equivalent, in conjunction with a metering pump and reservoir of 0.5N acetic acid. If such a system is not available, the following manual procedure shall be employed:

(a) A pH meter should be calibrated in accordance with the manufacturer's specifications.

(b) The pH of the solution should be checked and, if necessary, 0.5N acetic acid should be manually added to the extractor until the pH reaches  $5.0 \pm 0.2$ . The pH of the solution should be adjusted at 15, 30 and 60 minute intervals, moving to the next longer interval if the pH does not have to be adjusted more than 0.5N pH units.

(c) The adjustment procedure should be continued for at least 6 hours.

(d) If at the end of the 24-hour extraction period, the pH of the solution is not below 5.2 and the maximum amount of acid (4 ml per gram of solids) has not been added, the pH should be adjusted to  $5.0 \pm 0.2$  and the extraction continued for an additional four hours, during which the pH should be adjusted at one hour intervals.

6. At the end of the 24 hour extraction period, deionized water should be added to the extractor in an amount determined by the following equation:

$$V = (20)(W) - 16(W) - A$$

V = ml deionized water to be added

W = weight in grams of solid charged to extractor

A = ml of 0.5N acetic acid added during extraction

7. The material in the extractor should be separated into its component liquid and solid phases as described under "Separation Procedure."

8. The liquids resulting from Steps 2 and 7 should be combined. This

<sup>1</sup> Copies may be obtained from Solid Waste Information, U.S. Environmental Protection Agency, 26 W. St. Clair Street, Cincinnati, Ohio 45268.

<sup>2</sup> The percent solids is determined by drying the filter pad at 80° C until it reaches constant weight and then calculating the percent solids using the following equation:

$$\frac{(\text{weight of pad} + \text{solid}) - (\text{tare weight of pad})}{\text{initial weight of sample}} \times 100 = \% \text{ solids}$$

combined liquid (or the waste itself if it has less than 1/2 percent solids, as noted in Step 2) is the extract and should be analyzed for the presence of any of the contaminants specified in Table I of § 261.24 using the Analytical Procedures designated below.

#### *Separation Procedure*

**Equipment:** A filter holder, designed for filtration media having a nominal pore size of 0.45 micrometers and capable of applying a 5.3 kg/cm<sup>2</sup> (75 psi) hydrostatic pressure to the solution being filtered shall be used. For mixtures containing nonabsorptive solids, where separation can be affected without imposing a 5.3 kg/cm<sup>2</sup> pressure differential, vacuum filters employing a 0.45 micrometers filter media can be used. (For further guidance on filtration equipment or procedures see "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods.")

#### *Procedure:*<sup>3</sup>

(i) Following manufacturer's directions, the filter unit should be assembled with a filter bed consisting of a 0.45 micrometer filter membrane. For difficult or slow to filter mixtures a prefilter bed consisting of the following prefilters in increasing pore size (0.65 micrometer membrane, fine glass fiber prefilter, and coarse glass fiber prefilter) can be used.

(ii) The waste should be poured into the filtration unit.

(iii) The reservoir should be slowly pressurized until liquid begins to flow from the filtrate outlet at which point the pressure in the filter should be immediately lowered to 10-15 psig. Filtration should be continued until liquid flow ceases.

(iv) The pressure should be increased stepwise in 10 psi increments to 75 psig and filtration continued until flow ceases or the pressurizing gas begins to exit from the filtrate outlet.

(v) The filter unit should be depressurized, the solid material removed and weighed and then transferred to the extraction apparatus, or, in the case of final filtration prior to analysis, discarded. Do not allow the

material retained on the filter pad to dry prior to weighing.

(vi) The liquid phase should be stored at 4°C for subsequent use in Step 8.

#### *B. Structural Integrity Procedure*

**Equipment:** A Structural Integrity Tester having a 3.18 cm (1.25 in.) diameter hammer weighing 0.33 kg (0.73 lbs.) and having a free fall of 15.24 cm (6 in.) shall be used. This device is available from Associated Design and Manufacturing Company, Alexandria, VA., 22314, as Part No. 125, or it may be fabricated to meet the specifications shown in Figure 1.

#### *Procedure:*

1. The sample holder should be filled with the material to be tested. If the sample of waste is a large monolithic block, a portion should be cut from the block having the dimensions of a 3.3 cm (1.3 in.) diameter x 7.1 cm (2.8 in.) cylinder. For a fixated waste, samples may be cast in the form of a 3.3 cm (1.3 in.) diameter x 7.1 cm (2.8 in.) cylinder for purposes of conducting this test. In such cases, the waste may be allowed to cure for 30 days prior to further testing.

2. The sample holder should be placed into the Structural Integrity Tester, then the hammer should be raised to its maximum height and dropped. This should be repeated fifteen times.

3. The material should be removed from the sample holder, weighed, and transferred to the extraction apparatus for extraction.

#### *Analytical Procedures for Analyzing Extract Contaminants*

The test methods for analyzing the extract are as follows:

(1) For arsenic, barium, cadmium, chromium, lead, mercury, selenium or silver: "Methods for Analysis of Water and Wastes," Environmental Monitoring and Support Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268 (EPA-600/4-79-020, March 1979).

(2) For Endrin; Lindane; Methoxychlor; Toxaphene; 2,4-D; 2,4,5-TP Silver: in "Methods for Benzidine, Chlorinated Organic Compounds, Pentachlorophenol and Pesticides in Water and Wastewater," September 1978, U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio 42568.

as standardized in "Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods."

For all analyses, the method of standard addition shall be used for the quantification of species concentration.

This method is described in "Test Methods for the Evaluation of Solid Waste." (It is also described in "Methods for Analysis of Water and Wastes.")

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<sup>3</sup> This procedure is intended to result in separation of the "free" liquid portion of the waste from any solid matter having a particle size >0.45µm. If the sample will not filter, various other separation techniques can be used to aid in the filtration. As described above, pressure filtration is employed to speed up the filtration process. This does not alter the nature of the separation. If liquid does not separate during filtration, the waste can be centrifuged. If separation occurs during centrifugation the liquid portion (centrifugate) is filtered through the 0.45µm filter prior to becoming mixed with the liquid portion of the waste obtained from the initial filtration. Any material that will not pass through the filter after centrifugation is considered a solid and is extracted.



## Proposed Methods for LEACHING OF WASTE MATERIALS<sup>1</sup>

This proposed method has no status as an ASTM Standard and is published on behalf of the sponsoring committee for information only, for a maximum of two years. Comments are solicited and should be addressed to the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.

### 1. Scope

1.1 These methods cover procedures for leaching of waste materials to obtain an aqueous solution to be used to determine the leachable materials present. The following methods are included:

	Sections
Method A—Water Shake Extraction Procedure	6 to 14
Method B—Acid Shake Extraction Procedure	15 to 23

### 2. Applicable Documents

#### 2.1 ASTM Standards:

D 75 Sampling Aggregates<sup>2</sup>

D 420 Recommended Practice for Investigating and Sampling of Soil and Rock for Engineering Purposes<sup>3</sup>

D 1129 Definitions of Terms Relating to Water<sup>4</sup>

D 1193 Specification for Reagent Water<sup>5</sup>

D 1888 Tests for Particulate and Dissolved Matter in Water<sup>6</sup>

D 2216 Laboratory Determination of Moisture Content of Soils<sup>7</sup>

D 2234 Collection of a Gross Sample of Coal<sup>8</sup>

D 3370 Practices for Sampling Water<sup>9</sup>

E 122 Recommended Practice for Choice of Sample Size to Estimate the Average Quality of a Lot or Process<sup>10</sup>

E 380 Metric Practice<sup>11</sup>

### 3. Definitions

3.1 For definitions of terms used in these methods, see Definitions D 1129. For an explanation of the metric system including units, symbols, and conversion factors, see Standard E 380.

### 4. Purity of Reagents

4.1 Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the American Chemical Society, where such specifications are available.<sup>12</sup> Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

4.2 Unless otherwise indicated, references to water shall be understood to mean Type IV reagent water, Specification D 1193.

### 5. Sampling

5.1 Obtain a representative sample of the waste to be tested using ASTM sample methods developed for the specific industry where available.

5.2 Where no specific methods are available, sampling methodology for materials of similar physical form should be used.

5.3 A minimum sample of 5000 g shall be sent to the laboratory (see Method E 122).

5.4 Samples should be kept in closed containers appropriate to the sample type prior to testing. Biologically active samples should

<sup>1</sup> These proposed methods are under the jurisdiction of Committee D-19 on Water.

Published as information only May 1978.

<sup>2</sup> Annual Book of ASTM Standards, Part 19.

<sup>3</sup> Annual Book of ASTM Standards, Part 31.

<sup>4</sup> Annual Book of ASTM Standards, Part 26.

<sup>5</sup> Annual Book of ASTM Standards, Parts 11 and 41.

<sup>6</sup> Annual Book of ASTM Standards, Part 41 (Excerpts in Part 31).

<sup>7</sup> Reagent Chemicals, American Chemical Society Specifications. Am. Chemical Soc., Washington, D. C. For suggestions on the testing of reagents not listed by the American Chemical Society, see Reagent Chemicals and Standards, by Joseph Rosin, D. Van Nostrand Co., Inc., New York, N. Y., and the United States Pharmacopeia.

## Leaching of Waste Materials

be stored at 4°C (Practices D 3370) and the extraction of them should be started within 8 h if possible.

### METHOD A—WATER SHAKE EXTRACTION PROCEDURE

#### 6. Scope

6.1 This method covers the shaking of a known weight of waste with water of specified composition and the separation of the aqueous phase for analysis.

#### 7. Significance and Use

7.1 This method is intended as a rapid means of obtaining a solution for evaluation of the extractable materials in wastes. It may be used to produce solutions for the estimation of the relative environmental hazard inherent in the leachings from the waste.

7.2 This method is not intended to produce solutions to be used as a basis for engineering design of disposal sites.

7.3 This method is intended to determine collectively the immediate surface washing and the time-dependent diffusion-controlled contributions to leachings from the waste.

7.4 It is intended that the wastes used in this test shall be tested in the physical form in which they will be discarded.

#### 8. Apparatus

8.1 *Agitation Equipment*—Agitation equipment of any type that will produce constant movement of the aqueous phase equivalent to that of a reciprocating platform shaker operated at 60 to 70 one-inch (25-mm) strokes per minute without incorporation of air is suitable. Equipment used shall be designed for continuous operation without heating the samples being agitated.

8.2 *Membrane Filter Assembly*—A borosilicate glass or stainless steel funnel with a flat, fritted base of the same material and membrane filters.

8.3 *Containers*—Round, wide-mouth bottles of composition suitable to the nature of the waste and the analyses to be performed. One-gallon (or 4-litre) bottles should be used with 700-g samples and 1/2-gal (or 2-litre) bottles with 350-g samples. Multiples of these sizes may be used for larger samples. These sizes were selected to establish suitable ge-

ometry and provide that the sample plus liquid would occupy approximately 80 to 90 % of the container. Bottles must have a watertight closure. Containers for samples where gases may be released should be provided with a venting mechanism. Containers should be cleaned in a manner consistent with the analyses to be performed.

#### 9. Reagents

9.1 *Test Water*—Reagent water, Type IV, (Specification D 1193) at  $20 \pm 2^\circ\text{C}$ .

#### 10. Sampling

10.1 For free-flowing particulate wastes, obtain a sample of the approximate size required in the test by quartering the sample (Section 5) received for testing on an impermeable sheet of glazed paper, oil cloth, or other flexible material as follows:

10.1.1 Empty the sample container into the center of the sheet.

10.1.2 Flatten out the sample gently with a suitable straightedge until it is spread uniformly to a depth appropriate to its particle size.

10.1.3 Remix the sample by lifting a corner of the sheet and drawing it across, low down, to the opposite corner in a manner that the material is made to roll over and over and does not merely slide along. Continue operation with each corner, proceeding in a clockwise direction. Repeat this operation ten times.

10.1.4 Lift all four corners of the sheet towards the center and holding all four corners together, raise the entire sheet into the air to form a pocket for the sample.

10.1.5 Repeat Step 10.1.2.

10.1.6 With a straightedge at least as long as the flattened mound of sample (such as a thin-edged yard stick), gently divide the sample into quarters. An effort should be made to avoid using pressure on the straightedge sufficient to cause damage to the particles.

10.1.7 Discard alternate quarters.

10.1.8 If further reduction of sample size is necessary, repeat Steps 10.1.3 through 10.1.7. A minimum sample size of 350 g is recommended for each extraction. Additional samples should be provided for determination of solids content. If smaller samples are used

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## Leaching of Waste Materials

in the test, report this fact.

10.2 For field-cored wastes or castings produced in the laboratory, cut a representative vertical section weighing approximately 350 or 700 g for testing, plus samples for determination of solids content. The sample should be shaped so that the leaching solution will cover the material to be tested.

10.3 For fluid wastes, mix thoroughly in a manner that does not incorporate air to assure uniformity before withdrawing a 350 or 700-g sample for test. Take samples for determination of solids content at the same time as the test sample.

### 11. Procedure

11.1 Record the physical description of the sample to be tested including particle size so far as it is known.

11.2 *Solids Content*—Determine the solids content of separate portions of the sample as follows:

11.2.1 Dry two dishes or pans of size suitable to the waste being tested at  $104 \pm 2^\circ\text{C}$ . Cool in a desiccator and weigh. Record the value to  $\pm 0.1$  g.

11.2.2 Put an appropriately sized portion of sample of the waste to be tested into each pan. The weight used should be scaled to the physical form of the waste tested. Use a minimum of 50 g but use larger samples where particles larger than 10 mm in average diameter are being tested. Weigh. Record the weight to  $\pm 0.1$  g.

11.2.3 Dry  $18 \pm 2$  h at  $104 \pm 2^\circ\text{C}$ .

11.2.4 Cool to room temperature in a desiccator and reweigh. Record the weight to  $\pm 0.1$  g.

11.3 *Shake Procedure*—Weigh or tare the containers to be used in the shake test to 1 g.

11.4 Add to the container approximately 700 g of waste (Sections 7.4 and 10) and determine and record the weight of sample used to 1 g. If weights other than 700 g are used, note in the report.

11.5 Add to the container a volume of test water (9.1) equal in millilitres to four times the weight in grams of the sample used in 11.4.

11.6 Close the container and place it on the agitation equipment.

11.7 Agitate continuously for  $48 \text{ h} \pm 0.5 \text{ h}$

at  $20 \pm 2^\circ\text{C}$ .

11.8 Open the containers. Observe and record any changes in the sample and leaching solution.

11.9 Separate the bulk of the aqueous phase from any solid or nonaqueous phases by decantation, centrifugation, or filtration through filter paper as appropriate. Vacuum filter the aqueous phase through a  $0.45\text{-}\mu\text{m}$  membrane filter. For oily wastes such as those from API separators, use a  $8\text{-}\mu\text{m}$  filter. Retain any nonaqueous liquid separately.

11.10 Transfer the filtrate to sample bottles of a size such that the entire bottle is filled. Close and label. Preserve the filtrate in a manner consistent with the chemical analyses to be performed.

11.11 Analyze the filtrate for specific constituents or properties as desired using appropriate ASTM or other standard methods. Where nonaqueous liquid is present, analyze it also.

### 12. Calculation

12.1 Calculate the solids content of the individual samples from the data obtained in 11.2 as follows:

$$S = A/B$$

where:

A = weight in grams of sample after drying.

B = original weight in grams of sample, and

S = solid content, g/g.

Average the two values obtained. Record as the solids content.

12.2 Analytical results obtained and reported in milligrams per litre of filtrate may be converted to milligrams leached per gram of dry sample as follows:

$$L = \frac{C}{250 S}$$

where:

C = concentration of any constituent measured, mg/litre.

S = solids content, g/g and

L = constituent leached in milligrams per gram of dry sample.

### 13. Report

13.1 The report shall include the following:

13.1.1 Source of the waste and sampling

## Leaching of Waste Materials

information,

13.1.2 Description of the waste including physical characteristics and particle size (11.1).

13.1.3 Solids content (11.2).

13.1.4 Sample weight if other than 700 g.

13.1.5 Results of specific analyses calculated in appropriate units (12.2).

13.1.6 Observation of changes in test material or leaching solution recorded in 11.8.

### 14. Precision

14.1 The precision of analysis for individual constituents is that indicated in their specific methods of analysis.

14.2 The precision of the leaching procedure is to be determined.

## METHOD B—ACID SHAKE EXTRACTION PROCEDURE

### 15. Scope

15.1 This method covers the shaking of a known weight of waste with an acidic buffer solution, and the separation of the aqueous phase for analysis.

### 16. Significance and Use

16.1 This method is intended as a rapid means of obtaining a solution for evaluation of the extractable materials in waste under acidic conditions. It may be used to produce solutions for the estimation of the relative environmental hazard inherent in the leachings from the waste.

16.2 This method is not intended to produce solutions to be used as a basis for engineering design of disposal sites.

16.3 This method is intended to determine collectively the immediate surface washing and the time-dependent diffusion-controlled contributions to leaching from waste.

16.4 It is intended that the wastes used in this test shall be tested in the physical form in which they will be discarded.

### 17. Equipment

17.1 Equipment required for this test is described in Section 8.

### 18. Reagents

18.1 *Sodium Acetate—Acetic Acid Buffer Solution*—Dissolve 4.9 g of glacial acetic acid and 3.7 g of sodium acetate in 1 litre of water. Adjust the pH to  $4.5 \pm 0.1$  by the dropwise addition of acetic acid or sodium hydroxide (40 g/litre) as required. Solution temperature should be  $20 \pm 2^\circ\text{C}$ .

### 19. Sampling

19.1 Directions for obtaining a representative sample for test purposes are given in Section 10.

### 20. Procedure

20.1 Proceed in accordance with Section 11, using the sodium acetate buffer solution (18.1) in place of water in 11.5.

### 21. Calculation

21.1 Calculate the results obtained as directed in Section 12. The results of specific analyses should be corrected by subtraction of the blank values obtained by analyzing the sodium acetate buffer solution used as the extractant.

### 22. Report

22.1 Report the results of the test as directed in Section 12.

### 23. Precision

23.1 No information is presently available as to the precision of the analysis of specific constituents in this test solution. Until this can be done, it is recommended that users of this test check the applicability of their chosen methods of detection by spiking the test water before using these methods for the analysis of the filtrate from wastes.

23.2 The precision of the leaching procedure is to be determined.

**APPENDIX B**

**RESULTS OF WORTH ASSESSMENT ANALYSIS**

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# EGLIN AFB TECHNOLOGY ASSESSMENT CRITERIA

REVISED MODEL OF JANUARY 1982

<u>CRITERIA</u>		<u>ASSESSMENT</u>	<u>WEIGHT FACTOR</u>	<u>YES/NO FACTOR</u>
1. Development Status	(a)	1.0 Commercialized	0.04	1
	(b)	0.6 Industrial Demo		1
	(c)	0.3 Lab Success		1
	(d)	0.0 No Data		1
2. Pollutant Removal Capability	(a)	1.0 Better than CTP	0.1	1
	(b)	0.5 Equal to CTP		1
	(c)	0.0 Inferior to CTP		1
	(d)	0.5 Undefined or Cond.		1
3. Capital Cost	(a)	1.0 Potentially < CTP	0.04	1
	(b)	0.5 Equal to CTP		1
	(c)	0.0 Potentially > CTP		1
	(d)	0.5 Undefined or Cond.		1
4. Operating Cost	(a)	1.0 Potentially < CTP	0.04	1
	(b)	0.5 Equal to CTP		1
	(c)	0.0 Potentially > CTP		1
	(d)	0.5 Undefined or Cond.		1
5. Raw Material Recovery	(a)	1.0 Recovers H <sub>2</sub> O and Raw Materials	0.04	1
	(b)	0.5 Recovers H <sub>2</sub> O or Raw Materials		1
	(c)	0.0 No Recovery		1
	(d)	0.5 Undefined or Cond.		1
6. Total Dissolved Solids Impact	(a)	1.0 Decreases TDS	0.04	1
	(b)	0.7 No Effect on TDS		1
	(c)	0.5 Increases TDS		1
	(d)	0.5 Undefined or Cond.		1
7. Solids Generation	(a)	1.0 Potentially < CTP	0.16	1
	(b)	0.5 Equal to CTP		1
	(c)	0.0 Potentially > CTP		1
	(d)	0.5 Undefined or Cond.		1
8. Sludge De-watering	(a)	1.0 Better than Hydrox	0.10	1
	(b)	0.5 Equal to Hydrox		1
	(c)	0.0 Inferior to Hydrox		1
	(d)	0.5 Undefined or Cond.		1
9. Sludge Reactivity	(a)	1.0 Not Reactive	0.10	1
	(b)	0.0 Reactive		1
10. Sludge Recovery Potential	(a)	1.0 Immediate	0.10	1
	(b)	0.7 Minimal Treatment		1
	(c)	0.4 Significant Treatment		1
	(d)	0.0 No Recovery		1

# CHROMIUM REDUCTION PROCESSES

2	CR6 RED-FE ANODES	.776
8	FORMALIN	.624
6	CR6 RED-NABH4 RED	.616
1	CR6 RED-SO2 OR NAHSO3	.584
5	CR6 RED-CEMENTATION	.524
7	CR6 RED-FESO4	.514
3	CR6 RED-SULFIDE	.474
4	CR6 RED-ACT CARBON	.46

## (1) CR6 RED-SO2 OR NAHSO3

#	FACTOR NAME	VALUE	SELECTION DESCRIPTION	WEIGHT	Y/N	#	VALUE
1	DEVELOPMENT STATUS	1.0	COMMERCIALIZED	0.040	YES	0	04000
2	POLLUTANT REMOVAL	0.5	EQUAL TO CTP	0.100	YES	0	05000
3	CAPITAL COST	0.5	EQUAL TO CTP	0.040	YES	0	02000
4	OPERATING COST	0.5	EQUAL TO CTP	0.040	YES	0	02000
5	RAW MATERIAL REC.	0.0	NO REC	0.040	YES	0	00000
6	TDS IMPACT	0.5	INCREASES TDS	0.040	YES	0	02000
7	SOLIDS GENERATION	0.5	EQUAL TO CTP	0.180	YES	0	09000
8	SLUDGE DEWATERING	0.5	EQUAL TO HYDROX	0.100	YES	0	05000
9	SLUDGE REACTIVITY	1.0	NOT REACTIVE	0.100	YES	0	10000
10	RECOVERY POTENTIAL	0.4	SIGNIF TREATMENT	0.100	YES	0	04000
11	METAL LEACHABILTY	0.7	EQUAL TO HYDROX	0.040	YES	0	02800
12	OPERATIONAL REQ	0.7	AUTO CONT+SIMP LAB	0.180	YES	0	12600

TOTAL

0.58400

## (2) CR6 RED-FE ANODES

#	FACTOR NAME	VALUE	SELECTION DESCRIPTION	WEIGHT	Y/N	#	VALUE
1	DEVELOPMENT STATUS	1.0	COMMERCIALIZED	0.040	YES	0	04000
2	POLLUTANT REMOVAL	0.5	EQUAL TO CTP	0.100	YES	0	05000
3	CAPITAL COST	1.0	POTEN. < CTP	0.040	YES	0	04000
4	OPERATING COST	1.0	POTEN < CTP	0.040	YES	0	04000
5	RAW MATERIAL REC.	0.0	NO REC	0.040	YES	0	00000
6	TDS IMPACT	0.7	NO AFFECT ON TDS	0.040	YES	0	02800
7	SOLIDS GENERATION	1.0	POTEN<CTP	0.180	YES	0	18000
8	SLUDGE DEWATERING	0.5	EQUAL TO HYDROX	0.100	YES	0	05000
9	SLUDGE REACTIVITY	1.0	NOT REACTIVE	0.100	YES	0	10000
10	RECOVERY POTENTIAL	0.4	SIGNIF TREATMENT	0.100	YES	0	04000
11	METAL LEACHABILTY	0.7	EQUAL TO HYDROX	0.040	YES	0	02800
12	OPERATIONAL REQ	1.0	TOTAL AUTOMATION	0.180	YES	0	18000

TOTAL

0.77600

## (3) CR6 RED-SULFIDE

#	FACTOR NAME	VALUE	SELECTION DESCRIPTION	WEIGHT	Y/N	#	VALUE
1	DEVELOPMENT STATUS	0.6	INDUSTRIAL DEMO	0.040	YES	0	02400
2	POLLUTANT REMOVAL	0.5	EQUAL TO CTP	0.100	YES	0	05000
3	CAPITAL COST	0.0	POTEN. > CTP	0.040	YES	0	00000
4	OPERATING COST	0.0	POTEN > CTP	0.040	YES	0	00000
5	RAW MATERIAL REC.	0.0	NO REC	0.040	YES	0	00000
6	TDS IMPACT	0.5	INCREASES TDS	0.040	YES	0	02000
7	SOLIDS GENERATION	0.5	UNDEFINED OR COND	0.180	YES	0	09000
8	SLUDGE DEWATERING	0.5	EQUAL TO HYDROX	0.100	YES	0	05000
9	SLUDGE REACTIVITY	1.0	NOT REACTIVE	0.100	YES	0	10000
10	RECOVERY POTENTIAL	0.4	SIGNIF TREATMENT	0.100	YES	0	04000
11	METAL LEACHABILTY	0.7	EQUAL TO HYDROX	0.040	YES	0	02800
12	OPERATIONAL REQ	0.4	SIGNIF LABOR REQ	0.180	YES	0	07200

TOTAL

0.47400



## (4) CR6 RED-ACT CARBON

#	FACTOR NAME	VALUE	SELECTION DESCRIPTION	WEIGHT	Y/N	#	VALUE
1	DEVELOPMENT STATUS	0.3	LAB SUCCESS	0.040	YES	0.01200	
2	POLLUTANT REMOVAL	0.0	INFERIOR TO CTP	0.100	YES	0.00000	
3	CAPITAL COST	0.5	UNDEFINED OR COND	0.040	YES	0.02000	
4	OPERATING COST	0.5	UNDEFINED OR COND	0.040	YES	0.02000	
5	RAW MATERIAL REC.	0.0	NO REC	0.040	YES	0.00000	
6	TDS IMPACT	0.7	NO AFFECT ON TDS	0.040	YES	0.02800	
7	SOLIDS GENERATION	0.5	UNDEFINED OR COND	0.180	YES	0.09000	
8	SLUDGE DEWATERING	0.5	UNKNOWN OR COND	0.100	YES	0.05000	
9	SLUDGE REACTIVITY	1.0	NOT REACTIVE	0.100	YES	0.10000	
10	RECOVERY POTENTIAL	0.4	SIGNIF TREATMENT	0.100	YES	0.04000	
11	METAL LEACHABILITY	0.7	UNKNOWN OR COND	0.040	YES	0.02800	
12	OPERATIONAL REQ	0.4	SIGNIF LABOR REQ	0.180	YES	0.07200	
TOTAL							0.46000

## (5) CR6 RED-CEMENTATION

#	FACTOR NAME	VALUE	SELECTION DESCRIPTION	WEIGHT	Y/N	#	VALUE
1	DEVELOPMENT STATUS	0.3	LAB SUCCESS	0.040	YES	0.01200	
2	POLLUTANT REMOVAL	0.5	EQUAL TO CTP	0.100	YES	0.05000	
3	CAPITAL COST	0.0	POTEN. > CTP	0.040	YES	0.00000	
4	OPERATING COST	0.0	POTEN. > CTP	0.040	YES	0.00000	
5	RAW MATERIAL REC.	0.0	NO REC	0.040	YES	0.00000	
6	TDS IMPACT	0.7	NO AFFECT ON TDS	0.040	YES	0.02800	
7	SOLIDS GENERATION	0.5	UNDEFINED OR COND	0.180	YES	0.09000	
8	SLUDGE DEWATERING	0.5	UNKNOWN OR COND	0.100	YES	0.05000	
9	SLUDGE REACTIVITY	1.0	NOT REACTIVE	0.100	YES	0.10000	
10	RECOVERY POTENTIAL	0.4	SIGNIF TREATMENT	0.100	YES	0.04000	
11	METAL LEACHABILITY	0.7	UNKNOWN OR COND	0.040	YES	0.02800	
12	OPERATIONAL REQ	0.7	AUTO CONT+SIMP LAB	0.180	YES	0.12600	
TOTAL							0.52400

## (6) CR6 RED-NABH4 RED

#	FACTOR NAME	VALUE	SELECTION DESCRIPTION	WEIGHT	Y/N	#	VALUE
1	DEVELOPMENT STATUS	0.0	NO DATA	0.040	YES	0.00000	
2	POLLUTANT REMOVAL	0.5	UNDEFINED OR COND	0.100	YES	0.05000	
3	CAPITAL COST	0.5	UNDEFINED OR COND	0.040	YES	0.02000	
4	OPERATING COST	0.5	UNDEFINED OR COND	0.040	YES	0.02000	
5	RAW MATERIAL REC.	0.0	NO REC	0.040	YES	0.00000	
6	TDS IMPACT	0.5	INCREASES TDS	0.040	YES	0.02000	
7	SOLIDS GENERATION	0.5	EQUAL TO CTP	0.180	YES	0.09000	
8	SLUDGE DEWATERING	0.5	EQUAL TO HYDROX	0.100	YES	0.05000	
9	SLUDGE REACTIVITY	1.0	NOT REACTIVE	0.100	YES	0.10000	
10	RECOVERY POTENTIAL	1.0	IMMEDIATE	0.100	YES	0.10000	
11	METAL LEACHABILITY	1.0	LESS THAN HYDROX	0.040	YES	0.04000	
12	OPERATIONAL REQ	0.7	AUTO CONT+SIMP LAB	0.180	YES	0.12600	
TOTAL							0.61600

(7) CR6 RED-FES04

#	FACTOR NAME	VALUE	SELECTION DESCRIPTION	WEIGHT	Y/N	#	VALUE
1	DEVELOPMENT STATUS	1.0	COMMERCIALIZED	0.040	YES	0.04000	
2	POLLUTANT REMOVAL	0.5	EQUAL TO CTP	0.100	YES	0.05000	
3	CAPITAL COST	0.5	EQUAL TO CTP	0.040	YES	0.02000	
4	OPERATING COST	1.0	POTEN < CTP	0.040	YES	0.04000	
5	RAW MATERIAL REC.	0.0	NO REC	0.040	YES	0.00000	
6	TDS IMPACT	0.5	INCREASES TDS	0.040	YES	0.02000	
7	SOLIDS GENERATION	0.0	POTEN > CTP	0.180	YES	0.00000	
8	SLUDGE DEWATERING	0.5	EQUAL TO HYDROX	0.100	YES	0.05000	
9	SLUDGE REACTIVITY	1.0	NOT REACTIVE	0.100	YES	0.10000	
10	RECOVERY POTENTIAL	0.4	SIGNIF TREATMENT	0.100	YES	0.04000	
11	METAL LEACHABILITY	0.7	EQUAL TO HYDROX	0.040	YES	0.02800	
12	OPERATIONAL REQ	0.7	AUTO CONT+SIMP LAB	0.180	YES	0.12600	
TOTAL							0.51400

(8) FORMALIN

#	FACTOR NAME	VALUE	SELECTION DESCRIPTION	WEIGHT	Y/N	#	VALUE
1	DEVELOPMENT STATUS	1.0	COMMERCIALIZED	0.040	YES	0.04000	
2	POLLUTANT REMOVAL	0.5	EQUAL TO CTP	0.100	YES	0.05000	
3	CAPITAL COST	1.0	POTEN. < CTP	0.040	YES	0.04000	
4	OPERATING COST	0.5	EQUAL TO CTP	0.040	YES	0.02000	
5	RAW MATERIAL REC.	0.0	NO REC	0.040	YES	0.00000	
6	TDS IMPACT	1.0	REDUCES TDS	0.040	YES	0.04000	
7	SOLIDS GENERATION	0.5	EQUAL TO CTP	0.180	YES	0.09000	
8	SLUDGE DEWATERING	0.5	UNKNOWN OR COND	0.100	YES	0.05000	
9	SLUDGE REACTIVITY	1.0	NOT REACTIVE	0.100	YES	0.10000	
10	RECOVERY POTENTIAL	0.4	SIGNIF TREATMENT	0.100	YES	0.04000	
11	METAL LEACHABILITY	0.7	EQUAL TO HYDROX	0.040	YES	0.02800	
12	OPERATIONAL REQ	0.7	AUTO CONT+SIMP LAB	0.180	YES	0.12600	
TOTAL							0.62400

# CYANIDE OXIDATION PROCESSES

4	CN OXID-ELECTROLYTIC	.848
5	CN OXID-ELECT+NACL	.84
3	CN OXID-OZONE	.684
1	CN OXID-CL2	.584
2	CN OXID-NAOCL	.584

(1) CN OXID-CL2		VALUE	SELECTION	DESCRIPTION	WEIGHT	Y/N	#	VALUE
#	FACTOR NAME							
1	DEVELOPMENT STATUS	1.0		COMMERCIALIZED	0.040	YES	0.04000	
2	POLLUTANT REMOVAL	0.5		EQUAL TO CTP	0.100	YES	0.05000	
3	CAPITAL COST	0.5		EQUAL TO CTP	0.040	YES	0.02000	
4	OPERATING COST	0.5		EQUAL TO CTP	0.040	YES	0.02000	
5	RAW MATERIAL REC	0.0		NO REC	0.040	YES	0.00000	
6	TDS IMPACT	0.5		INCREASES TDS	0.040	YES	0.02000	
7	SOLIDS GENERATION	0.5		EQUAL TO CTP	0.180	YES	0.09000	
8	SLUDGE DEWATERING	0.5		EQUAL TO HYDROX	0.100	YES	0.05000	
9	SLUDGE REACTIVITY	1.0		NOT REACTIVE	0.100	YES	0.10000	
10	RECOVERY POTENTL	0.4		SIGNIF TREATMENT	0.100	YES	0.04000	
11	METAL LEACHABILTY	0.7		EQUAL TO HYDROX	0.040	YES	0.02800	
12	OPERATINAL REQ	0.7		AUTO CONT+SIMP LAB	0.180	YES	0.12600	
TOTAL								0.58400

(2) CN OXID-NAOCL		VALUE	SELECTION	DESCRIPTION	WEIGHT	Y/N	#	VALUE
#	FACTOR NAME							
1	DEVELOPMENT STATUS	1.0		COMMERCIALIZED	0.040	YES	0.04000	
2	POLLUTANT REMOVAL	0.5		EQUAL TO CTP	0.100	YES	0.05000	
3	CAPITAL COST	1.0		POTEN. < CTP	0.040	YES	0.04000	
4	OPERATING COST	0.0		POTEN. > CTP	0.040	YES	0.00000	
5	RAW MATERIAL REC	0.0		NO REC	0.040	YES	0.00000	
6	TDS IMPACT	0.5		INCREASES TDS	0.040	YES	0.02000	
7	SOLIDS GENERATION	0.5		EQUAL TO CTP	0.180	YES	0.09000	
8	SLUDGE DEWATERING	0.5		EQUAL TO HYDROX	0.100	YES	0.05000	
9	SLUDGE REACTIVITY	1.0		NOT REACTIVE	0.100	YES	0.10000	
10	RECOVERY POTENTL	0.4		SIGNIF TREATMENT	0.100	YES	0.04000	
11	METAL LEACHABILTY	0.7		EQUAL TO HYDROX	0.040	YES	0.02800	
12	OPERATINAL REQ	0.7		AUTO CONT+SIMP LAB	0.180	YES	0.12600	
TOTAL								0.58400

(3) CN OXID-OZONE		VALUE	SELECTION	DESCRIPTION	WEIGHT	Y/N	#	VALUE
#	FACTOR NAME							
1	DEVELOPMENT STATUS	1.0		COMMERCIALIZED	0.040	YES	0.04000	
2	POLLUTANT REMOVAL	0.5		EQUAL TO CTP	0.100	YES	0.05000	
3	CAPITAL COST	0.0		POTEN. > CTP	0.040	YES	0.00000	
4	OPERATING COST	1.0		POTEN. < CTP	0.040	YES	0.04000	
5	RAW MATERIAL REC	0.0		NO REC	0.040	YES	0.00000	
6	TDS IMPACT	0.7		NO AFFECT ON TDS	0.040	YES	0.02800	
7	SOLIDS GENERATION	0.5		EQUAL TO CTP	0.180	YES	0.09000	
8	SLUDGE DEWATERING	1.0		BETTER THAN HYDROX	0.100	YES	0.10000	
9	SLUDGE REACTIVITY	1.0		NOT REACTIVE	0.100	YES	0.10000	
10	RECOVERY POTENTL	0.7		MINIMAL TREATMENT	0.100	YES	0.07000	
11	METAL LEACHABILTY	1.0		LESS THAN HYDROX	0.040	YES	0.04000	
12	OPERATINAL REQ	0.7		AUTO CONT+SIMP LAB	0.180	YES	0.12600	
TOTAL								0.68400

## (4) CN OXID-ELECTROLYTIC

#	FACTOR NAME	VALUE	SELECTION DESCRIPTION	WEIGHT	Y/N	#	VALUE
1	DEVELOPMENT STATUS	1.0	COMMERCIALIZED	0.040	YES	0	0.04000
2	POLLUTANT REMOVAL	0.5	UNDEFINED OR COND.	0.100	YES	0	0.05000
3	CAPITAL COST	0.0	POTEN > CTP	0.040	YES	0	0.00000
4	OPERATING COST	1.0	POTEN < CTP	0.040	YES	0	0.04000
5	RAW MATERIAL REC	0.5	RECOVER H2OOR RAW MAT	0.040	YES	0	0.02000
6	TDS IMPACT	0.7	NO AFFECT ON TDS	0.040	YES	0	0.02800
7	SOLIDS GENERATION	1.0	POTEN<CTP	0.180	YES	0	0.18000
8	SLUDGE DEWATERING	1.0	BETTER THAN HYDROX	0.100	YES	0	0.10000
9	SLUDGE REACTIVITY	1.0	NOT REACTIVE	0.100	YES	0	0.10000
10	RECOVERY POTENTL	0.7	MINIMAL TREATMENT	0.100	YES	0	0.07000
11	METAL LEACHABILTY	1.0	LESS THAN HYDROX	0.040	YES	0	0.04000
12	OPERATINAL REQ	1.0	TOTAL AUTOMATION	0.180	YES	0	0.18000
TOTAL							0.84800

## (5) CN OXID-ELECT+NACL

#	FACTOR NAME	VALUE	SELECTION DESCRIPTION	WEIGHT	Y/N	#	VALUE
1	DEVELOPMENT STATUS	1.0	COMMERCIALIZED	0.040	YES	0	0.04000
2	POLLUTANT REMOVAL	0.5	EQUAL TO CTP	0.100	YES	0	0.05000
3	CAPITAL COST	0.0	POTEN > CTP	0.040	YES	0	0.00000
4	OPERATING COST	1.0	POTEN < CTP	0.040	YES	0	0.04000
5	RAW MATERIAL REC.	0.5	RECOVER H2OOR RAW MAT	0.040	YES	0	0.02000
6	TDS IMPACT	0.5	INCREASES TDS	0.040	YES	0	0.02000
7	SOLIDS GENERATION	1.0	POTEN<CTP	0.180	YES	0	0.18000
8	SLUDGE DEWATERING	1.0	BETTER THAN HYDROX	0.100	YES	0	0.10000
9	SLUDGE REACTIVITY	1.0	NOT REACTIVE	0.100	YES	0	0.10000
10	RECOVERY POTENTL	0.7	MINIMAL TREATMENT	0.100	YES	0	0.07000
11	METAL LEACHABILTY	1.0	LESS THAN HYDROX	0.040	YES	0	0.04000
12	OPERATINAL REQ	1.0	TOTAL AUTOMATION	0.180	YES	0	0.18000
TOTAL							0.84000

# METAL REMOVAL PROCESSES

3	SODIUM BOROHYDRIDE PRECIP	.692
4	OXIDE PRECIP BY OZONE (H2O2)	.629
2	NAOH PRECIP	.526
6	ION EXCH + BATCH TMT	.506
1	LIME PRECIP	.411
5	WATER SOFTENING	.391

(1) LIME PRECIP						
#	FACTOR NAME	VALUE	SELECTION DESCRIPTION	WEIGHT	Y/N	* VALUE
1	POLLUTANT REMOVAL	0.7	EQUAL TO CTP	0.060	YES	0.04200
2	SOLIDS GENERATION	0.5	EQUAL TO CTP	0.140	YES	0.07000
3	SLUDGE VOLUME	0.5	EQUAL TO CTP	0.090	YES	0.04500
4	SETTLING/SEPARAT CHA	1.0	GOOD BY CLAR	0.040	YES	0.04000
5	PERCEIVED DEWATERABI	0.7	MODERATE	0.040	YES	0.02800
6	SLUDGE LEACHABILITY	0.5	EQUAL TO HYDROX	0.100	YES	0.05000
7	TEND USE XCESS REAGE	0.0	LIKELY	0.060	YES	0.00000
8	PROCESS CONTROL	0.5	EQUAL TO CTP	0.040	YES	0.02000
9	REACTION TIME	0.0	SLOW	0.050	YES	0.00000
10	SLUDGE REC POTENTIAL	0.5	SIG TREAT	0.080	YES	0.04000
11	RAW MATL RECOVERY	0.0	NO RECOVERY	0.080	YES	0.00000
12	SIMULT CR+6 RED	0.0	NO	0.050	YES	0.00000
13	SIMULT CN OXIDATION	0.0	NO	0.050	YES	0.00000
14	CAPITAL COST EST	0.5	EQUAL TO CTP	0.020	YES	0.01000
15	OPERATING COST EST	0.5	EQUAL TO CTP	0.020	YES	0.01000
16	OPERATIONAL REQ	0.7	AUTO CONTROL + SIMP LABOR	0.080	YES	0.05600
TOTAL						0.41100

(2) NAOH PRECIP						
#	FACTOR NAME	VALUE	SELECTION DESCRIPTION	WEIGHT	Y/N	* VALUE
1	POLLUTANT REMOVAL	0.7	EQUAL TO CTP	0.060	YES	0.04200
2	SOLIDS GENERATION	1.0	LESS THAN CTP	0.140	YES	0.14000
3	SLUDGE VOLUME	0.0	GREATER THAN CTP	0.090	YES	0.00000
4	SETTLING/SEPARAT CHA	0.7	GOOD BY FILT	0.040	YES	0.02800
5	PERCEIVED DEWATERABI	0.0	POOR	0.040	YES	0.00000
6	SLUDGE LEACHABILITY	0.5	EQUAL TO HYDROX	0.100	YES	0.05000
7	TEND USE XCESS REAGE	1.0	UNLIKELY	0.060	YES	0.06000
8	PROCESS CONTROL	1.0	BETTER THAN CTP	0.040	YES	0.04000
9	REACTION TIME	1.0	RAPID	0.050	YES	0.05000
10	SLUDGE REC POTENTIAL	0.5	SIG TREAT	0.080	YES	0.04000
11	RAW MATL RECOVERY	0.0	NO RECOVERY	0.080	YES	0.00000
12	SIMULT CR+6 RED	0.0	NO	0.050	YES	0.00000
13	SIMULT CN OXIDATION	0.0	NO	0.050	YES	0.00000
14	CAPITAL COST EST	0.5	EQUAL TO CTP	0.020	YES	0.01000
15	OPERATING COST EST	0.5	EQUAL TO CTP	0.020	YES	0.01000
16	OPERATIONAL REQ	0.7	AUTO CONTROL + SIMP LABOR	0.080	YES	0.05600
TOTAL						0.52600

## (3) SODIUM BOROHYDRIDE PRECIP

#	FACTOR NAME	VALUE	SELECTION DESCRIPTION	WEIGHT	Y/N	#	VALUE
1	POLLUTANT REMOVAL	0.7	EQUAL TO CTP	0.060	YES	0.04200	
2	SOLIDS GENERATION	1.0	LESS THAN CTP	0.140	YES	0.14000	
3	SLUDGE VOLUME	0.5	EQUAL TO CTP	0.090	YES	0.04500	
4	SETTLING/SEPARAT CHA	0.7	GOOD BY FILT	0.040	YES	0.02800	
5	PERCEIVED DEWATERABI	1.0	GOOD	0.040	YES	0.04000	
6	SLUDGE LEACHABILITY	1.0	LESS THAN HYDROX	0.100	YES	0.10000	
7	TEND USE XCESS REAGE	1.0	UNLIKELY	0.060	YES	0.06000	
8	PROCESS CONTROL	1.0	BETTER THAN CTP	0.040	YES	0.04000	
9	REACTION TIME	0.5	MODERATE	0.050	YES	0.02500	
10	SLUDGE REC POTENTIAL	0.7	MIN TREAT	0.080	YES	0.05600	
11	RAW MATL RECOVERY	0.0	NO RECOVERY	0.080	YES	0.00000	
12	SIMULT CR+6 RED	1.0	YES	0.050	YES	0.05000	
13	SIMULT CN OXIDATION	0.0	NO	0.050	YES	0.00000	
14	CAPITAL COST EST	0.5	EQUAL TO CTP	0.020	YES	0.01000	
15	OPERATING COST EST	0.0	GREATER THAN CTP	0.020	YES	0.00000	
16	OPERATIONAL REQ	0.7	AUTO CONTROL + SIMP LABOR	0.080	YES	0.05600	

TOTAL

0.49200

## (4) OXIDE PRECIP BY OZONE (H2O2)

#	FACTOR NAME	VALUE	SELECTION DESCRIPTION	WEIGHT	Y/N	#	VALUE
1	POLLUTANT REMOVAL	0.7	EQUAL TO CTP	0.060	YES	0.04200	
2	SOLIDS GENERATION	1.0	LESS THAN CTP	0.140	YES	0.14000	
3	SLUDGE VOLUME	0.5	EQUAL TO CTP	0.090	YES	0.04500	
4	SETTLING/SEPARAT CHA	0.7	GOOD BY FILT	0.040	YES	0.02800	
5	PERCEIVED DEWATERABI	0.7	MODERATE	0.040	YES	0.02800	
6	SLUDGE LEACHABILITY	0.5	EQUAL TO HYDROX	0.100	YES	0.05000	
7	TEND USE XCESS REAGE	0.5	POSSIBLE	0.040	YES	0.03000	
8	PROCESS CONTROL	1.0	BETTER THAN CTP	0.040	YES	0.04000	
9	REACTION TIME	1.0	RAPID	0.050	YES	0.05000	
10	SLUDGE REC POTENTIAL	0.5	SIG TREAT	0.080	YES	0.04000	
11	RAW MATL RECOVERY	0.0	NO RECOVERY	0.080	YES	0.00000	
12	SIMULT CR+6 RED	0.0	NO	0.050	YES	0.00000	
13	SIMULT CN OXIDATION	1.0	YES	0.050	YES	0.05000	
14	CAPITAL COST EST	0.5	EQUAL TO CTP	0.020	YES	0.01000	
15	OPERATING COST EST	1.0	LESS THAN CTP	0.020	YES	0.02000	
16	OPERATIONAL REQ	0.7	AUTO CONTROL + SIMP LABOR	0.080	YES	0.05600	

TOTAL

0.42900



(5) WATER SOFTENING

#	FACTOR NAME	VALUE	SELECTION DESCRIPTION	WEIGHT	Y/N	* VALUE
1	POLLUTANT REMOVAL	0.7	EQUAL TO CTP	0.040	YES	0.04200
2	SOLIDS GENERATION	0.5	EQUAL TO CTP	0.140	YES	0.07000
3	SLUDGE VOLUME	0.5	EQUAL TO CTP	0.090	YES	0.04500
4	SETTLING/SEPARAT CHA	1.0	GOOD BY CLAR	0.040	YES	0.04000
5	PERCEIVED DEWATERABI	0.7	MODERATE	0.040	YES	0.02800
6	SLUDGE LEACHABILITY	0.5	EQUAL TO HYDROX	0.100	YES	0.05000
7	TEND USE XCESS REAGE	0.0	LIKELY	0.060	YES	0.00000
8	PROCESS CONTROL	0.5	EQUAL TO CTP	0.040	YES	0.02000
9	REACTION TIME	0.0	SLOW	0.050	YES	0.00000
10	SLUDGE REC POTENTIAL	0.5	SIG TREAT	0.080	YES	0.04000
11	RAW MATL RECOVERY	0.0	NO RECOVERY	0.080	YES	0.00000
12	SIMULT CR+6 RED	0.0	NO	0.050	YES	0.00000
13	SIMULT CN OXIDATION	0.0	NO	0.050	YES	0.00000
14	CAPITAL COST EST	0.0	GREATER THAN CTP	0.020	YES	0.00000
15	OPERATING COST EST	0.0	GREATER THAN CTP	0.020	YES	0.00000
16	OPERATIONAL REQ	0.7	AUTO CONTROL + SIMP LABOR	0.080	YES	0.05600

TOTAL

0.39100

(6) ION EXCH + BATCH TMT

#	FACTOR NAME	VALUE	SELECTION DESCRIPTION	WEIGHT	Y/N	* VALUE
1	POLLUTANT REMOVAL	0.7	EQUAL TO CTP	0.040	YES	0.04200
2	SOLIDS GENERATION	1.0	LESS THAN CTP	0.140	YES	0.14000
3	SLUDGE VOLUME	1.0	LESS THAN CTP	0.090	YES	0.09000
4	SETTLING/SEPARAT CHA	1.0	GOOD BY CLAR	0.040	YES	0.04000
5	PERCEIVED DEWATERABI	0.7	MODERATE	0.040	YES	0.02800
6	SLUDGE LEACHABILITY	0.5	EQUAL TO HYDROX	0.100	YES	0.05000
7	TEND USE XCESS REAGE	0.0	LIKELY	0.060	YES	0.00000
8	PROCESS CONTROL	0.5	EQUAL TO CTP	0.040	YES	0.02000
9	REACTION TIME	0.0	SLOW	0.050	YES	0.00000
10	SLUDGE REC POTENTIAL	0.5	SIG TREAT	0.080	YES	0.04000
11	RAW MATL RECOVERY	0.0	NO RECOVERY	0.080	YES	0.00000
12	SIMULT CR+6 RED	0.0	NO	0.050	YES	0.00000
13	SIMULT CN OXIDATION	0.0	NO	0.050	YES	0.00000
14	CAPITAL COST EST	0.0	GREATER THAN CTP	0.020	YES	0.00000
15	OPERATING COST EST	0.0	GREATER THAN CTP	0.020	YES	0.00000
16	OPERATIONAL REQ	0.7	AUTO CONTROL + SIMP LABOR	0.080	YES	0.05600

TOTAL

0.50600

