

**WORKPLAN FOR TREATABILITY
STUDY OF SOILS**

**SOIL WASHING/METALS RECOVERY AND
CHROMIUM REDUCTION/IMMOBILIZATION**

**ALARK HARD CHROME
2777 MAIN STREET
RIVERSIDE, CALIFORNIA**

Submitted and Prepared by:

URS Consultants, Inc.
4675 MacArthur Court, Suite 850
Newport Beach, CA 92660

Prepared for:

**State of California Department of Toxic
Substances Control
Region 4 Site Mitigation Branch**

Task Order Number 4-088-6.0-400003

Contract Number 91-T0088

December 11, 1992

**WORKPLAN FOR TREATABILITY
STUDY OF SOILS**

**SOIL WASHING/METALS RECOVERY AND
CHROMIUM REDUCTION/IMMOBILIZATION**

**ALARK HARD CHROME
2777 MAIN STREET
RIVERSIDE, CALIFORNIA**

Submitted and Prepared by:

URS Consultants, Inc.
4675 MacArthur Court, Suite 850
Newport Beach, CA 92660

Prepared for:

**State of California Department of Toxic
Substances Control
Region 4 Site Mitigation Branch**

Task Order Number 4-088-6.0-400003

Contract Number 91-T0088

December 11, 1992

Table of Contents

1.0	Project Description.....	5
2.0	Remedial Technology Description.....	7
2.1	Soil Washing.....	7
2.2	Immobilization	8
3.0	Test Objectives	10
3.1	Soil Washing Objective	10
3.2	Immobilization Objectives	12
4.0	Experimental Design and Procedures	15
4.1	Soil Washing.....	15
4.2	Immobilization	18
5.0	Sampling, Analysis, and Quality Assurance/Quality Control.....	25
5.1	Sampling.....	25
5.1.1	Chain-of-Custody.....	30
5.1.2	Equipment Decontamination.....	32
5.2	Analyses.....	32
5.2.1	Material Balance.....	32
5.2.2	Leaching Tests.....	34
5.2.3	Engineering/Geotechnical Tests	36
5.2.4	Environmental Analysis.....	38
5.2.5	Analytical Laboratories.....	38
5.3	Quality Assurance/Quality Control	39
5.3.1	Field Quality Assurance Sampling.....	39
5.3.2	Laboratory Quality Assurance.....	39
5.3.3	Data Validation Overview	40
6.0	Data Management and Interpretation.....	42
7.0	Health and Safety	44
8.0	Residuals Management.....	45

9.0 Reporting46

10.0 Schedule48

11.0 Management and Staffing51

12.0 Budget52

13.0 References57

List of Figures

Figure 1: Soil Washing Schematic.....16

Figure 2A: Soil Immobilization Schematic, Ferrous Sulfate Reduction21

Figure 2B: Soil Immobilization Schematic, Sodium Bisulfite Reduction22

Figure 2C: Soil Immobilization Schematic, Sodium Hydrosulfite Reduction.....23

Figure 3: Facility Map.....27

Figure 4: Treatability Study Schedule49

List of Tables

Table 1: Testing Matrix28

Table 2: Estimated Number of Laboratory Samples.....29

Table 3: List of Holding Times, Preservatives, and Special Handling Procedures.....33

Table 4: Proposed Organization of the Treatability Study Report.....47

Table 5: Estimated Treatability Study Costs53

Table 6: Detailed Cost Summary Sheet.....54

1.0 Project Description

The Alark Hard Chrome (Alark) site at 2777 Main Street, Riverside, California was the location of an electroplating business from 1971 to 1985. Operations included cadmium, chromium, and nickel electroplating baths.

URS Consultants, Inc. (URS) was retained by the Department of Toxic Substances Control (DTSC) of the California Environmental Protection Agency, to evaluate treatment alternatives for heavy metals contamination identified at the Alark site.

This treatability study addresses only the treatment of the soil. It addresses three treatment technologies: soil washing for volume reduction; soil washing for removal of contaminants; and, soil stabilization/fixation.

Soil sampling, conducted under the auspices of the California Department of Toxic Substances Control (DTSC), found elevated concentrations of four heavy metals: chromium, cadmium, lead and nickel. The soil contaminants of concern are chromium (total and trivalent) and cadmium, because both metals exist at concentrations exceeding the 10^{-6} risk level. In addition, both total chromium and hexavalent chromium concentrations in soil samples exceeded the California Total Threshold Limit Concentration (TTL) of 2500 and 500 parts per million (ppm), respectively. Total chromium concentrations were found in soil as high as 7000 ppm. The concentration of cadmium found on site has been found to be as high as the TTL of 100 ppm.

The site requires remediation to protect potential human receptors from exposure to soil-bound contaminants, to prevent contamination of the groundwater, and to prevent run-off of contaminants into surface waters. The Remedial Investigation/Feasibility Study Report, prepared by DTSC, estimates that 2,666 cubic yards of soil will require remediation to reduce the volume, toxicity, or mobility of the chemicals of concern. That volume is sensitive to the final cleanup standards adopted.

The Comprehensive Environmental Response Compensation and Liability Act (CERCLA) Section 121 (b) requests the selection of remedial options that "utilize permanent solutions and alternative treatment technologies or resources recovery technologies to the maximum extent practicable." These technologies must provide treatment they "permanently and significantly reduces the volume,

toxicity, or mobility of hazardous substances, pollutants, and contaminants." The soil treatment technologies that may meet the CERCLA mandate for Alark are soil washing for volume reduction, soil washing/metals recovery, and chromium reduction/immobilization.

A bench-scale treatability study is proposed to explore the effectiveness of these remedial options. Bench-scale testing consists of a series of tests designed for quantitative evaluation of the performance of each treatment method. Additionally, the treatability study should provide cost and design information. The operational and performance information resulting from bench-scale testing permits more accurate cost and schedule estimates to be made for full-scale remedial processes. Bench-scale tests may also provide some information needed to size some unit operations and to estimate treatment train considerations such as waste mixing and materials handling. The size and scope of bench-scale testing is limited to studies performed on the bench-top with equipment designed to simulate the basic operation of a treatment process.

2.0 Remedial Technology Description

2.1 Soil Washing

Soil washing consists of processing the soil after excavation in the presence of a liquid. Two possible objectives are possible which distinguish forms of this treatment. The first is a washing and size grading process, whereby the soil is separated into a coarser and a finer fraction (intermediate grades are possible). The practical effect is that often the greatest majority of the contamination is concentrated in the fine fraction. The coarse fraction, if sufficiently clean can be released as requiring no further treatment. This is called soil washing for volume reduction. The other objective is to process the soil so as to physically and chemically strip (extract) the contaminants from the soil so that the soil. In both the volume reduction and extraction approaches, a residue is produced which contains the contaminants.

Volume Reduction. This process uses machinery and procedures typically found in the aggregate industry that produce materials of various size grades. In this proposed study, soil samples will be wet-sieved to determine the size gradation of the soils and chemical analyses of the size fractions will be made to determine if contamination preferentially resides within a discrete fraction.

Extraction. Soil washing removes soil-bound contaminants using liquid extraction agents. During treatment, the extraction agents are placed in contact with the excavated soil matrix to mobilize contaminants that are chemically or physically attached to the soil particles. The purpose of soil washing is to increase the mobility of contaminants in the soil phase so that they may be collected in the liquid phase. Common extraction solutions are basic (caustic) or acidic (mineral or organic), or employ organic (methanol, KPEG), surfactant, and chelation.

Soil washing studies have explored the affect of several extractants. An alkaline extractant was used for industrial sludges contaminated with organic wastes (1); furthermore, a mobile treatment system using this technology has been evaluated (2). Mineral and organic acids have mobilized soil-bound heavy metal contaminants from soil (3,4,5). Methanol, an organic extractant, removed polychlorinated biphenyls (PCBs) from Superfund soil (6), and another organic extractant, potassium polyethylene glycolate, (KPEG) reduced polychlorinated dibenzo-p-dioxins

(PCDDs) and polychlorinated dibenzofurans (PCDFs) below 1 microgram/kilogram action level (7). In a pilot study, surfactants enhanced gasoline removal from sand, achieving a 76 % recovery rate (8). A chelating agent, ethylenediaminetetraacetic acid (EDTA), reduced lead contamination from two Superfund site soils by 85-97% during bench-scale studies (9, 10, 11, 12, 13). Full-scale washing reduced phenol and cresols 99.9% in site soil (14).

In this proposed treatability study, two sequential extractants are proposed, hydrogen peroxide the hydrogen peroxide treatment and EDTA. H_2O_2 is proposed to oxidize Cr^{+3} to Cr^{+6} , the more mobile chromium species, to mobilize and wash out the chromium. EDTA is used to bind on to the remaining metal salts, cadmium, lead, and nickel, to mobilize and remove these metals from the soil phase. Since EDTA does not have a high stability coefficient (strong binding) with chromium, a H_2O_2 pretreatment for chromium is necessary.

2.2 Immobilization

The U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response (OSWER) publication 9380.3-07FS, defines immobilization as "any of the technologies which limit the solubility or mobility of contaminants." Therefore, immobilization technologies are those methods which limit the migration of contaminants with or without major modification to the physical state, characteristics, or appearance of the waste matrix. The purpose of immobilization is to decrease the mobility of contaminants in the soil phase, the exact opposite of soil washing. To achieve this result, immobilization techniques involve the addition of chemical reagents, and/or other substances to the waste matrix to maintain the contaminants in an acceptably low form of mobility.

Immobilization involves the use of one or both of two general techniques to treat soil, stabilization/fixation and solidification. Stabilization/fixation techniques alter the contaminants chemically to limit their solubility, mobility, or chemical reactivity. Reagents or materials are added to the waste matrix to maintain the chemicals of concern in their least mobile or toxic form. Examples of this technique are the conversion of metals into their lower mobility hydroxide or sulfide species, or the change of the metal's valence or oxidation state to one of lower solubility.

Solidification is the result of treatment that produces a solid mass of waste material that has high structural integrity. The resulting product is often called a monolith. A mechanical

enclosure of contaminants by reagents, called microencapsulation, generally takes place during solidification. A chemical interaction between reagents and contaminants may also occur. The contaminant loss from the solidified matrix is limited by the encapsulating mechanism, which locks and isolates the waste from the environment, and by the reduction of surface area, which lowers the amount of waste exposed to environmental affects.

DTSC has provided information on immobilization as a viable remedial option for soils contaminated by heavy metals (15,16,17 and 18).

In this treatability study, a chemical reduction step, prior to or concurrent with immobilization, is proposed to reduce Cr^{+6} to Cr^{+3} , the least mobile species, to immobilize and retain the chromium. The purpose of the chemical reduction step in the immobilization study is the opposite of the purpose of the chemical oxidation step in soil washing.

3.0 Test Objectives

The purpose of this treatability study is to provide information on the selected remedial technologies to help meet the Alark project objectives for site remediation. Some of those project remediation objectives may be:

- ❑ To achieve the DTSC site goals for the reduction of chromium and cadmium concentrations;
- ❑ To minimize or eliminate the public health and environmental threats via the exposure pathways identified at the Alark site;
- ❑ To implement the remedial option safely and efficiently;
- ❑ To execute the remedial action at a reasonable cost; and,
- ❑ To produce a product, remediated soil, that can be delisted.

The overall objective of this treatability study is to evaluate the technical feasibility of two treatment technologies, soil washing and immobilization, in meeting the clean up goals set for the site in the Remedial Investigation (RI). The objectives of the bench-scale test are to ascertain the favorable, if not optimum, operating parameters and to obtain preliminary remedial design and cost information.

3.1 Soil Washing Objectives

The soil washing objectives are to mobilize the chemicals of concern from the soil matrix into the aqueous rinsate, where removal, recycling, or disposal of the chemicals of concern can more readily take place. The intention of mobilizing the chemicals of concern in Alark soil is to lower the concentration of chemicals and, thereby, meet the treatment goals. Treatment goals are discussed in the Feasibility Study.

The following technical goals are proposed to evaluate the soil washing technology:

- ❑ To meet the risk-based clean up levels contained in the RI for all the chemicals of concern;

- ❑ To reduce the chemicals of concern below the TTLC and Soluble Threshold Limit Concentration (STLC) regulatory levels;
- ❑ To reduce leachable and total concentrations of chemicals of concern that are currently below TTLC and STLC by 90% (i.e., Cd, Ni, Pb);
- ❑ To reduce the chemicals of concern below the U.S. Environmental Protection Agency (U.S. EPA) Toxicity Characteristic Leaching Procedure (TCLP) regulatory levels; and,
- ❑ To provide the chemicals of concern in a form that can be recycled.

It is recognized that the residue from volume reduction would not meet these objectives. However, subsequent treatment or disposal would be made more practical due to the reduced volume of the soil to be treated.

The ultimate clean up goals set for the site would include consideration of risk-based cleanup levels contained in the RI, and the regulatory TTLC, STLC, and TCLP levels. These values, along with the maximum total concentrations of the chemicals of concern prior to treatment, are listed below.

Chemical of Concern	Max Total (mg/kg)	Risk-based level (mg/kg)	Exposure Route	TTLC (mg/kg)	STLC (mg/l)	TCLP (mg/l)
Chromium VI	1400	1.7 0.08	Ingestion Inhalation	500	5	---
Chromium, total	7000	7000 23	Ingestion Inhalation	2500	5	5
Cadmium	100	350 2.27	Ingestion Inhalation	100	1	1
Lead	800	1300 300 NC	Ingestion-adult Ingestion-child Inhalation	1000	5	5
Nickel	120	14000 44	Ingestion Inhalation	2000	20	---

The following technology-related objectives are proposed to determine the most favorable operating parameters for soil washing and the site-specific feasibility of the remedial option:

- To explore the necessity of the H₂O₂ pre-wash prior to the extraction solution;
- To determine the duration required to leach the soil to reduce the chemicals of concern to their respective clean-up levels;
- To evaluate the acceptability of the extraction solutions; and,
- To determine the suitability of the Alark soil for soil washing.

3.2 Immobilization Objectives

Immobilization is done to chemically stabilize/fix the chemicals of concern so as to severely limit their solubility and mobility, and to solidify the soil matrix to reduce the leaching potential of the chemicals of concern into groundwater.

The following goals are proposed to evaluate the immobilization technology:

- To meet the DTSC risk-based clean up level contained in the RI for hexavalent chromium;
- To reduce all the chemicals of concern below the STLC regulatory levels by reducing their mobility;
- To reduce all the chemicals of concern below the U.S. EPA TCLP regulatory levels for the F006 standard and D-code standard;
- To achieve a minimum unconfined compressive strength of 50 psi in the immobilized matrix to ensure long term in-situ stability; and,
- To produce an immobilized matrix with acceptable long-term characteristics as measured by the multiple leach procedure tests.

The clean up goals set for the immobilization treatment of the site could consider a risk-based clean up level for hexavalent chromium, and the California regulatory STLC levels and U.S. EPA regulatory TCLP levels for all the chemicals of concern. The U.S. EPA clean up levels are the

F006 standard and the D-code standard from the land disposal restrictions. These values are listed below. Total metals (TTL) are not being analyzed and evaluated for the immobilized soil because this technology will not reduce their presence.

Chemical of Concern	Risk Based Level (ppm)	STLC (ppm)	F006 TCLP (ppm)	D-Code TCLP (ppm)
Chromium VI	0.08	5		
Chromium, total	---	5	5.2	5.0
Cadmium	---	1	0.066	1.0
Lead	---	5	0.51	5.0
Nickel	---	20	0.32	20.0

The following technology-related objectives are proposed to determine the most favorable operating parameters for immobilization and the site-specific feasibility of the remedial option:

- To explore the performance of the three selected reducing agents in reducing Cr⁺⁶ to Cr⁺³;
- To determine the optimum ferrous sulfate to soil ratio from the selected tested ratios;
- To confirm if chromium reduction can be accomplished within the short reaction time needed for a continuous operation;
- To select the binder (immobilization reagents) that provides the lowest mobility for the chemicals of concern and meets the clean up goals for these chemicals;
- To determine the optimum binder-to-soil ratio from the selected tested ratios which provides the lowest mobility for the chemicals of concern and meets the clean up goals for these chemicals;

- To measure the amount of SO₂ emission, if any, from soil reduced by sodium bisulfite; and,
- To measure the volumetric increase of matrix after immobilization by the various reducing agent-binder combination.

4.0 *Experimental Design and Procedures*

4.1 Soil Washing

The discussion that follows pertains to soil washing to extract the chemicals of concern. As part of the experimental design, wet-sieve grain-size analyses and chemical tests for the metals of interest in the various size fractions produced are included as a preliminary step to characterize the input soil conditions. These characterizations will develop the preliminary data necessary to evaluate the potential value of volume reduction.

The proposed experimental design for soil washing would continuously leach the soil with an extraction agent to mobilize the chemicals of concern from the soil phase to the aqueous phase. The experimental design for soil washing, shown in Figure 1, proposes to take Alark site soil and screen it to remove large particles, then wash the soil repeatedly until analytical tests indicate that the soil has met the study goals or until the end of the wash duration. Next, the experimental design proposes to treat the aqueous phase for removal of the chemicals of concern into a form that may be recycled. The rinsate from the wash will be treated to precipitate or concentrate the chemicals of concern into a form that can be recycled.

The following experimental procedures for soil washing address the soil screening, soil treatment, rinsate treatment, and analytical testing phases:

The soil screening phase will precede all other work in the soil washing treatability study. Untreated raw soil will be screened using one-quarter inch screen to remove oversized (>1/4") particles of soil which may interfere with bench-scale testing or analytical apparatus. Only the undersized (<1/4") particles will be used for this study. Oversized particles will not be used in this study; however, in a full-scale remedial process, the oversized fraction may be spray washed.

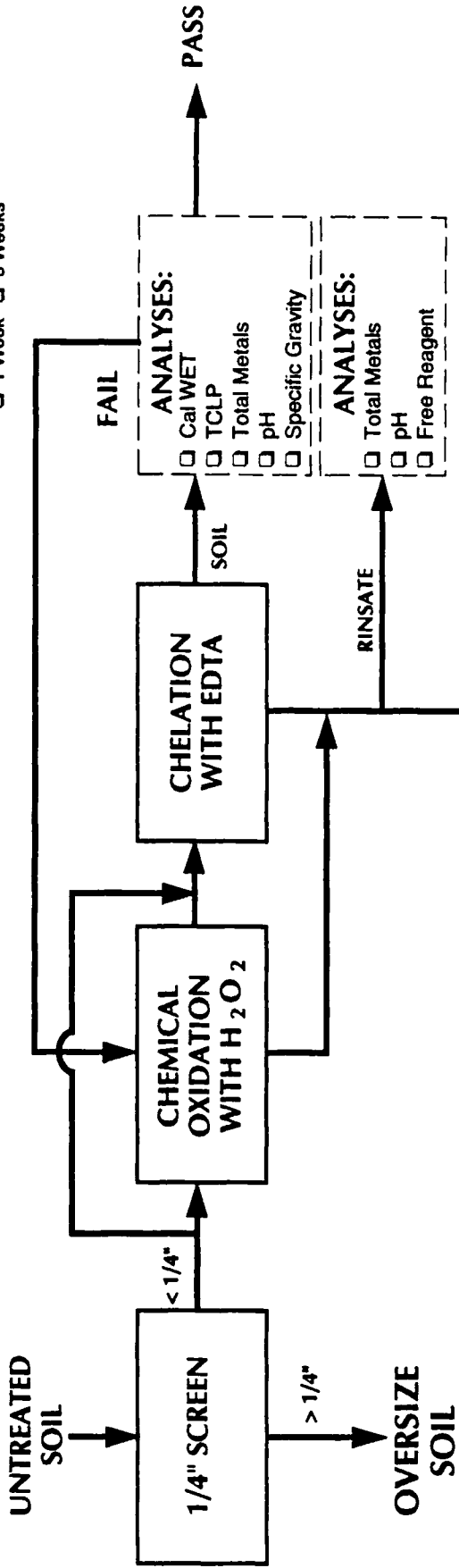
After screening, the soil will be treated sequentially with two aqueous phase extractants, to remove the Cr, Cd, Ni, and Pb salts from the soil. The first extractant will be a strong oxidizer, such as hydrogen peroxide, to convert Cr^{+3} to Cr^{+6} , the more soluble chromium valence state. After the chromium is oxidized and removed from the soil by the first extraction, the soil will be rinsed with

SCREENING

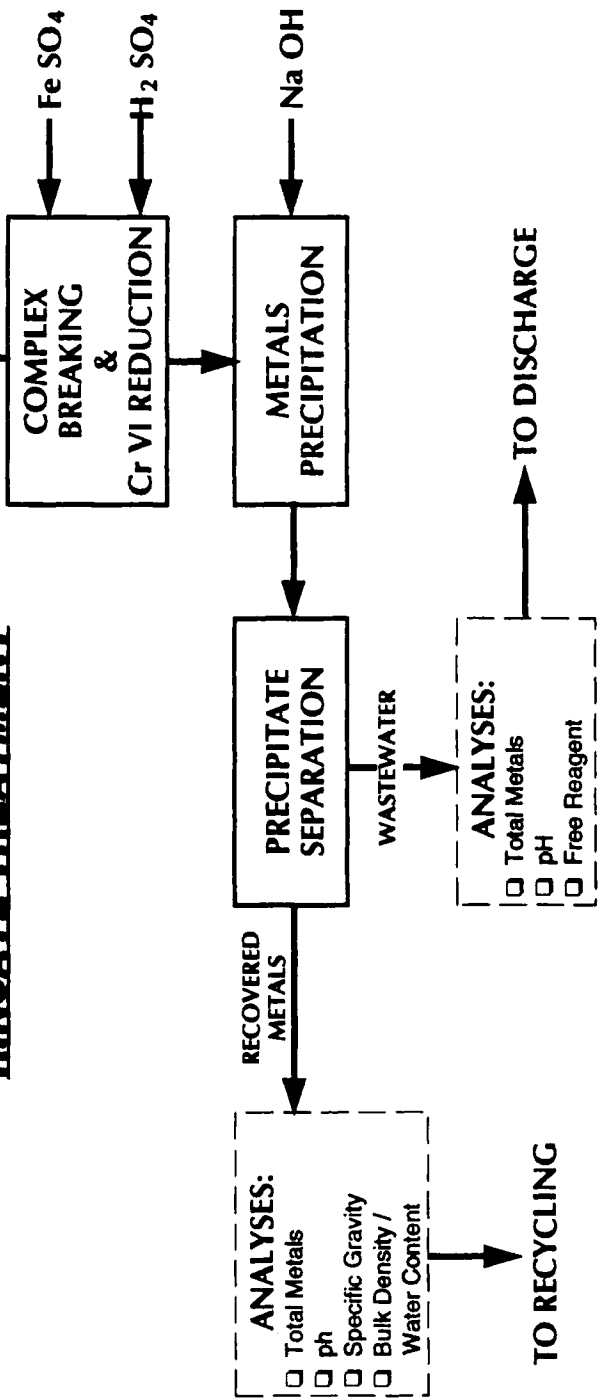
SOIL WASHING

ANALYTICAL TESTS

- 1 Day
- 2 Weeks
- 2 Days
- 4 Weeks
- 1 Week
- 8 Weeks



RINSATE TREATMENT



FIGURE

SOIL WASHING SCHEMATIC

demineralized water to remove the oxidizer. A second extraction will then commence.

The second proposed extractant is ethylenediamine-tetraacetic acid (EDTA). A 10% (w/w) solution is proposed to mobilize (chelate) the heavy metal species from the soil phase to the aqueous phase. EDTA, a ligand which bonds with the coordination points of metallic ions, is a safe, non-toxic compound that is used in food preparation. The chelating solution will continuously leach the soil for eight weeks. A total of six samples of treated soil will be taken during the eight week leach period, at one day, two day, one week, two week, four week, and eight week intervals respectively. These intervals are selected so as to provide the most information early in the leach process, yet still provide some information after extensive leaching.

Soil samples will be rinsed three times with deionized water to remove the extractant (EDTA solution). Prior to analyses, the rinsed samples will be filtered or centrifuged to remove the free liquid.

Soil samples will be analyzed for total metals of concern (Pb, Cd, Ni, Cr⁺³, and Cr⁺⁶) by the 6010 or 7000 series methods and analyzed for leachable metals of concern by California Waste Extraction Test (WET) and the TCLP.

At each of the six post treatment soil sampling events, a sample of each rinsate will be collected, filtered or centrifuged, and analyzed for total metals of concern and free reagent.

The procedure for treatment of the rinsate collected from the washed soil will include the following sequential steps: First, FeSO₄ will be added to the combined solution of the first extract (peroxide solution) and the second extract (EDTA solution) as a chelation-breaker/reducing agent to "free" the heavy metals for subsequent chemical treatment and to reduce Cr⁺⁶ to Cr⁺³. Next, NaOH will be added to increase the pH to 9.5 to lower the solubility of Cr⁺³ in the rinsate and to precipitate the metals of concern. A proprietary flocculating agent, such as Klear Aid A15L, will be added to the mixture to increase the speed of settling the heavy metal precipitate. The precipitate will be filtered from the rinsate prior to chemical analysis. The analysis of the precipitate will be sent to potential metal recycling facilities to determine the acceptability of the precipitate for recycling.

The treated rinsate (supernatant) will be filtered to remove suspended residual precipitate and then analyzed to confirm the removal of chemicals of concern.

To support the objective of the soil washing study, one tier of analytical tests will be performed after each sampling event during the test period. Since the soil washing goal is to remove total and leachable chemicals of concern from the soil, a simple sampling and analysis scheme is required. Both WET and TCLP leaching analyses will evaluate the leachable metals in the soil against STLC and TCLP criteria, respectively. A nitric acid digestion analysis will evaluate the total metals in the soil against the risk-based and TTLC criteria.

The rinsate will be tested for total metals of concern, pH, and free reagent. Total metals in the treated rinsate could be compared to drinking water standards and/or wastewater discharge criteria. The resulting recovered metals solid or sludge will be analyzed for total metals of concern, pH, specific gravity and bulk density/water content.

4.2 Immobilization

The immobilization study is a 3 x 4 x 2 experimental design. Three types of pretreatment reduction methods will be tested and for each will use four types of immobilization binders. Each binder will be tested at two, binder-to-soil ratios. The experimental designs for soil immobilization are shown in Figures 2A, 2B, and 2C - one schematic for each one of the three reducing agents.

The treatability study to immobilize the Alark soil consists of several distinct stages to insure the immobility of the chemicals of concern, and the durability of the immobilized matrix. These stages to evaluate include: soil screening, reduction, immobilization, curing, the first tier of analyses, and the second tier of analyses.

In the soil screening stage, soil will be screened with a one-quarter inch mesh to remove oversized soil particles. The purpose of the removal of the oversized particles is to provide some uniformity to the soil within the immobilized matrix. This increase in uniformity will increase the strength of the immobilized matrix and expose more soil surface area to the reducing reagents and immobilization binders. Therefore, more chemicals of concern will be exposed to the reducing reagents and binders. Additionally, any diffusion limiting mechanisms within a soil particle to soil pretreatment will be minimized

by the smaller particle size which should favorably affect the reaction kinetics. The oversized soil fraction will not be used in this treatability study; however, in a full-scale remediation process, the oversized particles may be crushed and re-screened.

The reduction step will prepare the hexavalent chromium within the soil for immobilization. Chemical reduction will convert the highly mobile Cr^{+6} species to the less mobile Cr^{+3} species. Since the objective of the immobilization step is to reduce the mobility of the chemicals of concern through chemical stabilization/fixation and physical/chemical solidification, the Cr^{+6} conversion to Cr^{+3} is an additional enhancement of chemical stabilization/fixation. Although numerous reducing agents can be used to make this chemical conversion of chromium, this study proposes to explore the efficiency of three reducing agents: ferrous sulfate, sodium bisulfite and sodium hydrosulfite.

Ferrous sulfate, FeSO_4 , is commonly used as a reducing agent for immobilizing chromium-laden wastes. Ferrous sulfate is safe, inexpensive (relative to other reducing agents), and co-precipitates other heavy metals. Its disadvantages are large volume increases and the requirement of low pH for acceptable, but relatively slower, reaction kinetics (processing time).

Sodium bisulfite, NaHSO_3 , and the bisulfite of commerce, sodium metabisulfite, $\text{Na}_2\text{S}_2\text{O}_5$, require less reagent but are more expensive compared to ferrous sulfate. The overall cost of the bisulfites may be more than ferrous sulfate. One disadvantage of the bisulfate is the potential evolution of SO_2 gas in the presence of a high solids matrix, like soil. Therefore, SO_2 released as a gas should be monitored during the bisulfite reduction stage of the treatability study.

Sodium hydrosulfite, $\text{Na}_2\text{S}_2\text{O}_4$, is an effective reducing agent at alkaline pH; therefore, it can be used together with alkaline immobilization binders in a mix of soil, reducing agent, and binder(s). This characteristic allows hydrosulfite reduction in the same step as immobilization so as to possibly eliminate a step in the immobilization process. Hydrosulfite can remain effective after the solidification of the matrix, thereby providing residual reduction for any Cr^{+6} which may leach from the soil particles in the future. The disadvantage of hydrosulfite is reagent cost since it is more expensive than bisulfite and more reagent may be required, although no acid and base reagents are added to the soil.

A three-step procedure is proposed for the use of ferrous sulfate as a reducing agent. First, the pH of the soil is

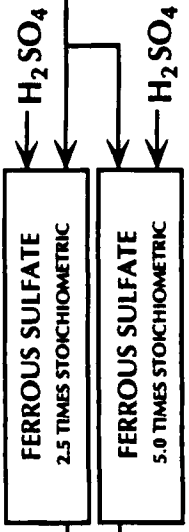
lowered to 2 to 3. Next, the ferrous sulfate is added to the soil at 2.5 times or 5.0 times the stoichiometric quantity of Cr^{+6} and mixed for 5 to 10 minutes until the reaction is complete. To insure a complete $\text{Cr}^{+6} \rightarrow \text{Cr}^{+3}$ reduction, an on-site colorometric test will be performed immediately following mixing to measure the presence of Cr^{+6} . Lastly, the soil pH will be raised to 7 or above to precipitate chromium as a hydroxide or as a co-precipitate with ferric and ferrous iron. In the final step, the ferrous iron (Fe^{+2}) is oxidized to ferric (Fe^{+3}), destroying any residual reagent.

A similar three-step procedure is proposed for the use of sodium bisulfite as a reducing agent. First, the pH of the soil is lowered to 2 to 3. Next, bisulfite is added to the soil at 1.25 times the stoichiometric quantity of Cr^{+6} and mixed for 5 to 10 minutes until the reaction is complete. To insure a complete $\text{Cr}^{+6} \rightarrow \text{Cr}^{+3}$ reduction, an on site colorimetric test will be performed immediately following mixing to measure the presence of Cr^{+6} . Lastly, the soil pH will be raised to 7 or above to precipitate chromium as a hydroxide.

A one-step procedure is proposed for the use of sodium hydrosulfite as a reducing agent. Hydrosulfite is added to the soil at 1.25 times the stoichiometric quantity of Cr^{+6} , along with the immobilization binder(s), and mixed for 5 to 10 minutes until the reduction is complete. To insure a complete $\text{Cr}^{+6} \rightarrow \text{Cr}^{+3}$ reduction, an on-site colorimetric test will be performed during and following mixing to measure the presence of Cr^{+6} .

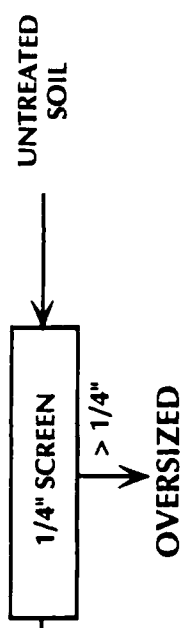
The immobilization of screened, pretreated soil is the next treatment stage. The four binders that will be explored are: 1.) Portland Cement, 2.) Portland Cement with soluble silicate, 3.) high alkaline (self-cementing) fly ash, and 4.) high alkaline fly ash with soluble silicate. The cement and fly ash binders will be evaluated at 10% and 40% (w/w) mixtures. For the ferrous sulfate and sodium bisulfite reduced soil, the addition of immobilization binders will follow Cr^{+6} reduction (Figures 2A and 2B). For the sodium hydrosulfite reduced soil, the 8 experimental tests resulting from the 4 x 2 experimental design will be performed concurrently with the reduction (Figure 2C).

REDUCTION



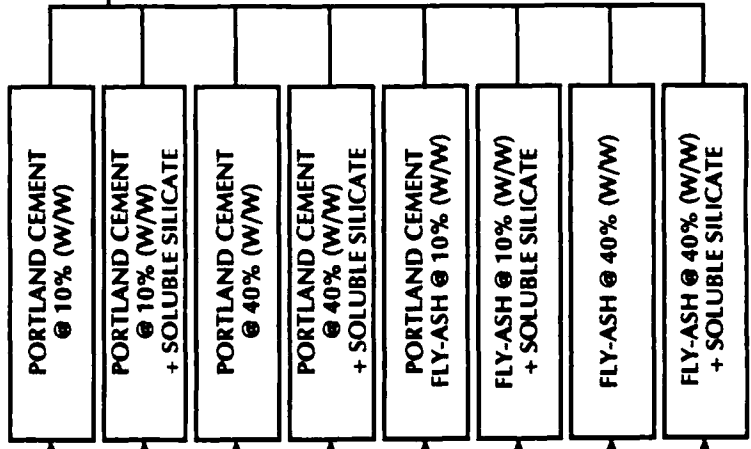
- ANALYSES:**
- Cr +6
 - pH
 - SO₄

SCREENING



- ANALYSES:**
- CAL WET
 - TCLP
 - TOTAL METALS
 - pH
 - SPECIFIC GRAVITY
 - BULK DENSITY/WATER CONTENT
 - GRAIN SIZE

IMMOBILIZATION



ANALYTICAL TESTS

- TIER 1 ANALYSES:**
- TCLP
 - VOLUMETRIC INCREASE
 - pH

PASS

CURING
24 HOURS

- TIER 2 ANALYSES:**
- CAL WET
 - MEP
 - UCS
 - BULK DENSITY
 - VOLUME DILUTION

PASS

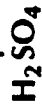
CURING
24 HOURS

SOIL IMMOBILIZATION SCHEMATIC
FERROUS SULFATE REDUCTION

REDUCTION

- ANALYSES:
- Cr +6
 - pH
 - SO₂
 - SO₄

SODIUM BISULFITE
1.25 TIMES STOICHIOMETRIC



SCREENING

1/4" SCREEN

UNTREATED SOIL

> 1/4"
OVERSIZED

< 1/4"

- ANALYSES:
- CAL WET
 - TCLP
 - TOTAL METALS
 - pH
 - SPECIFIC GRAVITY
 - BULK DENSITY/WATER CONTENT
 - GRAIN SIZE

ANALYTICAL TESTS

CURING
24 HOURS

IMMOBILIZATION

- PORTLAND CEMENT @ 10% (W/W)
- PORTLAND CEMENT @ 10% (W/W) + SOLUBLE SILICATE
- PORTLAND CEMENT @ 40% (W/W)
- PORTLAND CEMENT @ 40% (W/W) + SOLUBLE SILICATE
- PORTLAND CEMENT FLY-ASH @ 10% (W/W)
- FLY-ASH @ 10% (W/W) + SOLUBLE SILICATE
- FLY-ASH @ 40% (W/W)
- FLY-ASH @ 40% (W/W) + SOLUBLE SILICATE

- TIER 1 ANALYSES:
- TCLP
 - VOLUMETRIC INCREASE
 - pH

PASS

CURING
28 DAYS

- TIER 2 ANALYSES:
- CAL WET
 - MEP
 - UCS
 - BULK DENSITY
 - VOLUME DILUTION

PASS

SOIL IMMOBILIZATION SCHEMATIC
SODIUM BISULFITE REDUCTION

FIGURE
2B

SCREENING

UNTREATED SOIL

1/4" SCREEN

< 1/4"

> 1/4"

OVERSIZED

- ANALYSES:
- CAL WET
 - TCLP
 - TOTAL METALS
 - PH
 - SPECIFIC GRAVITY
 - BULK DENSITY/WATER CONTENT
 - GRAIN SIZE

ANALYTICAL TESTS

CURING 24 HOURS

- TIER 1 ANALYSES:
- TCLP
 - VOLUMETRIC INCREASE
 - PH

PASS

CURING 28 DAYS

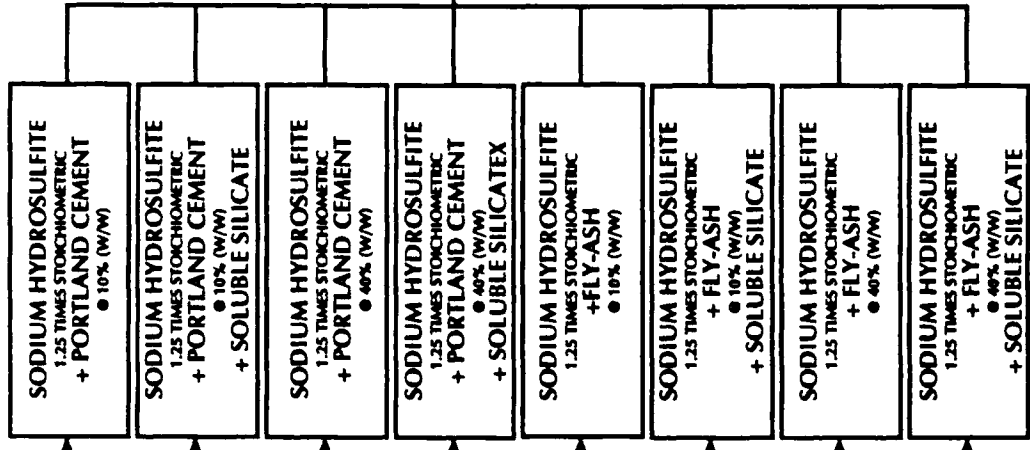
- TIER 2 ANALYSES:
- CAL WET
 - MEP
 - UCS
 - BULK DENSITY
 - VOLUME DILUTION

PASS

FAIL

FAIL

REDUCTION/IMMOBILIZATION



SOIL IMMOBILIZATION SCHEMATIC

SODIUM HYDROSULFITE REDUCTION

FIGURE

2C

The recommended cure time before the tier 1 analytical tests is twenty-four hours, while the recommended cure time before the tier 2 tests is twenty-eight days. Depending on the type of Portland cement used, this period could vary. Type 2 and type 5 cement may require longer cure times before the tier 1 and 2 tests. A pocket, cone penetrometer can be used to measure the hardness of the test cylinders before analyses.

The analytical testing step has been broken into two tiers. The first tier places primary emphasis on the TCLP leach test. The immobilization mixture with the lowest TCLP values will be tested in the second tier analyses. In addition, the pH of the immobilized matrix will be measured and the volumetric increase of the immobilized mixture will be quantified.

The second tier analyses involve measurement of the monolith's leaching values of California regulatory concern, long term leaching performance, and structural durability. The description of the methods are in Sections 5.2.2 and 5.2.3. The tier two test is WET for California STLC values. Long term leaching measured by the multiple extraction procedure. Durability is measure by the unconfined compressive strength analysis.

5.0 Sampling, Analysis, and Quality Assurance/Quality Control

5.1 Sampling

The objective of the sampling required for the treatability study is to collect discrete soil samples containing the highest concentrations of the respective chemicals of concern and to homogenize these discrete samples into a soil with uniform concentrations. This uniform soil will be used for all the treatability studies. Other sampling objectives, such as getting additional information on the existence of certain metals of concern, are not a part of the treatability study. Approximately fifteen gallons of soil is required to perform the treatability studies. The soil will be collected from soil borings designed to be representative of soils containing the chemicals of concern (Cr, Cd, Ni, and Pb). The most important consideration during sampling is that the soil used for treatability testing contain the four heavy metals of concern at elevated levels.

The representative soil used for treatability testing will be composited from four individual soil samples collected from discrete locations and depths. The choice of the discrete soil sample locations and depths are important because of the heterogeneous distribution of the chemicals of concern at the Alark site. The soil sample analysis listed in Table 3 of the RI/FS show that many of the previously collected soil samples contain only some of the four chemicals of concern. Therefore, to obtain representative soil with all four metals at elevated concentrations, soil will be taken at the four locations that contain high concentrations of the respective heavy metal of concern.

The previous sample locations and depths containing high relative concentrations of the respective heavy metals are:

- B27 which contained 3460 ppm Cr at 5 feet and 7000 ppm chromium at 30 feet;
- B19 contained 100 ppm Cd at 5 feet;
- B22 contained 800 ppm Pb and 120 ppm Ni at 5 feet.

The soil borings to collect treatability soils will be installed in locations adjacent to the above boring locations. Samples of soil cuttings will be collected from the surface to five foot interval in each boring. Additionally, cuttings from the 25 to 35 foot interval will be collected from the boring installed adjacent to Boring B27 due to the elevated

chromium detected at thirty feet. Figure 3 illustrates the proposed boring locations for the treatability study.

Approximately fifteen gallons of soil from each discrete sample location and depth will be placed in a clean plastic container, mixed thoroughly, and sampled for total metals of concern (Cr, Cd, Ni, and Pb). The individual soil samples containing elevated total concentrations of the target heavy metals will then be selected for combination into a composite fifteen gallon sample to be used for treatability testing. A selected mix of the discrete samples will be placed into a large container and mixed thoroughly. The resulting composite soil will be sampled for the parameters of interest shown in Tables 1 and 2. The analyses from the composite soil will be evaluated to determine if this sample is representative of the Alark site soil. This sample will also represent the starting concentrations of the target metals (pretreatment).

Data from the groundwater monitoring program at the Alark site suggest that there may be low-level contamination of groundwater with trichloroethene (TCE). Per the request of the DTSC remedial project manager, representative pretreatment soil samples will be analyzed for TCE. The objective of the TCE sampling is to explore the possibility of TCE contamination at Alark; therefore, this sampling event is quite distinct from the treatability study even though it is included within it. It is anticipated that no TCE contamination of soil exists; this sample event is designed to confirm this hypothesis.

Three soil borings will be drilled to obtain soil for TCE analysis, two borings at the locations B27 and B19 described above, and one boring collected near MW-2 because TCE was detected in MW-2. Three split-spoon soil samples will be extracted from each boring at the 10, 20, and 30 feet intervals. A field photo ionization detector (PID) will be used to screen each set of 3 soil samples from each boring for volatile organic compounds (VOC). One sample, with the highest PID reading, from each set of soil samples will be selected for chemical analysis. If all soil samples from a set are non-detect for VOC as measured by the PID, a field representative will select one sample from the set for TCE analysis by EPA method 8010.

Pretreatment samples will be well-mixed and screened to establish feedstock characteristics and waste uniformity. The pretreatment sampling will serve as the base level against which post-treatment sampling will be evaluated.

TS 1 } Treatability
 TS 2 }
 TS 3 }

TS-1 Top 10' w
 8" Auger, 6" Auger
 to 30'
 Top 10 feet for
 Treat Study

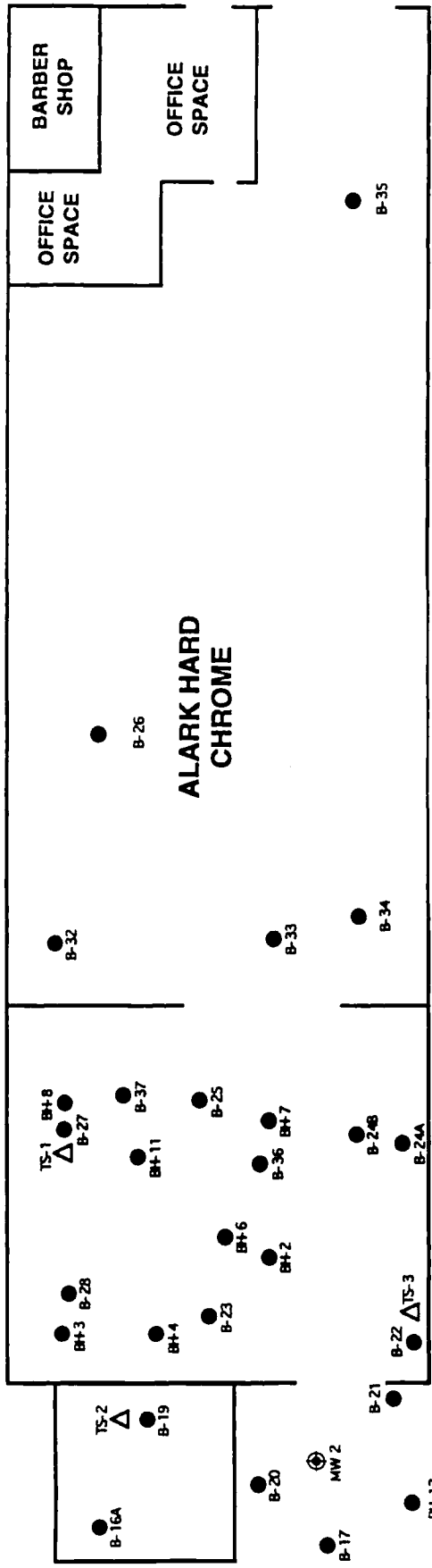
TS-2 Top 10' w
 8" Auger, 6" Auger
 to 30'
 Top 10 feet

TS-3 Only 8" Auger
 to collect sample
 to 10' only
 Hi Conc Ni, Cd, Pb

TS-4 6" Auger
 to 30 foot
 5 ft for metal
 10 foot for



KLURE & HARRIS FACILITY



PRECISION AUTO FACILITY

- LEGEND**
- Existing Soil Samples
 - ⊕ Existing Monitoring Wells
 - △ Proposed Treatability Study Borings

SOURCE: California Department of Toxic Substances Control
Region 4, Site Mitigation Branch

FACILITY MAP
Alark Hard Chrome
2777 Main St., Riverside, CA

URS Consultants
4675 MacArthur Court, #850
Newport Beach, CA 92660
November 19, 1992

FIGURE

3

Table 1
Testing Matrix

Test	Untreated Soil	Reducing Agent	Reduced Soil	Immobilization Agent	Immobilized Soil (1)	Washed Soil	Rinsate (2)	Recovered Metals
Material balance	*	*	—	*	*	*	*	*
Leaching Tests								
Cal WET	*	—	—	—	*	*	—	—
TCLP	*	—	—	—	*	*	—	—
MEP	—	—	—	—	*	—	—	—
Engineering/GeotechTests(3)								
Specific Gravity	*	—	—	—	*	*	—	*
Bulk Density/Water Content	*	—	—	—	*	*	—	*
UCS	—	—	—	—	*	—	—	—
Grain Size	*	—	—	—	—	—	—	—
Chemical Tests								
pH	*	—	*	—	*	*	*	*
Cr	*	—	—	—	—	*	*	*
Cr+6	*	—	—	—	—	*	*	*
Cd	*	—	—	—	—	*	*	*
Pb	*	—	—	—	—	*	*	*
Ni	*	—	—	—	—	*	*	*
SO4	*	—	*	—	—	—	—	—
TCE	*	—	—	—	—	—	—	—
SO2	—	—	*	—	—	—	—	—
H2O2	—	—	—	—	—	—	*	—
EDTA	—	—	—	—	—	—	*	—
Volume Dilution	—	—	—	—	*	—	—	—

Notes: (1) Initial solidified waste will be sampled after curing times of 24 hours and 28 days.
 (2) Before and after wastewater treatment
 (3) Specific test and/or sample preparation methods may vary

Key: * = Test will be considered; — = Test not being considered further

Table 2

Estimated Number of Laboratory Analyses

Sample Type	Cal WET	MEP	TCLP	H2O2	EDTA	SO4	SO2	TCE	Grain Size	Pore Volume	Specific Gravity	Bulk Density	UCS	Total Metals ^c	Total Metals ^d
Untreated Soil	1	—	1	—	—	2	—	2	3	2	2	1	—	13	—
Reduced Soil	—	—	—	—	—	3	3	—	—	—	—	—	—	1	—
Immobilized Soil	a	a	24	—	—	—	—	—	—	—	a	a	a	—	—
Washed soil	2	—	1	—	—	—	—	—	—	—	1	1	—	6	—
Washed soil without H2O2	1	—	1	—	—	—	—	—	—	—	—	—	—	1	—
Rinsate	—	—	—	8	8	—	—	—	—	—	—	—	—	—	8
Recovered Metals	1	—	1	—	—	—	—	—	—	—	1	1	—	1	—
Subtotal	8b	3b	29	8	8	5	3	2	3	2	7b	6b	3b	22	8
QA/QC															
Duplicate	—	—	—	—	—	—	—	—	—	—	1	1	1	1 ^f	—
Matrix Spike	1	—	1	1	1	1	—	1	—	—	—	—	—	1	1
Matrix Spike Dupl.	1	—	1	1	1	1	1	—	—	—	—	—	—	1	1
Blank	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Total	10b	1b	31	10	10	7	3	3	3	2	8b	7b	4b	25	11

a test on passed sample(s)

b estimated

c Cr, Cr⁺⁶, Cd, Pb, Ni in soil

d Cr, Cr⁺⁶, Cd, Pb, Ni in water

e Cal WET including Cr, Cr⁺⁶, Cd, Pb, and Ni (requires a separate extraction for Cr⁺⁶)

f CAM 17 metals in soil

Note: pH will be performed during the treatability test

Post-treatment sampling is required to establish the extent to which the soil has been washed or immobilized. The soil samples from the soil washing treatment will be taken at various time periods during the wash cycle. The soil samples from the immobilization treatment will be taken after the 28-day curing period.

5.1.1 Chain-of-Custody

The purpose of this procedure is to describe the proper chain-of-custody methods to be followed. This procedure will outline the documentation necessary to trace sample possession and will provide standardized chain-of-custody forms to be used in the field.

Field personnel (samplers) are responsible for performing the tasks in accordance with this procedure when conducting work related to hazardous waste projects. These personnel are responsible for the care and custody of the collected samples until the samples are transferred or dispatched properly.

The chain-of-custody documentation provides a written record of the handling of each sample from the time it is collected until it is destroyed. A Chain-of-Custody Record is required for each transmittal of samples. One sample number will be assigned to each sample location and cross referenced on the chain of custody. One Chain-of-Custody Record will be used per shipment. The Chain-of-Custody Record will be signed off when releasing the cooler to the shipper and will include the signature, date, time and the air bill number at the bottom of the page.

The following chain-of-custody procedure will be implemented to maintain and document sample possession:

Samples are collected as described in the Treatability Study Work Plan or Remedial Action Plan.

- The sampler (or person in possession of samples) is responsible for the care and custody of the samples collected until they are properly transferred or dispatched to the analytical laboratory.
- Sample labels and tags will be completed in indelible ink for each sample.
- The Site Manager will determine whether proper custody procedures are being followed

during the field work and will decide if additional samples are required.

A written statement is prepared detailing how the sample was collected, air dispatched, or hand transferred to the laboratory. The statement should include all pertinent information, such as entries in field logbooks regarding the sample, whether the sample was in the sample collector's physical possession or in a locked compartment until hand-transported to the laboratory.

- When possible, all samples pertaining to one physical sampling location should be recorded on the same chain-of-custody. For easier data storage, use separate chain-of-custody for each unique project site.
- When transferring the possession of samples, the individuals relinquishing and receiving will sign, date, and note the time on the chain-of-custody. This act documents the physical transfer of the sample from the sampler to the analyst in the laboratory.
- Samples will be separated and surrounded with vermiculite or equivalent packaging to prevent breakage and dispatched to the laboratory for analysis, with a chain-of-custody accompanying each shipment. Shipping containers will be padlocked or sealed. The method of shipment, courier name(s), and other pertinent information will be entered on the chain-of-custody.
- All shipments will be accompanied by the chain-of-custody identifying its contents. The original chain-of-custody will be sealed in a plastic bag and taped to the lid of the transport container. The original chain-of-custody accompanies the samples, the pink copy is forwarded to DTSC, and two photocopies are made. One photocopy is sent to the URS Project Manager and one is retained for the sampler's files.
- The cooler will be sealed, overlapping the lid and body with custody seals.
- If sent by mail, the package will be registered with return receipt requested. If sent by common carrier or air freight, proper documentation must be maintained, e.g, bill of lading.

Any delays or changes of scope will be reported (i.e., changes in number of samples to be collected, matrix changes, etc.) to the URS Project Manager. The project manager will then notify the DTSC.

5.1.2 Equipment Decontamination

This procedure describes the techniques used to decontaminate equipment prior to collecting samples or taking measurements. Proper decontamination ensures that equipment and sample cross-examination does not occur.

Field personnel decontaminating equipment are responsible for performing the applicable tasks outlined in this procedure when conducting work related to the treatability study. The URS Project Manager or his/her designed is responsible for checking all work performance and approving that the work satisfies the applicable tasks required by this procedure.

Immediately after sampling, each piece of sampling equipment shall be brushed with either a bristle or steel wire brush to remove gross particulate contamination. Oversized and drilling equipment shall be steam cleaned. Following the initial cleaning, the equipment will be scrubbed thoroughly with a laboratory-grade detergent/water solution, rinsed with reagent-grade distilled water, and rinsed with reagent-grade methanol. As a final rinse, the equipment will be wash thoroughly with reagent-grade distilled water. The equipment will be allowed to air dry or wipe dry with chemical-free paper towels.

5.2 Analyses

To develop an appropriate analytical plan for this soil washing and immobilization test, this study proposes the following types of analyses: materials balance, leaching, engineering/geotechnical, and chemical. Table 1 presents a preliminary analytical plan as a matrix of test methods and material tested. Table 2 presents an estimated number of laboratory samples. Table 3 presents a list of holding times, preservatives, container, and suggested volume for the analyses performed.

5.2.1 Material Balance

Material balance involves an accounting of all the reactants and products of a chemical reaction or mixing process. It involves weighing or determining the volume and density of each reactant and each reaction product. A detailed

Table 3

List of Holding Times, Preservatives, Container, and Suggested Volumes

Analyses	Holding Time	Preservative	Container	Suggested Volume	Special Handling
Cal Wet	6 months	Cool 40C	Wide Mouth Glass	150 gr	None
MEP	6 months	Cool 40C	Wide Mouth Glass	100 gr	None
TCLP	6 months	Cool 40C	Wide Mouth Glass	100 gr	None
EDTA	6 months	Cool 40C	Poly or Glass	500 ml	None
SO4	28 days	Cool 40C	Poly or Glass	500 ml	None
TCE	14 days	Cool 40C	VOA-Glass	2, 40 ml vials	None
Total Metals (Cr+6)	24 hours	Cool 40C	Poly	500 ml	None
Total Metals	6 months	HNO3 to pH <2	Poly	500 ml	None

material balance also involves measuring the total composition of each reactant and reaction product with respect to one or more constituents.

Immobilization processes will involve the addition of immobilization reagents which react with the soil to produce an immobilized matrix. For the Alark site immobilization study, there is no anticipated release of gaseous products (including steam) or volatilizing organic materials from the immobilized matrix. Therefore, the experimenter would only need to consider dilution effects caused by the addition of immobilization reagents. The material balance is dependent on the accurate measurements of:

- The volume and weight of the raw (or untreated) soil and any water added to the soil;
- The volumes and weights of each ingredient (solid and/or liquid) in the immobilization process; and,
- The volume and weight of the immobilized and washed soil.

5.2.2 Leaching Tests

The leaching test is the primary and most widely-used indicator of the chemical stability of an immobilized matrix. A wide variety of leaching tests have been used to determine the quantity of a particular constituent of a solid that will dissolve into a liquid with which it is in contact. Major factors that may vary with leaching methods include:

- Surface area of waste: powdered material versus monolithic mass;
- Type of leaching medium: distilled water, acid, others;
- Waste-to-leaching-medium ratio;
- Waste and leaching medium contact time;
- Agitation method; and,
- Sequential or continuous contact between waste and leaching medium.

No single test can duplicate the variable conditions associated with what a solidified waste would experience in the environment. However, the following tests, are generally recognized as being among the most commonly used procedures and are recommended for predicting

leachability of the chemicals of concern within untreated and immobilized Alark soil:

- California Waste Extraction Test (Cal WET)
- Toxicity Characteristic Leaching Procedure Test (TCLP)
- Multiple Extraction Procedure (MEP)

The testing rationale for sample leaching provides for two tiers of analysis (Figures 2A, 2B, 2C). The untreated soil without reduction (a control) and the immobilized soils will be subjected to the TCLP leach test. Next, the treated immobilized soil with the lowest TCLP results will be analyzed by the Cal WET and MEP leach tests. This later battery of leach tests will be used as a confirmation of the immobilization of the chemicals of concern.

The Cal WET and the TCLP tests are designed to determine the mobility of both organic and inorganic contaminants present in liquid, solid, and multiphase wastes. The TCLP test will be used as the primary indicator of performance in this study. It will be used in lieu of the Cal WET test, except for final confirmation. Although the most conservative method is to use both procedures to test the mobility of chemicals of concern within an immobilized matrix, the TCLP extraction test may give important information regarding the protectiveness of an immobilization remedy. The following paragraphs describes each of the three leach tests in more detail.

The TCLP test procedure may require that leaching be done at one of two pH values, 4.93 or 2.88, depending on specific conditions encountered during testing. The TCLP leaching medium used is a function of the alkalinity of the solid phase of the waste. The TCLP test extracts soil ground and sieved to <9.5 mm with acetic acid at an extract: soil ratio of 20:1 for 18 hours. The detailed test procedure is described in 40 CFR Part 268 Appendix I, as part of the land disposal restrictions (LDR) regulations. This test is used to determine if a waste is subject to the LDR regulations.

The Cal WET test procedure requires that soil leaching be done at an initial pH of 5.0. The Cal WET test extracts soil ground and sieved to <2 mm with citric acid at an extract: soil ratio of 10:1 for 48 hours. Chromium⁺⁶ must be extracted separately with distilled water. The detailed procedure is described in the California Administrative Code, Title 22, Appendix 6. This test is used to determine if a waste exceeds the STLC values listed in Title 22, 66696.

The MEP test is designed to simulate the leaching that a waste will be exposed to repetitive precipitation of acid rain on an improperly designed sanitary landfill. To achieve this purpose, the MEP uses multiple, sequential extractions of the matrix of concern. The repetitive extractions reveal the highest concentration of each constituent that is likely to leach into a natural environment. In the first extraction, the waste samples are extracted with the same acetic acid used in the extraction procedure toxicity test. Then, the solid portions of the samples remaining after the separation procedure are reextracted nine times, using synthetic acid rain extraction fluid (concentrated sulfuric acid: nitric acid:: 60:40, wt% diluted to pH 3). The detailed procedure for this test is described in SW-846, Method 1320. The MEP can also be used to determine whether a waste that has been immobilized should be delisted.

5.2.3 Engineering/Geotechnical Tests

Engineering/Geotechnical tests will involve the use of physical methods to characterize the Alark soil and the immobilized matrices. One important set of tests will determine the soil mass as a function of grain size. The separated soil would be subject to chemical tests to determine the portion by grain size. Other tests will provide measurements of the ability of the initial mass to withstand loss of weight as a result of immersion in water, the resistance of a solidified mass to stresses induced by wetting and drying, structural capacity of the solidified mass, the porosity of the immobilized material, and the degree of encapsulation of the treated wastes. These factors provide information relative to the efficiency and effectiveness of the immobilization process. This section describes some of the different geotechnical testing procedures, including their application to the immobilization of Alark soil.

Water content is the ratio of the weight of water retained by a solid to the weight of solids expressed as a percent. This value is used to determine if pretreatment is necessary and to design the proposed immobilization. The resulting test data will be used to evaluate the leachability and strength of immobilized soil. Water content measurement is also required for durability testing of immobilized soil.

Standard methods for water content are ASTM methods D2216-80 and TMSWC-4. ASTM method D2216-80 is used to determine the water content of raw waste samples. Moisture is determined on a dry-weight basis by measuring the mass of water removed by drying the sample to a constant mass at $110^{\circ}\text{C} \pm 5^{\circ}\text{C}$. This method is not applicable to solidified waste because hydrated water can

be lost when the sample is dried at 110°C. TMSWC-4 is used to determine the water content of solidified waste. The sample is ground to pass through an ASTM No. 10 sieve. The mass of the sample is measured before and after it is dried in an oven maintained at 60°C ± 3°C. The dry weight must be a constant weight (mass change of less than 0.03 g in 4 hours).

The grain size or particle-size distribution of a soil is an important consideration in designing remedial actions. Fine-grained soil generally presents more handling problems and is subject to wind dispersion. Fine-grained soil also presents problems in producing high-strength solidified wastes. Large percentages of fine particles lower the ultimate strength developed in cement/soil composites. The particle size distribution of samples of a soil is typically determined by combined sieve analysis and hydrometer analysis described in ASTM 422-63. A method that has more accuracy potential is the American Petroleum Institute (API) method using pressured helium gas; Boyle's law may be substituted for the ASTM method.

The bulk densities of the stabilized/solidified waste, along with the unconfined compressive strength (UCS) and permeability, will help to evaluate the leachability of the solidified waste. The bulk density of raw waste will be determined using the excavation ASA-13-3 method (American Society of Agronomy). Based on a soil sample of known volume and dry mass, the bulk density will be calculated. The bulk density of the immobilized soil will be determined using TMSWC-2 (Test Methods for Solid Waste Characterization). The bulk density is determined by weighing a cube or cylinder of the stabilized/solidified solid and measuring the dimensions of the cube or cylinder. The bulk density is calculated by dividing the volume into the mass. The data will be used to convert waste weight to volume or vice versa for material handling calculations.

The unconfined compressive strength (UCS) of immobilized soil will be measured in accordance with ASTM method D-1633. This test method determines the UCS characteristics of molded soil-cement cylinders using strain-controlled application of an axial load. UCS is defined as the load per unit area (psi) at which an unconfined cylindrical sample of solids will fail a compression test. Unconfined compressive strength tests will be used to provide information on the stability of the immobilized Alark soil in a disposal environment.

5.2.4 Environmental Analysis

The analytical methods to be used during the treatability study have been selected from USEPA methods. Analytical methods for priority pollutant metals are based on the EPA publication *Test Methods for Evaluating Solid Wastes, SW-846, 3rd Edition*, November 1986. The analytical methods to be used are presented below:

- EPA Method 6000/7000 series for total chromium, hexavalent chromium, cadmium, nickel, and lead in soil.
- EPA Method 8010 for halogenated volatile organics (trichloroethene) in soil. Method 8010 was selected over Method 8240 because of the higher costs of Method 8240.
- EPA Method 9035/9036/9038 for sulfate in soils. Total sulfate are being analyzed because of the sensitivity of certain types of Portland cement to sulfates.

5.2.5 Analytical Laboratories

The following California Certified Laboratories were petitioned for selection by URS for the leach tests and environmental analyses on the treatability study:

- Ensotech, Inc., Sun Valley, CA;
- Tox Scan, Inc., Watsonville, CA;
- BC Analytical, Anaheim, CA;
- Del Mar Analytical, Irvine, CA;
- Geotest, Long Beach, CA;
- Central Coast Analytical Services, Camarillo, CA;
and
- West Coast Analytical Services, Santa Fe Springs, CA.

The following California laboratories were petitioned for selection by URS for the engineering/geotechnical tests on the treatability study:

- PSI, Newport Beach, CA;
- Certified Labs, Garden Grove, CA;

- Core Labs, Bakersfield, CA; and
- Earth Technologies, Inc., Huntington Beach, CA.

5.3 Quality Assurance/Quality Control

To assess the integrity of field sampling techniques, quality assurance samples will be collected and analyzed. In addition, quality control and quality assurance procedures will be implemented by the selected analytical laboratories. Field and laboratory quality assurance data will be evaluated to ensure compliance with EPA-approved methods. Analytical data discrepancies will be identified during the course of this evaluation and their possible effects on environmental samples will be determined. The procedures for evaluating field and laboratory quality assurance samples and a discussion of analytical data validation is provided below.

5.3.1 Field Quality Assurance Sampling

The collection and analysis of field quality assurance samples will be conducted to provide quality control checks on the thoroughness of field equipment decontamination procedures and the integrity of sample transport. Equipment rinsate blanks and trip blanks will be collected for halogenated volatile organic compounds to determine if external contamination is being introduced into environmental samples during sample collection or transport to the analytical laboratory.

5.3.2 Laboratory Quality Assurance

The Alark treatability study will be performed in a systematic fashion to ensure that the data generated can support the remedy evaluation process. Data Quality Objectives (DQOs) ensure that the environmental data collected to support a DTSC decision concerning remedial response are of known and documented quality. For this treatability study, the DQOs will be quantitative for tests that measure regulatory criteria, such as leachable metals and total metals. DQOs will be semi-quantitative for tests that measure technical criteria, such as geotechnical and engineering tests. Analytical methodologies and data validation techniques will be implemented accordingly: Level I quality assurance/quality control will be required for data that does not support measurements of regulatory concern and Level III quality assurance/quality control will be required for data that will be evaluated to regulatory criteria. The treatability test may be used to decide whether

a particular remedial alternative is valid and/or effective, and, therefore, the establishment of DQOs is an important, early step in the effective planning and conducting of the study.

Analytical quality control procedures will be implemented to identify possible introduction of contaminants into environmental and quality control samples as a result of equipment contamination and/or analytical procedures, and to assess the validity, accuracy, and precision of analytical results. Specific quality control procedures for each analytical method will be evaluated to ensure that DQOs (accuracy, precision, representativeness, and completeness) are met. The evaluation process is generally referred to as data validation. An overview of the data validation process and the is provided below.

5.3.3 Data Validation Overview

One focus of the data validation process is to assess the accuracy and precision of the analytical methods and procedures used. Accuracy is determined by evaluating matrix spike or blank spike recovery limits. Matrix and blank spikes are samples with a known concentration of certain compounds of interest (spike) added to a sample matrix or method blank, respectively. The amount, or percent, of the spike compound that is recovered is used to assess the accuracy of the analysis. The spike recovery limits must be within control limits established by laboratory historical spike or method-specific recovery values (historical laboratory values must also be within ranges established by the EPA). Sample results that fall outside of the quality control limit range do not meet accuracy standards and are flagged accordingly.

Precision for most analytical methods is determined by evaluating the recovery results obtained by a second analysis of the matrix spike (matrix spike duplicate). Precision for metals analyses are determined by the duplicate analysis of an environmental sample. In both instances, the recovery values, or recovery percent, are evaluated by calculating the relative percent difference (RPD) between the two samples (the matrix spike/matrix spike duplicate or the environmental sample/duplicate sample). Just as the control limits set forth for matrix spike recovery limits, or accuracy, must be within set control limits, the relative percent difference between these duplicate samples must also be within established acceptance criteria for precision. Samples that fall outside of these control limits do not meet precision standards and are also flagged.

The data validation process also evaluates the possibility of external contamination of environmental or quality assurance samples in the laboratory. This assessment is accomplished through the use of method blank analyses. Method blanks are used to identify any contaminants introduced to the sample during analytical procedures. Method blanks are simply blank samples (e.g., do not contain target analytes) that are analyzed by the same method as the environmental samples. Each environmental and quality assurance sample has a corresponding method blank that is analyzed for contamination. If contamination is observed, external contaminants have entered the method blank sample and each of the corresponding environmental and quality assurance samples are flagged with a qualifier noting that contamination in the blank is present. In many cases, depending on the procedures used by the selected analytical subcontractor, the amount of contaminant in the method blank is subtracted from the associated environmental or quality assurance samples. This analytical procedure is known as "blank correcting".

Certain analytical methods require surrogate spikes. Surrogate spikes are used to determine method accuracy by assessing the percent recovery for the surrogate spike. Surrogate spikes differ from matrix spikes in that the chemicals used to spike the sample are not compounds of interest, but rather are chemically-similar species. The percentage of the "spiked" species recovered indicate a loss or gain of accuracy resulting from the analytical equipment or procedures used. Like other accuracy and precision measurements, surrogate spike recovery values must fall within established control limits. Surrogate spikes that are outside of the acceptance criteria range indicate potential accuracy problems and the corresponding environmental samples are flagged accordingly.

The data validation process also evaluates sample holding times. Sample holding time requirements apply to all samples. The holding time is defined as the maximum allowable time that can elapse from the time a sample is collected until its extraction or analysis in the laboratory. Each analytical method has a specific allowable holding time. Samples that violate the maximum allowable holding time are flagged accordingly, and the analytical results are generally used for estimation purposes only.

6.0 Data Management and Interpretation

Technical decisions must be based on accurate, timely, and valid data. In addition, the data on which such decisions are made must be formalized into a permanent project record. Implementation of a standard data management system ensures that data accurately and precisely characterize the condition and situations on which significant site-specific decisions and actions will be based.

In order to assure the accuracy, precision, completeness, representativeness and comparability of field and analytical data, it is necessary to develop processes and procedures for collecting, accessing, screening, validating, storing, retrieving, transferring, modifying and securing data. These processes and procedures also ensure that data, and the reports in which the data are presented, are scientifically valid, legally defensible, and of known accuracy and precision.

An effective data management program includes established documentation protocols and documentation validation procedures. Implementation of a documentation validation process ensures that field and laboratory data were collected, processed, and documented in accordance with the protocols set forth in project guidance documents. Data failing to meet established guidelines may therefore be eliminated from consideration during the treatability study or may be used for limited purposes only. During the treatability study, a comprehensive data management program will be in place to document and monitor field and laboratory activities

During the feasibility study, the recording of field observations and raw data will require the use of a bound, numbered project notebook. Photographs will be taken when possible. The bound notebook will be the repository of the field activity daily log. Field personnel will document in the project notebook each day, at a minimum:

- project name,
- project number,
- date,
- field activity subject,
- description of daily activities and events,
- visitors on site,

- changes from plans and specifications, and other special orders and important decisions,
- weather conditions,
- samples collected,
- sample preservations, as appropriate
- chain of custody numbers used,
- field instrumentation and calibration information,
- personnel on site, and
- supervisor's signature.

Data interpretation will commence upon completion of the treatability study. Validated analytical and geotechnical data will be summarized and evaluated to determine the performance of the treatment process.

7.0 Health and Safety

The on-site pretreatment sampling and treatability study activities will be performed in accordance with the URS Consultants health and safety plan currently being prepared for the site.

8.0 Residuals Management

Residuals generated as a result of the Alark treatability study will be managed in an environmentally sound manner. Whenever possible, the residuals will stay on or be returned to the Alark site for treatment during the remedial phase of the project. Drums (55-gallon DOT type) will be provided for excess soil cuttings, personnel protective equipment, decontamination water, and other wastes generated during treatability study activities. Residuals generated by off-site laboratories will be disposed of by the laboratory at an off-site facility that is in compliance with state and federal regulations.

9.0 Reporting

This section details the project deliverables and the interim reporting requirements. All reporting will be from the URS Project Manager to the DTSC Project Manager. The following reports will be provided to DTSC under this project:

Report

Draft Work Plan

Final Draft Work Plan

Final Work Plan

Draft Report

Final Draft Report

Final Report

Section 10.0 presents the schedule for report delivery. The Final Report will provide complete and accurate reporting of the test results, as well as conclusions and recommendations about treatment alternatives that will be based, in part, on the outcome of treatability studies.

To facilitate the reporting of the Alark treatability study results, a suggested organization for this treatability study report is presented in Table 4. This manner of reporting treatability study results will expedite the process of comparing treatment alternatives.

Table 4
***Proposed Organization of the
Treatability Study Report***

- 1.0 Introduction
 - 1.1 Site Description
 - 1.1.1 Site name and location
 - 1.1.2 History of operations
 - 1.1.3 Prior removal and remediation activities
 - 1.2 Waste Stream Description
 - 1.2.1 Waste matrices
 - 1.2.2 Chemicals of concern
 - 1.3 Remedial Technology Description
 - 1.3.1 Soil Washing
 - 1.3.2 Immobilization
 - 1.4 Previous Studies at the Site
- 2.0 Treatability Study Approach
 - 2.1 Test Objectives
 - 2.2 Experimental Design and Procedures
 - 2.3 Equipment and Materials
 - 2.4 Sampling and Analysis
 - 2.5 Data Management
 - 2.6 Deviations from the Work Plan
- 3.0 Results and Discussion
 - 3.1 Data Analysis and Interpretation
 - 3.2 Comparison to Test Objectives
 - 3.3 Quality Assurance/Quality Control
- 4.0 Conclusions
- 5.0 Recommendations
- References
- Appendices

10.0 Schedule

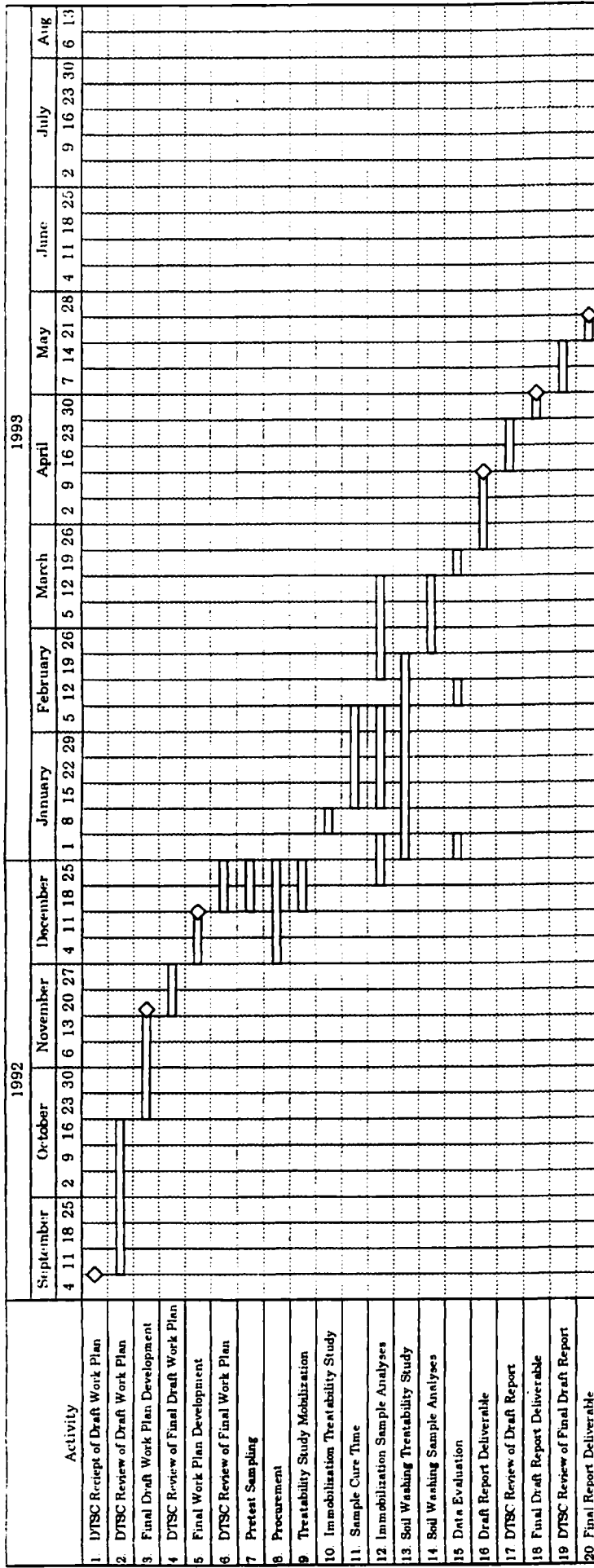
The project schedule for the Alark treatability study is given in Figure 4. Time frames shown may vary depending on the analytical laboratory turn-around times, the DTSC review period for the work plans and the reports, and unanticipated equipment rental/purchase delays. The following paragraph gives the anticipated task duration and end date for each of the tasks outlined in Figure 4. Where tasks are being performed by other organizations, such as report review and chemical analysis, the task duration, and the corresponding end date, has been assumed.

The Draft Work Plan will be reviewed by DTSC; comments were given by the DTSC to URS on or about October 16, 1992. After receipt of the DTSC comments on the Draft Work Plan by URS, the Final Draft Work Plan will be completed. If URS has the approval to proceed with the treatability study upon delivery of the Final Draft Work Plan to DTSC, one week will be required to procure homogeneous pretreatment samples. Concurrently, several weeks will be needed to procure equipment and to mobilize for the on-site studies.

The immobilization treatment will commence on January 4 and terminate by January 11, 1993. After immobilization, a 24-hour cure time is allowed for the immobilized samples prior to analysis. After the cure time, a four-week laboratory analysis turnaround time is scheduled for the first set of immobilization samples, followed by a short data evaluation period ending on or around February 12, 1993. A second laboratory effort for a selected immobilized sample with a subsequent four-week analyses turnaround will follow immediately.

The soil washing treatability study will commence on December 26, 1992, immediately after the end of the immobilization treatability study, and will take 8 weeks, during which soil will be washed and the rinsate treated. Laboratory analyses of washed samples will commence on February 19, 1993, after the completion of soil washing. A four-week turnaround time is allowed for analyses.

The Draft Report, will be on April 9, 1993. Allowing a two-week period for the DTSC review of the Draft Report and a one-week period for addressing DTSC comments, the Draft Final Report will be issued on April 30, 1993.



Allowing a two-week period for the DTSC review of the Draft Final Report, the Final Report on the Alark site treatability study will be delivered on May 21, 1993.

11.0 Management and Staffing

The DTSC Project Manager is Pamela LePen, will provide overall direction to the URS staff concerning project needs, objectives, and schedule.

The URS Project Manager, Carl E. Schubert, Ph.D., is the primary URS point of contact with the DTSC Project Manager. The URS Project Manager is responsible for: the development and completion of the Work Plan, project team organization, and supervision of all project tasks, including reporting and deliverables.

The URS Project Engineer, Larry Smith, is responsible for the engineering studies and remedial design.

The treatability specialist, Robert Evangelista, is responsible for the project aspects surrounding the treatability study.

12.0 Budget

The estimated costs to complete this on-site bench-scale treatability test are listed in Table 5, below. The costs are listed in Table 5 by three categories: 1) general costs, 2) immobilization costs, and 3) soil washing costs. Table 6 contains the detailed costs segregated by category and further itemized by labor tasks and non labor items.

TABLE 6. DETAILED COST SUMMARY SHEET

GENERAL LABOR COSTS			
TASK	Hours	Dollars	
Work plan:			
(Eng.Geo 2)	180	\$10,800	
(Project Director)	40	\$2,840	
(Eng/Geo 3)	20	\$1,300	
(Tech 2)	24	\$1,056	
(Clerical)	20	\$740	
Equipment and Laboratory select and procure:			
(Eng/Geo 2)	10	\$600	
(Tech 2)	10	\$440	
Sampling:			
(Eng Geo 2)	24	\$1,440	
(Prof. 2)	12	\$672	
Treatability test mobilization/demobilization:			
(Eng/Geo 2)	40	\$2,400	
Data evaluation & reporting:			
(Eng/Geo 2)	140	\$8,400	
(Project Director)	40	\$2,840	
(Eng/Geo 3)	10	\$650	
(Prof. 2)	2	\$112	
(Tech 2)	24	\$1,056	
(Clerical)	2	\$74	
Labor		\$35,420	
GENERAL NONLABOR COSTS			
ITEM	Amount	Unit Price	Total Price
Laboratory Analyses:			
Leaching Tests:			
Cal WET (Cr, Cd, Ni, Pb)	1	\$180	\$180
Cal WET (Cr+6)	1	\$200	\$200
TCLP	1	\$180	\$180
Engr/Geotechnical Tests:			
Pore Volume	2	\$100	\$200
Specific Gravity	2	\$84	\$168
Grain Size Distribution	3	\$200	\$600
Bulk Density/Water Content	1	\$20	\$20
Chemical Tests:			
Cr, Cd, Ni, Pb (soil)	16	\$100	\$1,600
CAM 17	1	\$225	\$225
Cr+6 (soil)	7	\$100	\$700
Trichloroethene	3	\$200	\$600
Laboratory Analyses			\$4,873
Drilling (includes rig, drillers, mob/demob)			\$1,000
Travel:			
Transportation	1600	\$0.24	\$384
Per Diem/Subsistence	7 trips	\$84.00	\$588
Travel			\$972
Other:			
Plumbing			\$500
Electrical			\$400
Shipping			\$200
Printing			\$250
Other			\$1,350
TOTAL GENERAL COST BUDGET			\$43,415

TABLE 6. DETAILED COST SUMMARY SHEET

IMMOBILIZATION LABOR COSTS			
TASK	Hours	Dollars	
Treatability test mobilization/demobilization: (Eng/Geo 2)	40	\$2,400	
Treatability test: Immobilization: Project Director (Eng/Geo 3) (Eng/Geo2) (Tech 2)	5 3 40 12	\$355 \$195 \$2,400 \$528	
Labor		\$5,878	
IMMOBILIZATION NONLABOR COSTS			
ITEM	Amount	Unit Price	Total Price
Laboratory Analyses:			
Leaching Tests:			
Cal WET (Cr, Cd, Ni, Pb)	5	\$180	\$900
Cal WET (Cr+6)	5	\$200	\$1,000
TCLP	27	\$180	\$4,860
MEP	1	\$3,300	\$3,300
Engr./Geotechnical Tests:			
Pore Volume	4	\$100	\$400
Bulk Density/Water Content	4	\$20	\$80
Unconfined Compressive Strength	4	\$84	\$336
Chemical Tests:			
Cr, Cd, Ni, Pb (soil)	8	\$100	\$800
Cr+6 (soil)	1	\$100	\$100
Sulfate	7	\$100	\$700
SO2	3	\$200	\$600
Laboratory Analyses			\$13,076
Other:			
Reagents			\$600
Field Supplies			\$150
Field Equipment			\$1,000
Miscellaneous			\$100
Other			\$1,850
TOTAL IMMOBILIZATION BUDGET			\$20,804

TABLE 6. DETAILED COST SUMMARY SHEET

SOIL WASHING LABOR COSTS			
TASK	Hours	Dollars	
Treatability test mobilization/demobilization: (Eng/Geo 2)	40	\$2,400	
Treatability test:			
Soil Washing:			
(Project Director)	10	\$710	
(Eng/Geo 3)	4	\$260	
(Eng/Geo 2)	70	\$4,200	
(Tech 2)	24	\$1,056	
Rinsate Recovery:			
Project Director	5	\$355	
(Eng/Geo 3)	3	\$195	
(Eng/Geo 2)	10	\$600	
(Tech 2)	12	\$528	
Labor		\$10,304	
SOIL WASHING NONLABOR COSTS			
ITEM	Amount	Unit Price	Total Price
Laboratory Analyses:			
Leaching Tests:			
Cal WET (Cr, Cd, Ni, Pb)	4	\$180	\$720
Cal WET (Cr+6)	4	\$200	\$800
TCLP	3	\$180	\$540
Engr./Geotechnical Tests:			
Pore Volume	2	\$100	\$200
Specific Gravity	6	\$84	\$504
Bulk Density/Water Content	2	\$20	\$40
Chemical Tests:			
Cr, Cd, Ni, Pb (soil)	8	\$100	\$800
Cr+6 (soil)	8	\$100	\$800
Cr, Cd, Ni, Pb (water)	11	\$80	\$880
Cr+6 (water)	11	\$100	\$1,100
EDTA	10	\$150	\$1,500
H2O2	3	\$200	\$600
Laboratory Analyses			\$8,484
Other:			
Reagents			\$400
Field Supplies			\$150
Field Equipment			\$3,000
Miscellaneous			\$100
Other			\$3,650
TOTAL SOIL WASHING BUDGET			\$22,438

13.0 References

1. Kosson, D.S., Ahlert, R.C., Boyer, J.D., Dienemann, E.A., and Magee II, J.F., *Development and Application of On-Site Treatment Technologies for Sludge Filled Lagoons*, Proc. International Conference on New Frontiers for Hazardous Waste Management, EPA/600/9-85/025, Sept. 1985, pp. 118-127.
2. Onufer, R., Evangelista, R., Ahlert, R.C., and Kosson, D.S., *Transportable System for Biodegrading Leachate/Extract from CERCLA Site Excavated Soil*, Draft Report, Contract No. 68-03-3255, U.S. EPA, Office of Research & Development, Releases Control Branch, Edison, NJ, Sept. 1986.
3. Farah, H. and Pickering, W.F., *Extraction of Heavy Metal Ions Sorbed on Clays*, Water, Air, and Soil Pollution, 9 (4), pp. 491-498, 1978.
4. Cao, H.F., Chang, A.C., and Page, A.L., *Heavy Metal Contents of Sludge-Treated Soils as Determined by Three Extraction Procedures*, Journal of Environmental Quality, 12 (3), pp. 632-634, 1984.
5. Singh, B.R. and Narwol, R.P., *Plant Availability of Heavy Metals in a Sludge Treated Soil: II. Metal Extractability Compared with Plant Metal Uptake*, Journal of Environmental Quality, 12 (3), pp. 344-349, 1984.
6. O.H. Materials Co., *Solvent Extraction of PCB Contaminated Soils Bench and Pilot Scale Tests*, Draft Report, U.S. EPA, Region III, Philadelphia, PA Contract No. 2364-E52, June, 1985.
7. Rodgers, C.J., Dornel, A., and Peterson, R.L., *Mobile KPEG Destruction Unit for PCBs, Dioxin, and Furans in Contaminated Waste, Land Disposal, Remedial Action, Incineration and Treatment of Hazardous Waste*, U.S. EPA, Office of Research and Development, Cincinnati, OH, EPA/600/9-87-015, pp. 361-365, Sept. 1987.
8. Texas Research Institute, Inc., *Test Results of Surfactant Enhanced Gasoline Recovery in a Large-Scale Model Aquifer*, API Publication 4390, 1985.

9. Rayford, R., Evangelista, R., and Unger, R., *Lead Extraction Process*, Final Report, U.S. EPA, Environmental Response Team, Edison, NJ, Contract No. 6803-3255, July, 1986.
10. Evangelista, R. and Zownir, A., *Lead Extraction from Excavated Soil*, 1988 Conference on Hazardous Wastes and Hazardous Materials, HMCRI, Las Vegas, NV, April, 1988.
11. Evangelista, R., *Soil Washing Treatability Study for SAPP Battery Site*, Jackson County, Florida, Final Report, U.S. EPA, Environmental Response Team, Edison NJ, Contract No. 68-03-3255, June, 1987.
12. Dietz, D., Marlowe, C., Albulescu, P., Evangelista, R., and Rayford, R., *Cleaning Contaminated Excavated Soil Using Extraction Agents*, Draft Report, U.S. EPA, Office of Research and Development, Release Control Branch, Edison, NJ, Contract No 68-03-3255, Sept. 1986.
13. Personal communication with Richard Traver, USEPA, Hazardous Waste Engineering Laboratory, Edison, NJ, on the Demonstration of the EPA's Mobile Soil Washer for the Removal of Lead Contamination in Leeds, AL.
14. Evangelista, R., Allen, H., and Mandel, R., *Treatment of Phenol and Cresol Contaminated Soil*, Journal of Hazardous Materials, 25, pp. 343-360, 1990.
15. B. Lee (1989), *California Land Ban of Metal Containing Aqueous Wastes*, Symposium: Metal Waste Management Alternative, Pasadena, California.
16. California Department of Health Services (1981), Staff Report: *Chemical Reduction of Hexavalent Chromium Contaminated Soils for a Site in Bakersfield, California*.
17. B. Lee (1989), staff report on *Proposed Treatment Standards for Solid Wastes with Metals*.
18. B. Lee (1990), *Chemical Stabilization as a Basis of Treatment Standard Requisitions for Non-RCRA Solid Hazardous Waste with Metals*. HAZMACON 91, San Jose, California.