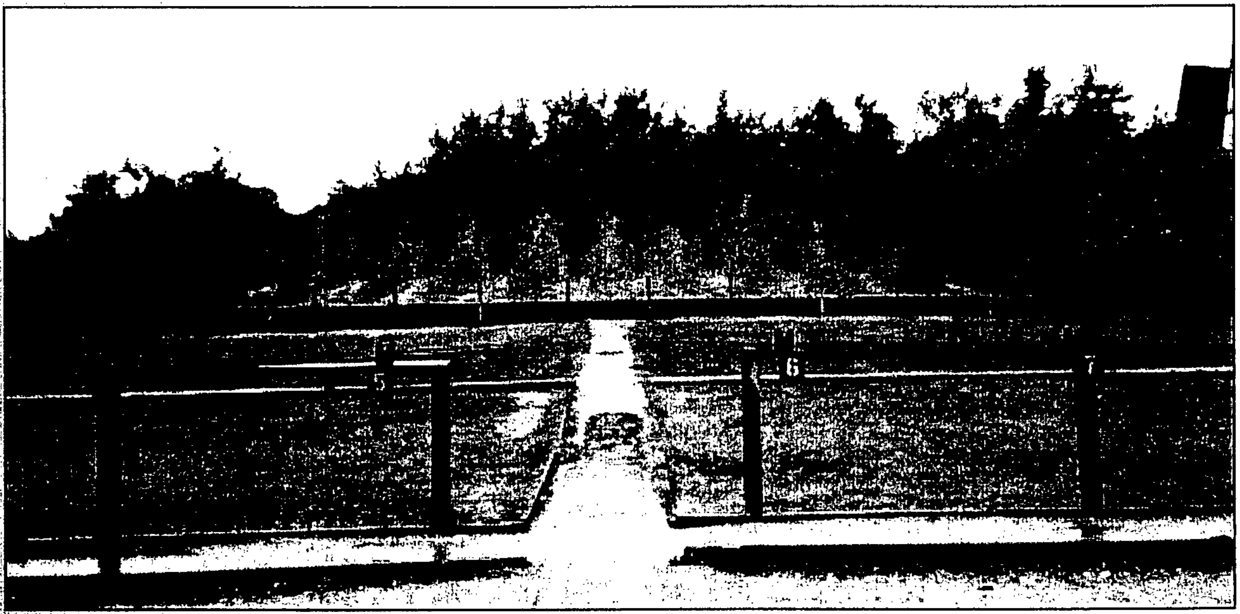
FINAL

IMPLEMENTATION GUIDANCE HANDBOOK

Physical Separation and Acid Leaching to Process Small-Arms Range Soils



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by

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. . . Putting Technology To Work

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The U.S. Army Environmental Center in partnership with the Naval Facilities Engineering Services Center and the U.S. Army Engineer Waterways Experiment Station demonstrated Physical Separation/Leaching methods for the remediation of small arms range soils. The demonstration occurred at Fort Polk, Louisiana. After conducting a world-wide search, two vendors were selected to demonstrate two variations of the physical separation/leaching technologies. The first using a process based on acetic (weak) acid chemistry and the second based on hydrochloric (strong) acid chemistry. Following completion of the bench treatability studies, each vendor performed a full scale (5-10 tons per hour, 1000 tons total) demonstration of their respective technologies.

This handbook provides technical background and guidance for conducting the following activities at outdoor small-arms ranges: 1) Planning and conducting treatability studies of physical separation/acid leaching, 2) determining the effectiveness, implementability, and cost of physical separation/acid leaching, 3) preparing a Statement of Work to obtain comptetitive quotations for range maintenance/remediation, and 4) managing and implementing range maintenance/remediation.

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Acronyms and Abbreviations

AA	atomic absorption
ACGIH	American Conference of Governmental and Industrial Hygienists
AL	action level
ARAR	applicable or relevant and appropriate requirement
ASTM	American Society for Testing and Materials
BDL	below detection limit
BMRC	Bureau of Mines Research Center
BRAC	Base Realignment and Closure
BZO	battle sight zero
CAAA	Clean Air Act Amendment
CATEX	Categorical Exclusion
cc	concentration criterion
CEC	cation exchange capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CWA	Clean Water Act
DE	diatomaceous earth
DoD	Department of Defense
DOT	Department of Transportation
EDTA	ethylenediaminetetraacetic acid
EPA	U.S. Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
FUDS	Formerly Used Defense Site
HASP	health and safety plan
HAZWOPER	hazardous waste operations
HCl	hydrochloric acid
HOAc	acetic acid
HRS	hazard ranking system
HSO	Health and Safety Officer
ICP	inductively coupled plasma
IEUBK	Integrated Exposure Uptake Biokinetic (model)
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
NA	not applicable
NAAQS	National Ambient Air Quality Standards
NCP	National Contingency Plan

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NEPA	National Environmental Policy Act
NESHAPS	National Emission Standards for Hazardous Air Pollutants
NFESC	Naval Facilities Engineering Service Center
NIOSH	National Institute for Occupational Safety and Health
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NSPS	New Source Performance Standards
OSHA	Occupational Safety and Health Administration/Act
OSWER	Office of Solid Waste and Emergency Response
PAH	polycyclic aromatic hydrocarbon
PEL	permissible exposure limit
POTW	publicly owned treatment works
PPE	personal protective equipment
PRP	potentially responsible party
PSD	prevention of significant deterioration
QA	quality assurance
QC	quality control
RCRA	Resource Conservation and Recovery Act
REC	Record of Environmental Consideration
RFP	request for proposals
RPM	remedial project manager
SARA	Superfund Amendments and Reauthorization Act
SEM	scanning electron microscope
SITE	Superfund Innovative Technology Evaluation
SMCL	secondary maximum contaminant level
SOW	statement of work
S/S	solidification/stabilization
STLC	soluble threshold limit concentration
SWDA	Safe Water Drinking Act
TCLP	toxicity characteristic leaching procedure
TLV	threshold limit value
TPQ	threshold planning quantities
TSD	treatment, storage, and disposal
TTLC	total threshold limit concentration
USACE	U.S. Army Corps of Engineers
VISITT	Vendor Information System for Innovative Treatment Technologies
WET	Waste Extraction Test

Implementation Guidance Handbook

Using Physical Separation and Acid Leaching to Process Small-Arms Range Soils

1.0 Introduction

This implementation guidance handbook is intended to assist personnel at Department of Defense (DoD) facilities responsible for evaluating and applying physical separation and acid leaching processes for maintenance or remediation of outdoor small-arms ranges. As used in this handbook, “maintenance” refers to the removal of bullet metals from berm soils of an active range to correct ricochet problems or as a proactive environmental measure. “Remediation” refers to an environmental cleanup under the Resource Conservation and Recovery Act (RCRA) or the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The combination of physical separation and acid leaching is an innovative remedial alternative that has received increasing interest (van Benschoten et al., 1997). Physical separation processes are effective for range maintenance activities involving removal of bullets and bullet fragments from berm soil. The processed soil may not be sufficiently clean to meet cleanup standards. However, it works well as a pretreatment so that the volume of soil requiring acid leaching is reduced. When particulate metals are present, physical separation reduces the load on the leaching process. Section 4 provides a detailed description of various physical separation and leaching techniques.

Physical separation and acid leaching are particularly useful at sites where metals are present as particulates, e.g., small-arms ranges or battery recycling sites. First, oversize debris, such as rock, that typically has low concentrations of metals is removed. This debris fraction can usually be cleaned easily by washing or leaching with a dilute acid solution. Metal fragments are then separated from the bulk soil based on particle size and density. The separated metals stream may be suitable for off-site recycling. The lighter, smaller soil that remains consists of sands, silts, and clay and may also contain very fine metal particulates and bound molecular or ionic metals. The soil and fine metal particles can be effectively treated with acid leaching. Different extractants may be used depending on the physical and chemical form of the heavy metals and the matrix characteristics.

This handbook provides technical background and guidance for conducting the following activities at outdoor small-arms ranges:

- ☐ Planning and conducting treatability studies of physical separation and acid leaching for processing metals-laden soils at small-arms ranges
- ☐ Determining the effectiveness, implementability, and cost of physical separation and acid leaching
- ☐ Preparing a Statement of Work (SOW) to obtain competitive quotations for range maintenance/remediation
- ☐ Managing and implementing range maintenance/remediation.

1.1 Background

Small-arms ranges in use by the DoD today have been operated for years without a comprehensive policy on preventive range maintenance to address lead and other metals. Because of the inevitable buildup of bullets in impact areas, these ranges are potential source areas for heavy metals accumulation. If left unattended, the metal may be transported into the environment along various pathways, including surface water runoff, groundwater migration, and airborne dust migration. Identification and demonstration of technologies is being pursued to provide cost-effective options with potential for maintaining or cleaning up the more than 2,600 small-arms ranges operated by DoD.

1.2 Scope

This handbook is designed primarily for technically oriented personnel in DoD environmental offices at military facilities, but may provide meaningful information to other military personnel as well. This handbook can help program managers and remedial project managers (RPMs) who manage environmental projects at outdoor small-arms ranges to evaluate the technical strength and cost-effectiveness of proposed maintenance or remediation activities. Additionally, government contractors may find this handbook useful when preparing treatability studies, feasibility studies, and maintenance or remedial action work plans.

The handbook is intended for application to outdoor ranges that support the firing of weapons discharging bullets of 50 caliber or less (e.g., pistols, rifles, submachine guns, machine guns, and shotguns). The handbook is applicable to a wide variety of range configurations, including but not limited to the following types:

☐ Long-distance ranges for high-powered rifles
☐ Short-distance ranges for pistols and battle sight zero (BZO) operations
☐ Ranges for combat training and simulation
☐ Trap and skeet ranges for shotguns.

More detail on range configuration is provided in a Military Handbook (DoD, 1992). The main elements of interest are lead, copper, zinc, antimony, and arsenic. For convenience, the general term metals will be used for these elements. However, it should be noted that, strictly speaking, antimony and arsenic are metalloids. Cleanup of indoor ranges is not covered by this handbook. Armor-piercing bullets containing depleted uranium are not discussed. Impact areas for explosive ordnance, such as artillery, mortar, tank, and air-to-surface missile projectiles, also are not discussed.

2.0 Small-Arms Range Characteristics

The detailed arrangement of small-arms ranges varies widely depending on the local topography and the mission of the range, but there are many features which are common. This section outlines background information about physical and environmental conditions at small-arms ranges to provide a baseline for evaluating the conditions at the range under consideration for maintenance or remediation.

2.1 Composition of Small-Arms Projectiles

As shown in Figure 2-1, a typical round of ammunition consists of a bullet, a cartridge case containing the propellant, and a primer to ignite the propellant. There are a number of bullet types, as shown in Figure 2-2. Bullets may be bare lead alloy or lead alloy with an outer metal jacket, or special-purpose bullets containing a core or filling material. Some jacketed bullets are used for antipersonnel and armor-piercing roles. Jacketed bullets used in rifles, called "penetrator rounds," have a small iron tip. The unjacketed or Abare™ lead is used in shot for shotgun shells and bullets in .22 caliber rim fire ammunition and in many revolver cartridges. Filled bullets are used for special applications, such as tracer or incendiary ammunition.

The bullet or ball is usually made of a lead alloy with antimony added to increase hardness or improve other properties. Traces of copper or tin may also be present (Ross, 1980). Table 2-1 presents the composition of lead alloys used in bullet making.

Metal-jacketed bullets are used in high-velocity and automatic weapons, such as M16 rifles and M60 machine guns. The outer metal jacket is usually either copper-plated or covered with a thin layer of gilding metal. Various grades of gilding metals used as bullet jackets have copper and zinc as their major components (Table 2-2). Jacketed bullets have been shown to reduce the amount of airborne lead particulate (Juhasz, 1977), but the bullet may shatter upon impact, exposing the lead core. Metals of significant mass fraction in a bullet are lead, copper, zinc, and antimony. Arsenic may be present in ranges where shot gun pellets are used because arsenic is added to the shot to improve roundness.

Filled bullets (i.e., tracer munitions) are used to provide an effective means of determining the direction of fire for rapid firing of small-arms. When used in machine guns, filled bullets are belted in a predetermined sequence. Tracers are generally made up of chemical compounds of strontium and magnesium. Typical chemical compositions of igniters and tracers for small-arms are given in Table 2-3.

In addition to the bullet, the ignition system primer may be a possible source of metals accumulation in the soils. Primer compounds for small-arms ammunition are generally mixtures of lead styphnate and barium nitrate.

Disks called "clay pigeons" are used as targets at trap and skeet shotgun ranges. These targets accumulate in the shotfall area as broken rubble. The target disks are made from mineral powder (e.g., dolomite limestone) held together with a petroleum pitch binder similar to asphalt cement used in paving. The target disks typically contain about 67% limestone, 32% pitch, and 1% fluorescent paint. The concentration of polycyclic aromatic hydrocarbons (PAHs) in a disk is about 1,000 mg/kg (Baer et al., 1995).

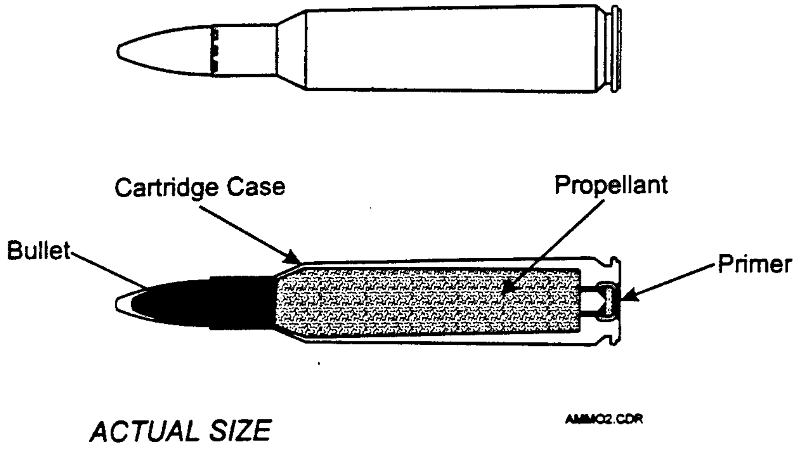


Figure 2-1. Main components of center-fire ammunition

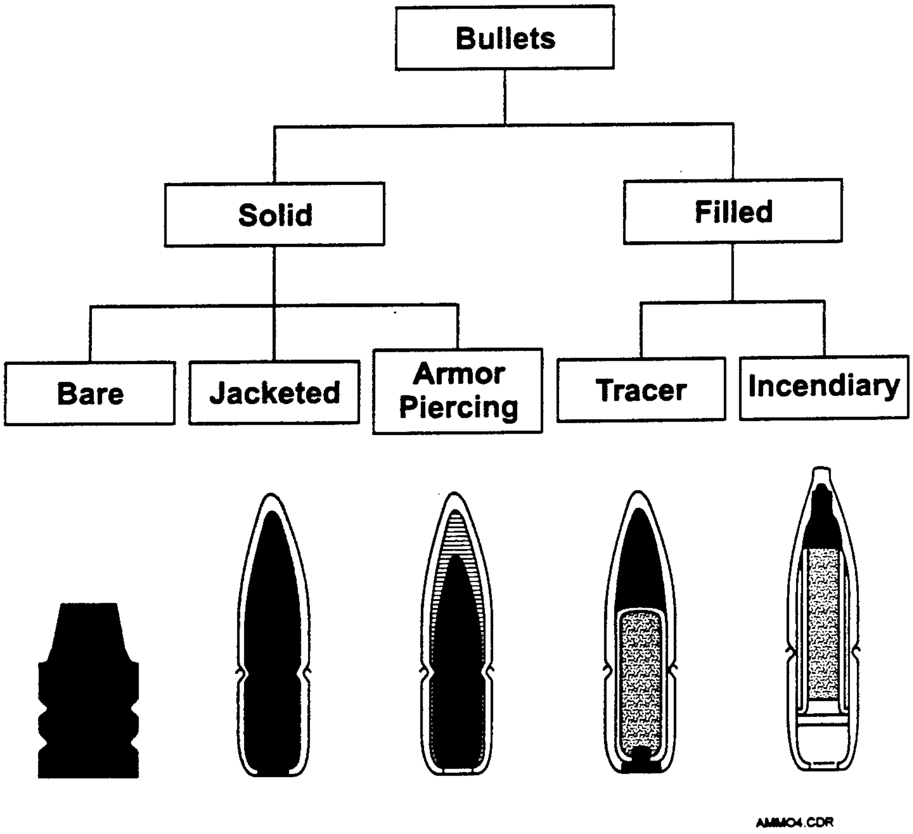


Figure 2-2. Example small-arms bullet types

Table 2-1. Typical Composition of Bullet Core Alloys

Element	Grade 1[a]	Grade 2[a]	Grade 3[a]	Typical Alloy[b]
Lead and antimony minimum (wt%)	99.2	99.2	99.2	Balance lead
Antimony (wt%)	1.0 - 2.5	9.0 - 10.5	9.0 - 9.1	0.5 - 12
Tin (wt%)	No data	No data	No data	0.25 - 1.0
Copper maximum (wt%)	0.1	0.1	0.1	No data

(a) MIL-L-13283B(MR). Source: Fedoroff and Sheffield, 1975, p. L7.
(b) Source: Archer and Carapella, 1995.

Table 2-2. Typical Composition of Bullet Jacket Alloys

Element	ASTM B-130 Brass[a]	95/5 Brass Gilding Metal[b]	90/10 Gilding Metal[b]
Copper (wt%)	89.0 - 91.0	94 - 95	89 - 91
Lead maximum (wt%)	0.05	0.03	0.03
Iron maximum (wt%)	0.05	0.05	0.05
Zinc (wt%)	Remainder	5 - 6	9 - 11

(a) ASTM Standard Specification for Commercial Bronze Strip for Bullet Jackets.
(b) Fedoroff and Sheffield, 1974, p. G74.

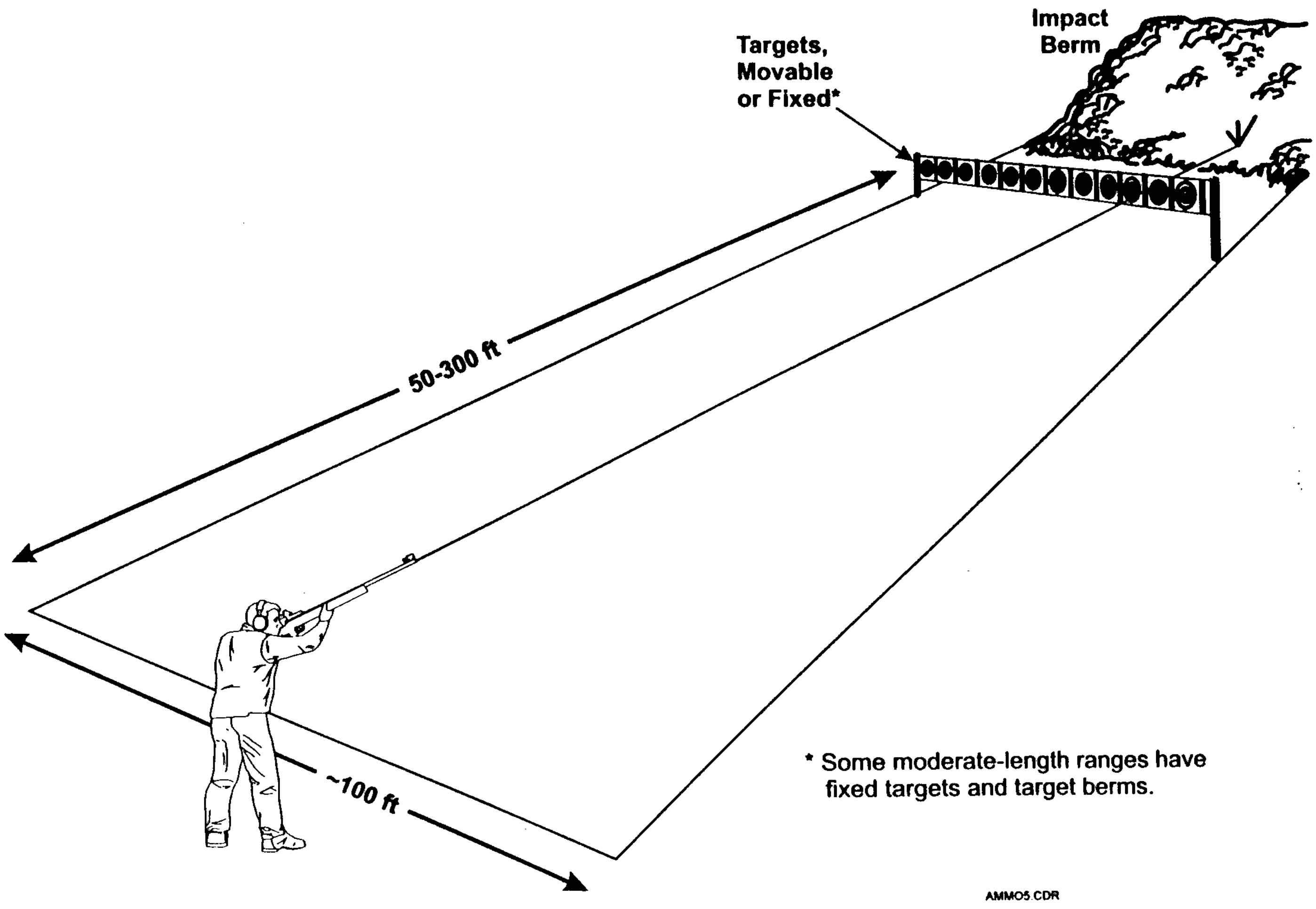
Table 2-3. Typical Formulations for Igniters and Tracers

Compound	Delayed Action Igniter, I-136	Dim Igniter, I-194	Bright Igniter, I-276	Red Tracer, R-257	Fumer, R-284
Strontium peroxide	90	85	C	C	C
Magnesium	C	6	15	28	28
Calcium resinate	10	9	C	4	C
Barium peroxide	C	C	83	C	C
Zinc stearate	C	C	1	C	C
Toluidine red	C	C	1	C	C
Strontium nitrate	C	C	C	40	55
Strontium oxalate	C	C	C	8	C
Potassium perchlorate	C	C	C	20	C
Polyvinyl chloride	C	C	C	C	17

Source: Kaye, 1978, p. P510.

2.2 *Configuration of Small-Arms Ranges*

The configuration of small-arms ranges varies widely, but most ranges have a firing line, a target line, an impact berm or area, and an overflight area. Long-range rifle and automated ranges may have a low berm in front of the targets to protect target mechanisms or spotters. The distance from the firing line to the target line is normally 50 to 300 feet for basic small-arms ranges and up to 2,000 feet for long-range rifle ranges. Impact berms vary in height from 5 feet to as high as 50 feet. Figures 2-3 and 2-4 show example configurations for small-arms and long-range rifle ranges. These figures are general illustrations of main features of ranges, but the implementations vary significantly at actual ranges. For example, a berm in front of the line of targets may be present or absent at small-arms or long-range rifle ranges. Combat or assault training ranges have pop-up targets at varying angles and distances in each lane or may require the shooter to move along a trail with pop-up targets.



* Some moderate-length ranges have fixed targets and target berms.

Figure 2-3. Main features of an example small-arms range

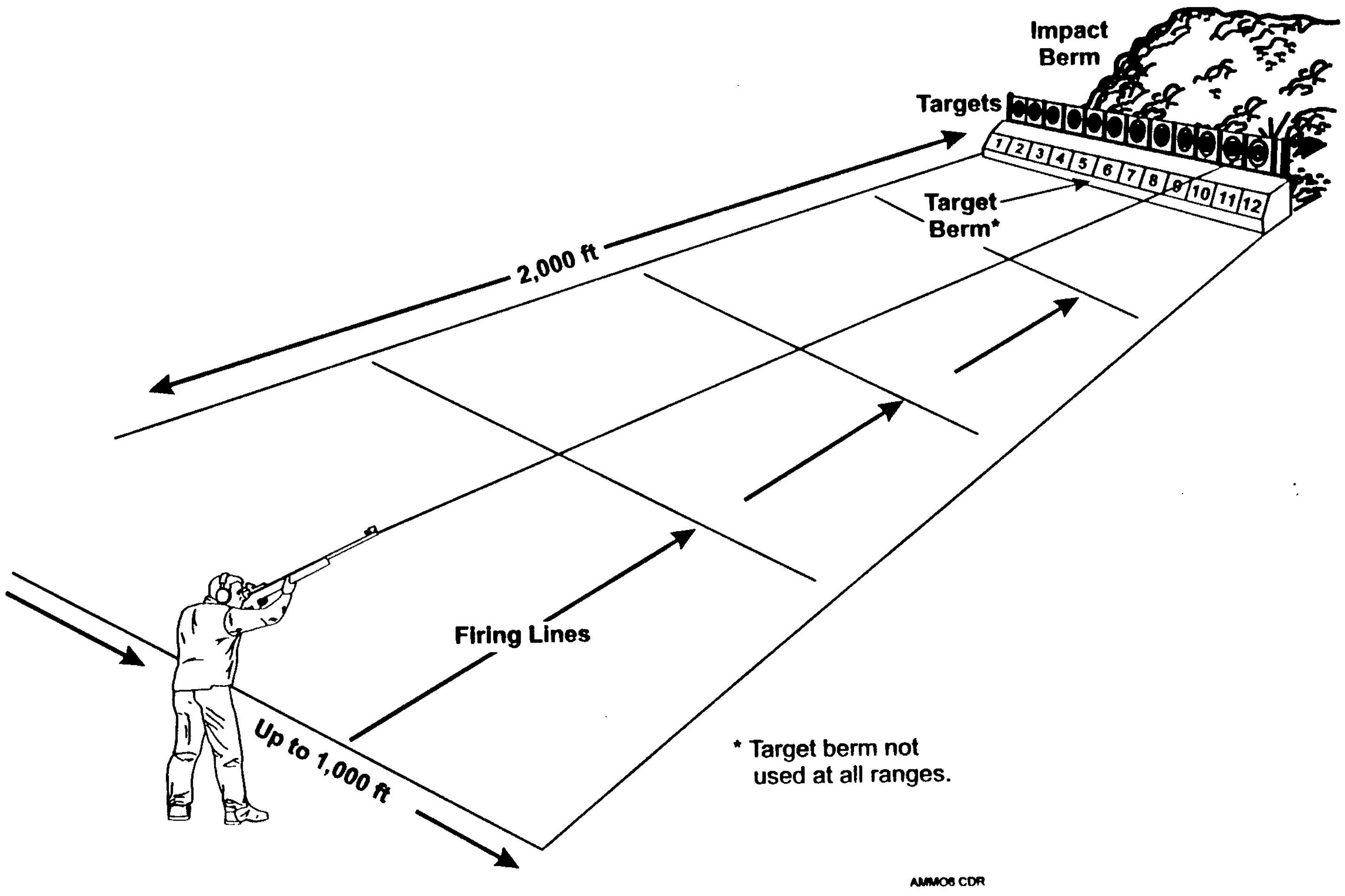


Figure 2-4. Main features of an example long-range rifle range

Trap and skeet ranges do not have impact berms. Clay disk targets (clay pigeons) are discharged from houses at the sides (skeet shooting) or center (trap shooting) of the range at random angles. Firing at the clay pigeons results in a generally uniform distribution of shot spanning about 150° (for skeet ranges or combined trap and skeet ranges) or about 95° (for trap ranges) across in front of the firing position for about 300 yd beyond the firing position (Whiting, 1989). The general arrangement of a combined trap and skeet range is shown in Figure 2-5.

2.3 Environmental Conditions at Small-Arms Ranges

Ricochet problems often result from the buildup of compacted bullets and bullet fragments in bullet pockets. Currently practiced solutions for the ricochet problem include the following:

☐ Removing and replacing the berm with clean soil
☐ Adding a clean layer of soil to the face of the berm
☐ Removing large projectiles by screening and returning the soil to the berm
☐ Abandoning the berm.

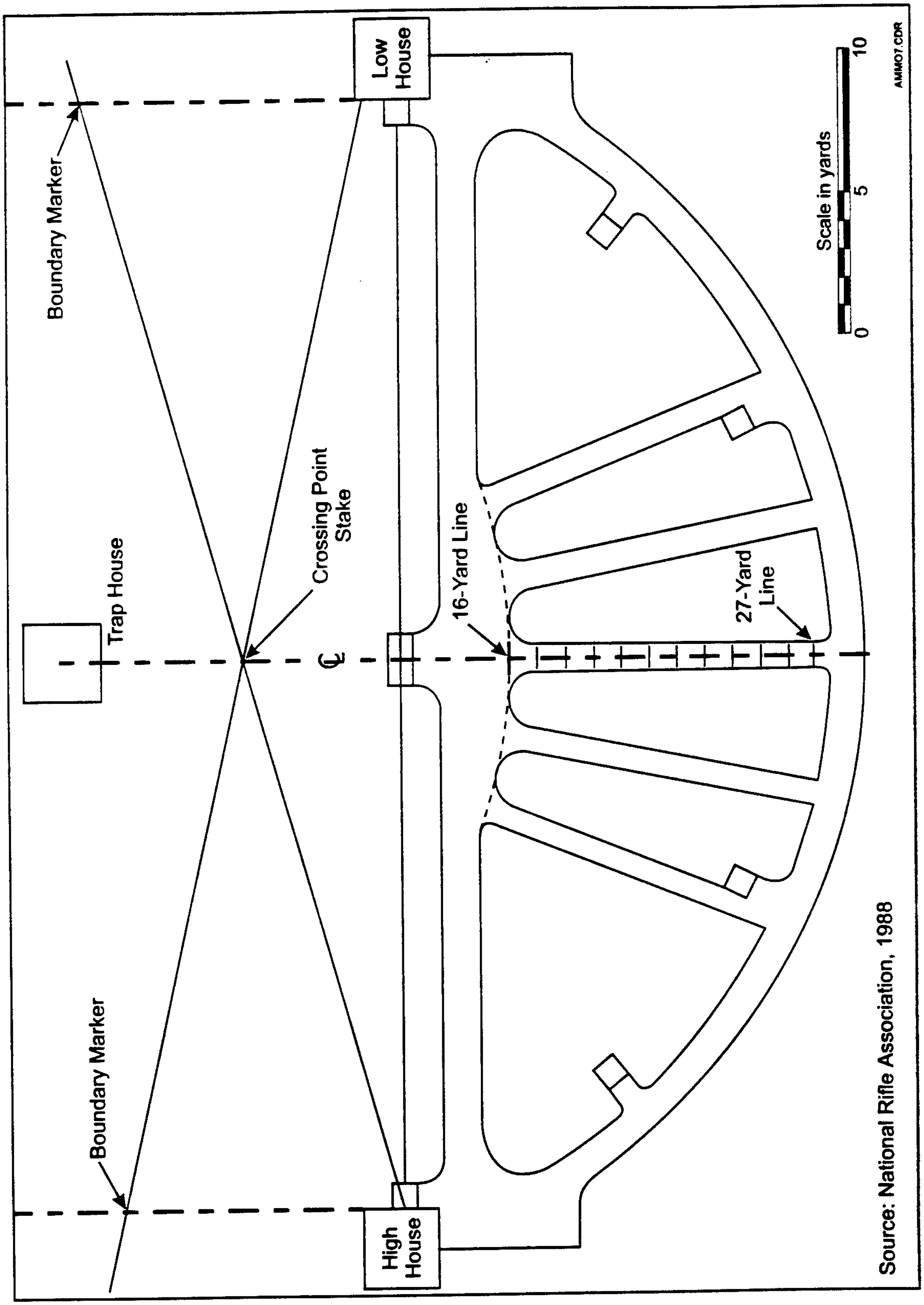
Berms often are surrounded by a halo of lead accumulation in surface soils and plants, particularly along runoff pathways.

Projectiles impacting the berm or shotfall area enter the environment as elemental metals. Some bullets may remain largely intact, but a considerable amount of metal particulate is generated by shock and abrasion on impact with the soils. Shotgun shot, pistol bullets, and rifle bullets impact the berm or soil at different velocities. The low-impact velocity of shot does not cause fragmentation. Pistol bullets strike the berm with enough energy to cause some fragmentation. Rifle bullets impact at the highest velocity and often generate a significant fraction of fine particulate.

After entering the environment, the bullet metals — lead, copper, zinc, antimony, and possibly arsenic — interact with the soil constituents and water. In soil and sediment, metals are dissolved in soil solutions, held on inorganic soil constituents through adsorption or ion exchange, complexed with insoluble soil organic matter, and precipitated as pure or mixed solids (Gavini, et al., 1995; Mellor and McCartney, 1994). Lead concentrations along the face of small-arms range impact berms typically are in the range of 100 to 10,000 mg/kg with concentrations reaching as high as 50% in bullet pockets.

The metals also may be dissolved in surface water or carried with sediment in surface water. Some surface water containing dissolved metals infiltrates into the soil. This soil moisture may be taken up by plants or may carry dissolved metals as it moves through the vadose zone or a perched aquifer on its way down to the water table.

Personnel from the Naval Facilities Engineering Service Center (NFESC), formerly the Naval Civil Engineering Laboratory, have studied metals in the impact berms at two Naval small-arms ranges (Karr et al., 1990; Karr, 1990). Soil samples from 1- to 2-inch depth and from 4- to 6-inch depth horizons as well as vegetation samples were collected from the face and top of the berm. The samples were analyzed for lead, copper, and zinc content, and the results are summarized in Table 2-4. The lead concentrations in soils at both sites and from both depths are higher than the control samples taken at the same depths and higher than the lead concentrations normally found in soils. The copper and zinc concentrations were above those in control samples, but fall within the range of concentrations found in natural settings. Samples taken from a drainage ditch running away from the berm at one range indicated possible transport of lead carried in surface water runoff either sorbed on sediment or as fine particulate.



Source: National Rifle Association, 1988

Figure 2-5. Main features of an example combined trap and skeet range

Table 2-4. Total Metal Concentrations in Impact Berm Soil and Vegetation at Two Small-Arms Ranges

	Pb (mg/kg)	Cu (mg/kg)	Zn (mg/kg)
Soil 1- to 2-in. depth			
Sample - mean	3,860	348	68
Sample - range	15.1 to 23,200	1.9 to 1,619	1.3 to 294
Control - range	4.8 to 37.0	2.9 to 10.3	3.2 to 40.2
Soil 4- to 6-in. depth			
Sample - mean	1,233	240	70
Sample - range	7.2 to 8,421	2 to 1,139	1.5 to 294
Control - range	5.0 to 103	2.2 to 121	1.7 to 91.0
Vegetation			
Sample - mean	59.9	11.7	50.0
Sample - range	20 to 265	6.5 to 26.1	21.2 to 111.5
Control - range	0.7 to 2.0	3.8 to 13.2	32.2 to 152

Source: Karr et al., 1990 and Karr, 1990.

The toxicity characteristic leaching procedure (TCLP) leachable lead content of soil from the bullet pocket at one range was found to be as high as 18.6 mg/L. This concentration is higher than the toxicity characteristic limit of 5.0 mg/L.

The U.S. Geological Survey sampled soil and groundwater around a small-arms range at Shaw Air Force Base, Sumter, South Carolina in October 1991 (Landmeyer, 1994). A wide range of pistol, rifle, and shotgun ammunition was expended at the range. The berm operated from 1967 to 1986, when it suffered storm damage. The berm then was moved 150 ft to the north and reformed. The moving operation resulting in mixing of the berm soils. Soil sampling results are summarized in Table 2-5. Samples collected from four wells in the shallow aquifer (water table about 10 ft below ground surface) indicated that total trace metal concentrations were at or below detection limits.

Table 2-5. Total Metal Concentrations in Impact Berm Soil at Shaw Air Force Base

	Lead Content in Soil at Depth Intervals (mg/kg)					
Sample Location	**0' to 0.5'**	**1' to 1.5'**	**3' to 3.5'**	**5' to 5.5'**	**9' to 9.5'**	**13' to 13.5'**
Berm Top	12,500	2,410	94	384	3,630	No data
Berm Face	2,790	No data	6,040	5,380	No data	No data
Berm Toe	4,920	No data	16.2	No data	15.2	3.02

Source: Landmeyer, 1994.

Samples were collected and analyzed at two U.S. Army small-arms ranges, Range 122 and Range 124, at the Grafenwöhr Training Area in Germany (Zellmer and Schneider, 1993). Range 122 is a pistol range with 10 firing points and a 23-foot-high earthen berm located about 180 feet from the firing line. Range 124 is used for checking the sight setting for rifles. There are 10 pads for firing from the prone position and 10 pits for firing from simulated foxhole positions. A 10-foot-high earthen berm is located about 120 feet from the firing pads. The results for total metals and TCLP extractable metals are shown in Tables 2-6 and 2-7, respectively.

Table 2-6. Total Metal Concentrations in Soils from Two Small-Arms Ranges at the Grafenwöhr Training Area, Germany

Sample Location	Sample Depth (cm)	Total Metal Concentration (mg/kg)			
		As	Cu	Pb	Zn
Range 122					
Behind target	0 to 15	BDL(a)	146	398	48.2
Behind target	15 to 30	BDL(a)	28.6	41.2	26.0
Bullet pocket	0 to 15	BDL(a)	57.0	123	23.8
Berm	0 to 15	BDL(a)	51.1	55.0	30.2
Background	15 to 30	BDL(a)	23.7	31.6	23.0
Sediment	Surface	BDL(a)	32.6	314	72.7
Range 124					
Bullet pocket	0 to 15	19.4	271	7,870	77.6
Bullet pocket	15 to 30	145	798	126,000	125
Berm	0 to 6	BDL(a)	6,420	4,800	700
Bullet pocket	0 to 6	BDL(a)	13,200	13,600	1,350
Back of berm	15 to 30	BDL(a)	29.9	1,800	105
Sediment	Surface	BDL(a)	35.0	648	39.6

(a) BDL = below detection limit.

Source: Zellmer and Schneider, 1993.

Table 2-7. Metal Concentrations in TCLP Extracts from Soils from Two Small-Arms Ranges at the Grafenwöhr Training Area, Germany

Sample Location	Sample Depth (cm)	Metal Concentration (mg/L)		
		Cu	Pb	Zn
Range 122				
Behind target	0 to 15	0.42	1.89	0.26
Behind target	15 to 30	0.04	0.03	0.02
Bullet pocket	0 to 15	0.38	1.01	0.14
Berm	0 to 15	0.22	BDL	0.13
Background	15 to 30	BDL(a)	BDL	BDL
Sediment	Surface	0.06	0.56	0.05
Range 124				
Bullet pocket	0 to 15	1.80	222	0.69
Bullet pocket	15 to 30	4.85	678	1.18
Berm	0 to 6	4.01	361	0.73
Bullet pocket	0 to 6	3.63	451	0.84
Back of berm	15 to 30	0.44	51.2	0.43
Sediment	Surface	0.16	12.7	0.05
TCLP Limit	NA(b)	NA(b)	0.5	NA(b)

(a) BDL = below detection limit.

(b) NA = not applicable.

Source: Zellmer and Schneider, 1993.

Personnel from the U.S. Army Corps of Engineers (USACE) Waterways Experiment Station surveyed rifle ranges at Fort Ord, California as part of a study of metals at U.S. Army facilities. A series of ranges at the site were heavily used during the eras of World War II and the Vietnam conflict. Berm soils contained significant lead particulate ranging from whole bullets to fine fragments. The TCLP leachate from soils in the berm contained more than 1,000 mg/L lead (Bricka et al., 1994).

In general, the shot used at trap and skeet ranges is distributed on the surface of the soil over an area out to about 300 yards from the firing point. The shot remains near the surface, unless range maintenance activities disturb the soil. The distribution of lead in shotgun range soil was measured at three ranges in Denmark by Jørgensen and Willems (1987). The characteristics of the ranges are described in Table 2-8, and the results for the areal density of lead shot and the lead concentration of soil after the shot was removed are shown in Table 2-9.

Table 2-8. Characteristics of Shotgun Ranges in Danish Study

Characteristic	Stenlille	Holstebro	Parup
Soil type	Sandy loam	Coarse sand with strongly developed leach zone	High organic
Rainfall (mm/yr)	600	750	550
Runoff (mm/yr)	200	350	200
Age of range (yr)	26	12	13
Shot loading (kg/yr)	1,200	240	5,500
Soil organic content (wt%)	2.3	8.0	38.1
Soil pH	5.5	3.5	5.5
Soil CEC[(a)] (m_{eq}/g)	11.3	8.0	96
Comments	Plowed at least once per year	Not applicable	Not applicable

(a) CEC = cation exchange capacity

Source: Jørgensen and Willems, 1987.

Table 2-9. Total Lead Concentration in Soils from Shotfall Areas in Danish Study

Sample Depth (cm)	Concentration of Pellets (g/m^2)	Lead in Soil After Pellets are Removed	
		Shotfall Area (mg/kg)	Control Area (mg/kg)
Stenlille			
0 to 5	370	1,000	7
5 to 10	454	965	7
10 to 15	462	965	6
15 to 20	421	715	7
20 to 25	105	15	7
25 to 35	0	4	2
35 to 50	0	5	1
Holstebro			
0 to 9	531	274	9
9 to 15	0	<1	5
15 to 20	0	<1	2
Parup			
0 to 8	830	615	12
8 to 14	52	138	12
14 to 20	0	28	12
20 to 27	0	20	11
27 to 35	0	7	11
35 to 50	0	4	<1

Source: Jørgensen and Willems, 1987.

3.0 Regulatory Issues

The following regulations need to be addressed for the application of physical separation/acid leaching technologies to small-arms range maintenance or remediation activities:

- ☐ National Environmental Policy Act (NEPA)
- ☐ Resource Conservation and Recovery Act (RCRA)
- ☐ Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
- ☐ U.S. Environmental Protection Agency's (EPA's) Military Munitions Rule (40 Code of Federal Regulations [CFR] Part 260) and the DoD's Military Range Rule (Deliberative Draft of 32 CFR Part 339)
- ☐ Emergency Planning and Community Right-to-Know Act (EPCRA)
- ☐ Clean Water Act (CWA)
- ☐ Safe Drinking Water Act (SWDA)
- ☐ Clean Air Act Amendment (CAAA)
- ☐ Occupational Safety and Health Act (OSHA)
- ☐ State and local regulations (e.g., Title 22, California Code of Regulations).

The level of regulatory and administrative oversight depends on whether berm soil processing activities are carried out as range maintenance (at active ranges) or range remediation (at inactive ranges or under conditions of eminent danger to public health or the environment).

3.1 *National Environmental Policy Act (NEPA)*

NEPA must always be considered when dealing with small-arms range maintenance and remediation activities, because a blanket statement cannot be made as to the potential environmental impact on range maintenance/remediation activities. Instead, each site-specific application must be evaluated. However, it may be possible to fulfill NEPA requirements by applying a Categorical Exclusion (CATEX) with a Record of Environmental Consideration (REC), as described in Chapter 4 of Army Regulation (AR) 200-2, because of the limited scope of many range maintenance or remediation projects.

3.2 *Resource Conservation and Recovery Act (RCRA)*

RCRA, which regulates the classification, treatment, storage, and disposal of solid and hazardous waste, has the single greatest potential impact on this technology type because the lead in the soil could be categorized as a RCRA characteristic hazardous waste. In order to clarify this issue, both the U.S. EPA and the DoD have released draft procedural rulings. The U.S. EPA finalized their proposed "Military Munitions Rule" on February 12, 1997 (40 CFR Part 260). It clarified the issue of hazardous waste identification and management for military munitions, including small-arms ranges. It addressed issues beyond the scope of range maintenance and provided regulatory tools to allow the military services to largely manage their munitions cradle to grave without having to subscribe to the cumbersome RCRA hazardous waste management standards. Moreover, it recognized the military as being the subject matter experts in this area, and would recognize DoD precedence in such matters if and once the DoD issued their own proposed standards via a set of regulations.

The DoD responded to the EPA draft ruling on March 19, 1996, with their proposed "Military Range Rule." Both the final U.S. EPA and proposed DoD rules indicate that if maintenance activities occur on site at an "active" small-arms range, the soil is not considered a RCRA hazardous waste, although all states may not recognize this. Personnel working with small-arms ranges need to carefully review these rulings and ensure that they understand the concepts of "on site," "active," "inactive," and "closed." In this report, the term *maintenance* is used to describe activities that do not fall under the RCRA regulations, while those that do are referred to as *remediation*. RCRA hazardous waste may be generated during processing activities, and wastes such as used personal protective equipment (PPE), organic materials, and process water will have to be managed following the full RCRA protocols.

Recycling lead-bearing materials from a small-arms range maintenance or remediation project is a cost-effective and environmentally protective approach. The total cost of shipping to and processing at a recycling center will be competitive with disposal at a RCRA-permitted treatment, storage, and disposal (TSD) facility, but recycling has the following added advantages:

- The material returns to a beneficial reuse and does not become a waste.
- Potential future liability is minimized because the recovered lead forms a commercial product. Some liability may remain, however, if hazardous byproducts result from recycling process slag.
- Recycling reduces a variety of regulatory requirements, such as manifesting waste in accordance with RCRA requirements and reporting transfers in accordance with Superfund Amendments and Reauthorization Act (SARA) Title III requirements.

The recycling operation will not result in a net profit because of both the low concentration of lead in the wastestreams and the cost of shipping. Bullets removed from the small-arms range soil by physical separation typically contain 30 to 60% lead. The precipitate that results from the treatment of the acid leaching solution typically contains 1 to 5% lead. A lead recycler will charge a tolling fee to process material with a lead content below about 95%. Costs to transport the recovered lead-bearing materials from the site to the recycling facility must also be paid.

Recycling the lead-bearing materials must be done in a careful and responsible manner. The materials must be compatible with the requirements of the recycling facility. Potential recyclers should be contacted during the early stages of project planning to determine the availability and capability of their facilities as well as reliability regarding waste management and other liability issues. Typically, facilities require a sample of the material to allow compatibility testing in their laboratory. During the Fort Polk demonstration (Battelle, 1997a), some of the materials could not be recycled as planned, even though the lead content was typical of and similar to that in materials that were successfully recycled.

RCRA does not specify cleanup levels for lead in soil. These levels are determined on a site-specific basis with approval by the authorized regulatory agency, usually the state or the regional EPA. Determination of appropriate soil lead levels often is difficult and must consider numerous factors. Therefore, on July 14, 1994, the U.S. EPA issued guidance (*Revised Interim Soil Lead Guidance for CERCLA Sites and RCRA Corrective Action Facilities*, OSWER Directive 9355.4-12) providing a streamlined approach for determining protective cleanup levels for lead in soil at CERCLA sites and RCRA facilities subject to corrective action under RCRA Section 3004(u) or 3008(h). The guidance is intended to provide more consistent decisions nationwide and to improve the use of site-specific information for RCRA and CERCLA sites contaminated with lead.

The main components of this guidance are as follows:

- The OSWER directive recommends a screening level for lead in soil for residential land use of 400 mg/kg, not as a cleanup goal but rather as a tool to determine which sites or portions of sites do not require further study and to encourage voluntary cleanup. Lead levels above the screening level would not automatically require a removal action or cause a site to be designated as contaminated.

☐ The OSWER directive describes how to develop site-specific preliminary remediation goals (PRGs) at CERCLA sites and media cleanup standards (MCSs) at RCRA Corrective Action Facilities for residential land use. Risk-based PRGs and MCSs can be developed using the IEUBK model.

☐ The directive describes a plan for soil lead cleanup at CERCLA sites and RCRA Corrective Action facilities that have multiple sources of lead.

3.3 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly referred to as Superfund, was enacted on December 11, 1980. The purpose of CERCLA was to provide authorities the ability to respond to uncontrolled releases of hazardous substances from inactive hazardous waste sites that endanger public health and the environment. CERCLA established prohibitions and requirements concerning closed and abandoned hazardous waste sites, provided for liability of persons responsible for releases of hazardous waste at such sites, and established a trust fund to provide for cleanup when no responsible party could be identified. In addition, CERCLA provided for the revision and republishing of the National Contingency Plan (NCP, 40 CFR Part 300) that provides the guidelines and procedures needed to respond to releases and threatened releases of hazardous substances, pollutants, or contaminants. The NCP also provides for the National Priorities List, a list of national priorities among releases or threatened releases throughout the United States for the purpose of taking remedial action.

The Superfund Amendments and Reauthorization Act (SARA) amended CERCLA on October 17, 1986. This amendment had several key features:

☐ Increased the size of the Hazardous Response Trust Fund to $8.5 billion
☐ Expanded EPA's response authority
☐ Strengthened enforcement activities at Superfund sites
☐ Broadened the application of the law to include federal facilities.

In addition, new provisions were added to the law that dealt with emergency planning and community right-to-know. SARA also required EPA to revise the Hazard Ranking System (HRS) to ensure that the HRS accurately assesses the relative degree of risk to human health and the environment posed by sites and facilities subject to review for listing on the NPL.

3.4 Emergency Planning and Community Right-to-Know Act (EPCRA)

EPCRA was promulgated to establish emergency planning criteria and ensure that communities are informed about hazardous materials in their areas. The EPCRA requires facility owners who accumulate hazardous materials in excess of threshold planning quantities (TPQs) to report such presence to local fire-fighting and emergency response agencies. If the separation and leaching technology uses hazardous materials (e.g., acids, etc.) in amounts that exceed these limits, it will require reporting interaction with the installation's Environmental Management staff.

3.5 Clean Water Act (CWA)

The CWA sets standards and requirements for pollutant discharge. The National Pollutant Discharge Elimination System (NPDES) (40 CFR Parts 122 and 125) requires permits for the discharge of pollutants from any point source into the waters of the United States. General pretreatment regulations are enforceable standards promulgated under 40 CFR Part 403 for discharge to a publicly owned treatment works (POTW) and could be applicable or relevant and appropriate requirements (ARARs) if surface or groundwater remediation results in discharge to a POTW. The CWA also applies to the physical separation/acid leaching technology. The leaching or soil washing element eventually will generate contaminated wastewater. The processing plants employed in this demonstration used closed loops and make-up water, but the final water discharge had to be disposed of in a proper manner. Under most circumstances, such water may not be allowed into a storm sewer system. Some installation wastewater treatment plants may be capable of handling such wastewater, but others may not. The wastewater handling issue needs to be dealt with in accordance with the local wastewater treatment plant's capability and NPDES permit requirements. An equally important consideration is the surface runoff that will be generated from the wet processing involved in this technology. Special care must be taken to implement both spill prevention, control, and countermeasures plans, as well as stormwater pollution prevention plans.

During the Fort Polk demonstration (Battelle, 1997a), the nonrecycled wastewater was treated and tested to meet the acceptance criteria for the base wastewater treatment plant. If the wastewater met the criteria, it was discharged to the sewer leading to the wastewater treatment plant. If not, it was hauled away by a licensed hazardous waste disposal contractor. If the precipitation step of the leaching plant is carried out effectively, most of the wastewater can be discharged to the sewer.

3.6 Safe Drinking Water Act (SDWA)

The SDWA was passed in 1974 and has been amended several times to expand both its breadth and the EPA's power to enforce it. The Act's primary purpose is the protection of drinking water systems by:

- ☐ Establishing quality standards for drinking water
- ☐ Monitoring public water systems
- ☐ Guarding against groundwater contamination from injection wells.

The SWDA promulgated both the National Primary Drinking Water Regulations (40 CFR Part 141) and National Secondary Drinking Water Regulations (40 CFR Part 143). Primary MCLs are enforceable standards for contaminants in public drinking water supply systems. Primary MCLs are set with regard to health factors and the economic and technical feasibility of removing a contaminant from a water supply system. Secondary MCLs are intended as guidelines to protect the public welfare. Contaminants covered by secondary MCLs are those that may adversely affect the aesthetic qualities of drinking water such as taste, odor, color, and appearance, which may deter public acceptance of drinking water from public water systems.

Maximum contaminant limit goals (MCLGs) exist for several organic and inorganic compounds found in drinking water. MCLGs are nonenforceable guidelines that consider only health factors. MCLs or MCLGs may be used to determine remedial actions for any surface water or groundwater that is a current or potential source of drinking water. The NCP requires that MCLGs set at levels above zero (i.e., non-zero MCLGs) be attained during a CERCLA cleanup. In cases where the MCLG equals zero, the corresponding MCL is applicable [40 CFR 300.430(e)(2)(i)(B) and (C)]. Underground injection control regulations (40 CFR Parts 144-147) are designed to protect underground drinking water sources. These regulations may apply if the remedial design includes reinjection of water.

3.7 Clean Air Act Amendment (CAAA) and Occupational Safety and Health Act (OSHA)

The CAAA was promulgated to establish standards and methods to reduce air pollution. Portions of the CAAA that may influence maintenance or remediation at small-arms ranges include the following:

- ☐ National Ambient Air Quality Standards (NAAQS) apply to total suspended particulate, sulfur dioxide, nitrogen dioxide, carbon monoxide, ozone, and lead concentrations in ambient air and are not applicable to individual emission sources. "Prevention of significant deterioration" (PSD) regulations may apply preconstruction guidelines and monitoring to statutory sources.

- New Source Performance Standards (NSPS) were developed for specific industrial categories to provide a ceiling for emissions from new sources.
- National Emission Standards for Hazardous Air Pollutants (NESHAPS) regulate asbestos, beryllium, mercury, vinyl chloride, coke oven emissions, benzene, radionuclides, and inorganic arsenic.

The CAAA has two major issues associated with this type of technology: the potential for acid fumes in the ambient atmosphere, and the presence of lead dust above the allowable limit. Perimeter monitoring was used during the demonstration to evaluate fume and dust potential for OSHA-type concerns. This is important, as it affects the level of PPE that workers must wear. If PPE requirements go above Level D, work efficiency may decrease and project costs will increase. Lead exposure in construction is addressed in 29 CFR 1926.62.

3.8 A Discussion of the Regulatory Issues at Small-Arms Ranges

Currently, the DoD ranges do not have a cohesive range maintenance program for processing berm soil containing spent bullets and shot. Most efforts have been directed toward safety issues related to clearing unexploded ordnance. Only with matters related to Formerly Used Defense Site (FUDS) and Base Realignment and Closure (BRAC)-driven requirements, influenced by RCRA, have range maintenance and remediation become items of interest. The two principal methods of remediation in the past have been (1) excavation, hauling, and landfilling; and (2) stabilization.

Excavation, hauling, and landfilling can be expensive for larger berms, and does not provide a long-term solution. In fact, it is possible that former owners may become potentially responsible parties (PRPs). Stabilization is more cost-effective with regard to capital costs, but it limits other future beneficial land uses. Considering current defense installation realignments and the many installation closures, on-site stabilization and reuse is not a workable solution at many locations. The physical separation/acid leaching technology can potentially provide a cost-effective long-term alternative, and is expected to be attractive to site managers and regulators.

From a regulatory standpoint, the principal heavy metal of concern in the range soil is lead. Lead can exhibit RCRA waste characteristics based on toxicity. Concern over this has driven all the deliberations on the subject of range remediation. If the soluble lead concentration in the soil as determined by the TCLP test exceeds the criterion of 5 mg/L, reuse of the land for other beneficial purposes is severely restricted. Range soils contain other metals of concern as well. Copper, zinc, and antimony are present in many types of bullets and are regulated in some states such as California.

The combination of physical separation and acid leaching can significantly remove both particulate and ionic lead. This technology has great potential for widespread application nationwide. Although the TCLP criterion for the processed soil was met at the Fort Polk demonstration, the STLC limit for lead from a Waste Extraction Test (WET) extraction for California hazardous waste designation was not met, as shown in Table 3-1. Passing the California WET was not a goal of this particular demonstration, but sites that are subject to more stringent regulatory requirements may require additional soil processing (with the associated higher cost).

Table 3-1. Leachable Lead Concentrations (Battelle, 1997a)

	TCLP (mg/L)				California WET (STLC) (mg/L)			
Sample No.	**Lead**	**Copper**	**Zinc**	**Antimony**	**Lead**	**Copper**	**Zinc**	**Antimony**
Nov. 22, processed soil	0.47	0.022	0.15	0.68	9.4	2.5	<1	5.1
Nov. 30, processed soil	3.6	0.38	0.30	0.036	19	3.1	<1	2.1
Limits	5.0	N/A	N/A	N/A	5.0	25	250	15

4.0 Technology Description

This section describes the types of equipment and processes used to accomplish physical separation and acid leaching for treatment of metals in soils.

4.1 Physical Separation Processes Descriptions

This subsection provides background information on a variety of commonly used physical separation methods. Physical separation techniques have been used commonly in the chemical and mining industries for many years. These techniques involve the physical separation of particles from each other based on particle characteristics such as size, shape, density, or magnetism. Five classes of physical characteristics provide a practical basis for separating particles:

- Particle size (screening)
- Particle hydrodynamics (settling velocity)
- Particle density (gravity separation)
- Surface properties of particles (flotation)
- Magnetic properties (magnetic separation).

The attributes of these common particle separation techniques are summarized in Table 4-1.

Table 4-1. Key Attributes of Common Particle Separation Techniques

	Technique				
	Size Separation (Screening)	**Hydrodynamic Separation (Classification)**	**Density (Gravity) Separation**	**Froth Flotation**	**Magnetic Separation**
Basic Principle	Various diameter openings allow passage of particles with different effective size	Different settling rates due to particle density, size, or shape	Separation due to density differences	Particles are attracted to bubbles due to their surface properties	Magnetic susceptibility
Major Advantage	High-throughput continuous processing with simple, inexpensive equipment	High-throughput continuous processing with simple, inexpensive equipment	High-throughput continuous processing with simple, inexpensive equipment	Very effective for fine particles	Can recover a wide variety of materials when high gradient fields are used
Limitations	Screens can plug; fine screens are fragile; dry screening produces dust	Difficult when high proportions of clay, silt, and humic materials are present	Difficult when high proportions of clay, silt, and humic materials are present	Particulate must be present at low concentration	High capital and operating cost
Typical Implementation	Screens, sieves, or trommels (wet or dry)	Clarifier, elutriator, hydrocyclone	Shaking table, spiral concentrator, jig	Air flotation columns or cells	Electromagnets, magnetic filters

Sources: U.S. EPA, 1995, EPA/540/R-95/512.

4.1.1 Size Separation

Segregating solids according to particle size, called screening or sieving, is done by passing the solids through a screen formed by a wire mesh with specifically sized openings. The oversize fraction tends to remain on the screen and the undersize fraction tends to pass through, but the separation is not absolute. Larger particles may pass through to the undersize fraction, if the particle shape is highly asymmetric. Smaller particles may be retained in the oversize fraction due to blocking of some screen openings or physical attachment to larger particles. The oversize fraction, if allowed to build up on the screen, can block the openings. Therefore, screens often are sloped to allow the oversize fraction to roll off. Screens can either be stationary or have some motion (shaking, vibrating, or gyrating) to dislodge particles that block the openings.

Screening can be conducted either dry or wet. In dry screening, the soil is placed directly onto the screen without any water addition. In wet screening, the soil is wetted by mixing with water to form a slurry before screening or by spraying water on the screen to dislodge blocking particles.

4.1.1.1 Dry Screening

Screening of dry soil invariably is required at most soil remediation sites, if for nothing else than to remove rocks, branches, or other oversize material from the bulk of the soil. Dry screening is effective on large to intermediate particle size ranges as long as the feed material is essentially dry. However, this condition is rarely satisfied in field operation, where natural moisture makes dry screening difficult below 2 or 3 inches because of clogging. If finer screening is required, the soil must be dried before screening; alternatively, wet screening can be applied.

4.1.1.2 Wet Screening

In soil remediation, caution should be exercised before selecting a wet separation technique, which invariably generates a water stream that must be treated before discharge. Although a dewatering step allows the water to be recirculated, the user is still left with a wastewater stream after the last batch of soil has been treated. The other consideration is that wet separation processes may leave the user with wet soil that is difficult to handle in downstream chemical treatment. Clay soils especially become very difficult to handle and may stick to equipment when wet. Therefore, wet separation should be conducted only after weighing its potential benefits. The following guidelines should be followed in deciding whether or not to use wet separation:

- ☐ Wet separation is most worthwhile if a sizable fraction of the metals is particulate. In that case, wet separation may either render the soil nonhazardous (not requiring further treatment) or reduce the quantity of metal particles to a level where significantly smaller amounts of treatment chemicals are required downstream.
- ☐ Wet separation is worthwhile if the chemical treatment that follows benefits from water addition, e.g., soil washing or heap leaching.

In addition, wet separation could still be beneficial if the metal fraction recovered is recyclable or if downstream chemical treatment requirements are significantly reduced.

4.1.1.3 Attrition Scrubbing

Attrition scrubbers are not really size separation units, but they are often used to pretreat the raw soil feed before size or density separation. Attrition scrubbers break up soil agglomerates into individual particles and "scrub" oxide or other coatings from the particles. Soil scrubbing is accomplished mostly by particle-to-particle abrasion or attrition, but also by the interaction between equipment parts (e.g., paddles or propellers) and the particles. Attrition scrubbers intensively mix and scrub materials with two large-diameter propellers that are oppositely pitched and enclosed in a cell. Baffles are sometimes included in the cells to direct the flow of material. Single- or multiple-cell designs are available for the required throughput.

A log washer consists of an inclined trough that surrounds two shafts fitted with paddles. The incline reduces the transport effect of the paddles and increases the mass weight against the paddles. The paddles are pitched to convey materials to the discharge end against the incline of the trough. The name "log washer" is a misnomer because it implies that the machine is designed to wash logs. The name actually comes from the fact that the first units used to wash sand and gravel incorporated wooden logs as the shafts, with steel paddles set into them. In the aggregate business, the log washer is known best for its ability to remove tough, plastic clays from natural and crushed gravel, crushed stone, and ore feeds.

A blade mill is similar to a log washer in design, and is used to perform the same function. Unlike a log washer, a blade mill has just one shaft. Because of the single-shaft design, a blade mill may impart less energy to the material being washed than a log washer. Log washers and blade mills are designed to handle larger particle sizes than can be accommodated by conventional attrition scrubbers.

4.1.2 Hydrodynamic Separation (Classification)

Hydrodynamic separation, or classification, is a technique of separating particles into two or more fractions based on the velocity of particles moving through a viscous fluid. A particle's velocity in the fluid is determined by the particle's size, density, and shape. Separation often is enhanced by keeping the fluid in motion in a direction (upward) opposite to that of the falling particles.

When the particle size falls below that required for efficient screening (usually about 200 µm), classification is used. As with screening, separation by classification depends on particle size; however unlike screening, classification also depends on particle density. Wet classifiers (hydroclassifiers) are more common than air classifiers. Classifiers operate over a wide range of particle sizes. Large elutriators have been used in the past to separate lead particles (from car batteries) several millimeters in diameter from junkyard waste. Other classifiers, such as spiral classifiers and settling cones, are used for desliming, i.e., removing very fine particulates from a slurry. The hydrocyclone classifier efficiently separates very fine particles and has been used to deslime, degrit, and dewater (thicken). Hydrocyclones most commonly are used on particles in the 150- to 5-µm size range, although coarser materials can be separated. Hydrocyclones are relatively small, inexpensive devices. A cyclone bank (group of cyclones in parallel) is used for higher capacities.

4.1.2.1 Elutriator

An elutriator consists of a vertical column containing water flowing from the bottom to the top. Soil to be processed is introduced at the top or part way down the column. The falling particles reach their terminal velocity based on their size, shape, and density. The water flow into the bottom of the column is adjusted such that particles having a terminal velocity less than the water velocity are carried up by the rising water stream. The mixture of water and finer, lighter particles is called slimes or tailings. Larger, heavier particles settle fast enough to overcome the water velocity and travel down the column. Desired fractions of the settling particles (middlings and concentrate) can be collected at different depths along the column. Alternatively, a series of sorting columns, each with a different water velocity, can be used to obtain the desired fractions.

4.1.2.2 Mechanical Classifier

Hydrodynamic separation can also be accomplished by mechanical action in a mechanical classifier, where a soil water slurry is introduced into an inclined trough. Coarse particles quickly settle out of the slurry and fall to the bottom. The slimes overflow from the lower end of the trough. The coarse particles are carried up the incline by a rake (rake classifier) or spiral (spiral classifier or "sand screw") and discharged, as shown in Figure 4-1.

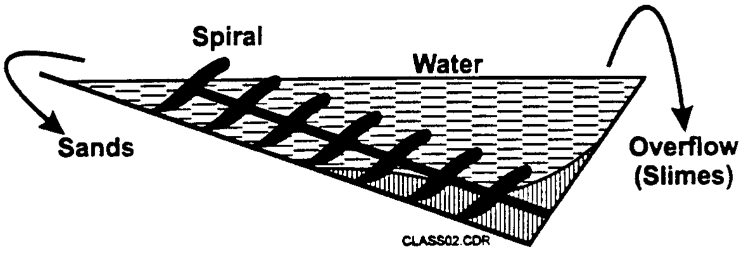


Figure 4-1. Schematic of a spiral classifier or "sand screw"

4.1.2.3 Hydrocyclone

A hydrocyclone is a continuously operating device that uses centrifugal force to accelerate the settling rate of particles (Figure 4-2). The hydrocyclone consists of a vertical cone into which the feed (in the form of a slurry) is introduced tangentially at the top. A vortex is created with a low-pressure zone along the vertical axis of the cone. Faster settling particles (those having large size or higher density) are accelerated to the wall of the cyclone by centrifugal force, and move in spiral form along the wall down to the bottom opening. The slower-settling particles (fines) are drawn to the low-pressure zone along the axis and pulled out at the top through a central tube called the vortex finder. Hydrocyclones often are very small devices. For higher throughput, a group of hydrocyclones (hydrocyclone bank) are configured in parallel.

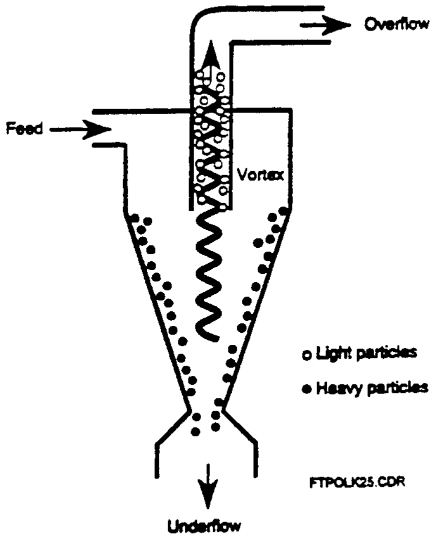


Figure 4-2. Hydrocyclone

4.1.3 Density (or Gravity) Separation

Gravity concentration methods separate particles mainly on the basis of their density. Particles with different densities respond differently to gravity and to one or more other forces applied simultaneously in opposition to gravity. Although density difference is the main criterion for gravity separation, particle size and shape also influence the separation. In general, gravity separation is more efficient with coarser particles.

Techniques using gravity concentration are efficient down to the 50- or 10-µm range, and high throughputs are possible using relatively small equipment. Among gravity concentrators, jigs can separate out relatively coarse material ranging in size from 2 inches down to 150 µm. Relatively good recoveries are possible even down to 75 µm. Performance is better with either (1) a high-particle-density difference in an unclassified feed (wide size range) or (2) a low-particle-density difference in a classified feed (narrow size range).

4.1.3.1 Jig

The jig, one of the oldest gravity separation devices, achieves particle separation using a pulsating water column as shown in Figure 4-3. A mixture of soil and water is subjected to vertical flow pulsations that alternately lift and lower the entire mass (water and particles). The upward pulse tends to loosen the bed of particles, whereas the downward pulse tends to consolidate the bed. The heavier particles make their way progressively to the bottom with each pulse cycle. The downward movement of the lighter particles is retarded by the upward pulse, but is not accelerated fast enough by the downward pulse. A bed of heavier particles soon builds at the bottom and the lighter particles go with the overflow.

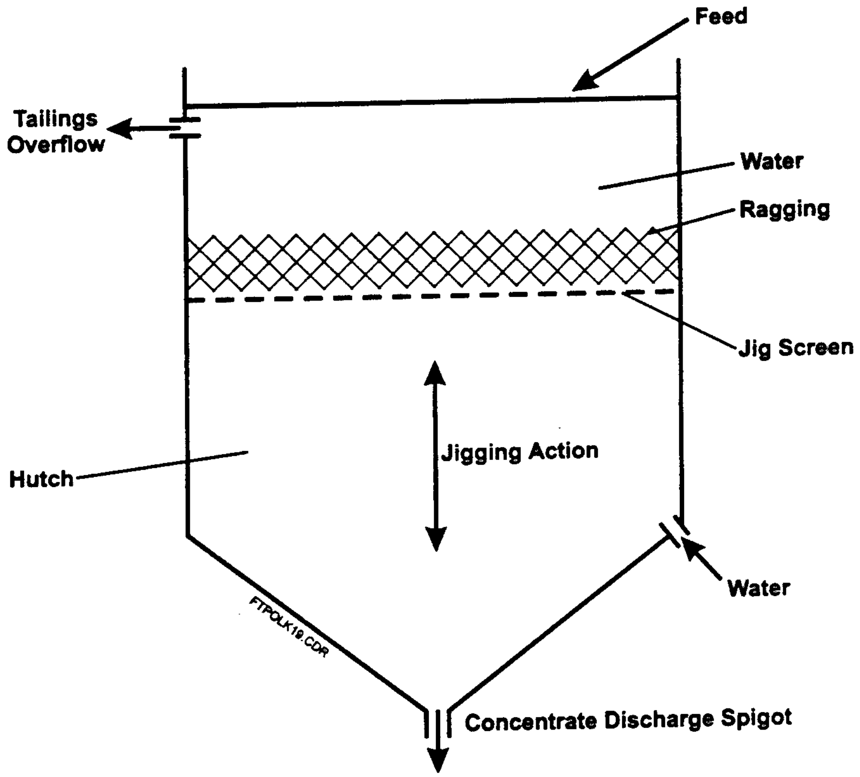


Figure 4-3. Basic jig construction

4.1.3.2 *Spiral Concentrator*

The spiral concentrator is another popular type of gravity separator. This device consists of a helical channel that winds down a central pole. Feed is introduced at the top of the spiral as a 10% to 40% solids slurry. As the slurry flows down the spiral, a velocity gradient is created along the thickness of the water film. The water closest to the channel surface flows very slowly due to friction, whereas the velocity increases toward the top of the water film as shown in Figure 4-4. The smallest particles submerge in the slower moving layer of the film. The larger particles and the bulk of the fluid are faster moving and are subjected to centrifugal force along the curved path, which causes them to move outward. The smallest, densest particles, in trying to take the shortest path down, move to the axis of the spiral where they form a band. Ports collect the dense material at several points along the downward path of this band. The width of the concentrate band removed at the port is controlled by adjustable wedges (called splitters). The most concentrated product goes to the highest port in the spiral, and concentration quality declines as the channel winds downward. The lighter particles are carried outward by the faster moving water at the outer edge of the spiral and descend to the bottom as tailings. A middlings product can be isolated between the concentrate band and the tailings band. Because the concentrate band is very high in solids and the bulk of the water flows to the outer edge of the channel, washwater has to be continuously introduced along the spiral to keep the band moving.

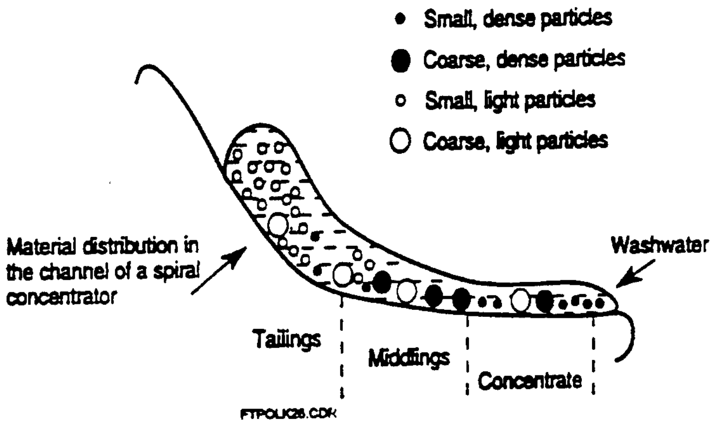


Figure 4-4. Cross section of a spiral channel in a spiral concentrator

Spiral concentrators are used in the size range of 3 mm to 75 μm. The high capacities can be further increased in the same space by winding two channels down the same column (double spiral).

4.1.3.3 *Shaking Table*

The shaking table operates according to a principle similar to that of the spiral concentrator. This device consists of a slightly inclined deck to which a 25% solids slurry is introduced at the higher corner. The flowing film separates the small dense particles (which move quickly to the lower, slower-moving layer of the film) from the coarse, light particles as shown in Figure 4-5. The effect is enhanced by vibrating the table at right angles to the water flow in a slow forward stroke and a fast return stroke. The net effect is that the particles move diagonally across the table. Stratification is enhanced by riffles that run along the long axis of the table parallel to the vibrations. The small, dense particles settle down quickly into the riffles near the feed end. These particles travel along the riffles to the side of the table. The coarser, lighter particles go over the riffles to the front of the table. Concentrate, middlings, and tailings can be isolated as required by adjustable splitters placed along the edges of the table.

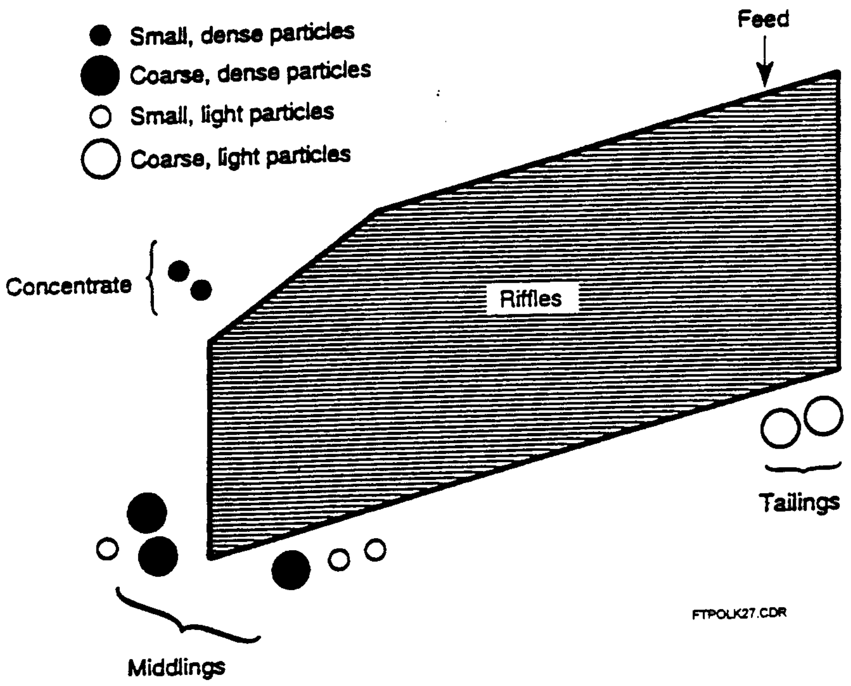


Figure 4-5. Schematic of shaking table

Shaking tables effectively separate coarse, light particles from fine, dense particles. Therefore, the feed is first classified, because classifiers put these two types of particles in the same product. Sands tables operate on feed sizes between 3 mm to 100 µm. Slimes tables operate on sizes below 100 µm.

4.1.3.4 Bartles-Mozley Table

The Bartles-Mozley Table is used for particles in the size range from 100 µm all the way down to 5 µm. On a normal table, such a small particle size would require a very large surface area. However, this table combines a very high capacity in a very small space with low power consumption.

4.1.4 Froth Flotation

Flotation was developed in the early 1900s as a way of recovering metal value from low-grade ores that otherwise would have been discarded as uneconomical to process. Particle separation by froth flotation is based on the fact that different minerals have different surface properties. These differences in surface properties can be accentuated by adding suitable chemicals to a slurry containing the minerals. Air is sparged from the bottom of a tank or column containing the slurry. One type of mineral selectively attaches to the air bubbles, rises to the top, and forms froth that can be collected. Successful flotation depends on the mineral surface being somewhat hydrophobic so the air bubbles attach. Also, if the bubbles are to continue to hold the mineral at the top, the froth formed should be stable. These characteristics are imparted by the addition of chemicals called flotation reagents.

4.1.5 Magnetic Separation

Magnetic separation is based on the differences in magnetic properties of the various minerals, especially for separating ferrous from nonferrous materials. Commercial units generally operate continuously by subjecting a moving stream of particulates (transported by a conveyor belt or drum) to a strong magnetic field.

4.1.6 Dewatering

With the exception of dry screening, physical separation techniques use water to facilitate transfer and separation of the solid particles. Dewatering often is required to recover and reuse water. It is important to recover this water because it may contain elevated levels of soluble and suspended metals. Commonly used processes for dewatering include filtration, expression, centrifugation, and sedimentation (or thickening). These four dewatering techniques are summarized briefly in Table 4-2. A combination of these methods typically is used to obtain successively drier solids.

Table 4-2. Key Attributes of Common Dewatering Techniques

Technique	Filtration	Expression	Centrifugation	Sedimentation
Basic Principle	Passage through porous medium: particle size	Compression with fluid escape through porous medium: particle size	Artificial gravity settling: particle size, shape, density, and fluid density	Gravity settling: particle size, shape, density, and fluid density; aided by flocculants
Advantages	Simple operation, more selective separation	Handles slurry materials that are difficult to pump Produces solid with low water content	Fast, large capacity	Simple, less expensive equipment; large capacity
Limitations	Batch nature of operations, washing may be poor	High pressures required, high resistance to flow in some cases	Expensive, more complicated equipment	Slow
Example Equipment Types	Drum, disk, horizontal (belt) filters	Batch and continuous pressure	Solid bowl sedimentation and centrifugal, perforated basket	Cylindrical continuous clarifiers, rakes, overflow, lamella, deep cone thickeners
Typical Bench Test Equipment	Vacuum filters, filter press	Filter press, pressure equipment	Bench or floor centrifuge	Cylindrical tubes, beaker, flocculants

4.1.6.1 Filtration and Expression

The process of filtration involves passing a slurry through a porous medium in which the solids are trapped and the liquid goes through. The process of expression involves compressing the liquid, with liquid escape through a porous filter. In any filtration or expression application, a cake of solids gradually forms on the filter media that resists the flow of water. This resistance is overcome by applying a pressure field upstream of the filter or a vacuum downstream from the filter. Filtration equipment is available in several different types. The most common is the filter press, which consists of a row of plates and frames placed alternately. A filter cloth covers each plate. The slurry is introduced into the empty frames. The plates are then pressed toward each other by a screw or hydraulic piston. The water gets squeezed through the filter cloth into grooves in the plate and is removed. The filter cake in the frames can be washed, and the plates can be separated one by one to discharge the cake. The filter cloth is often precoated with a filter aid, such as diatomaceous earth, to prevent clogging.

4.1.6.2 Sedimentation

The settling of solid particles in water is called sedimentation. Because very fine particles settle very slowly, coagulants or flocculants must be added to agglomerate the particles to improve the settling rate. Sedimentation is performed in specialized tanks called either clarifiers or thickeners, depending on the main performance objective. Clarifiers are used if the objective is to remove solids from liquids, and the clarified liquid is decanted from the top. Thickeners are used if the objective is to remove liquids from solids. The settled solids can be thickened continuously by introducing the feed slurry to the center of the tank, letting the clear liquid overflow over the sides, and evacuating the thickened sludge from the bottom.

4.1.6.3 Centrifugation

The process of centrifugation involves the use of a centrifugal force created by a rotating bowl instead of gravity to bring about separation. For continuous operation, a bowl centrifuge can be used. The solids settle out on the sides of the bowl and the screw conveyor discharges them at the smaller end. A slightly different type of centrifuge is the basket centrifuge, in which solids move to the sides of the rotating basket and are trapped there, whereas the water flows through.

4.2 Application of Physical Separation Processes to Small-Arms Range Soils

Physical separation is a simple, low-cost method to separate metal particles from soil particles by size, density, or magnetic properties. These separations do not have a high degree of selectivity. These processes can be used for range maintenance activities to effectively remove and concentrate bullets and bullet fragments from berm soils. Physical separation also can make a preliminary differentiation that reduces the volume of material treated or helps to optimize the operation of subsequent steps, but usually is not sufficient to clean soil to meet remediation goals.

Physical separation is ideally suited to treatment of small-arms range soils. Both the density differences and size characteristics ease physical separation of bullet metals from soils. The lead and copper alloy fragments and oxides have a significantly higher density than soil materials. Many bullets will remain sufficiently intact to be larger than soil materials. A basic dry screening step to remove bullets that have remained largely intact is a first step in treatment of soils from most small-arms range berms or impact areas. The smaller alloy fragments are similar in size to soil particles. Separating these smaller fragments from soils requires more complex physical separation steps, but may still be economical.

The applicability of physical separation techniques depends, to a large extent, on particle size. The size ranges suitable for the various techniques are shown in Table 4-3. As seen in this table, many of these techniques have good applicability in the intermediate size range (between 100 and 1,000 µm). Very few techniques are applicable in the fine particle range. In the case of froth flotation, there is an upper limit on the size range based on the size (or weight) of the particle that the air bubbles are capable of supporting. Because soil usually contains a wide range of particle sizes and the performance of physical separation techniques depends on particle size, there are often situations in which a single technique will not achieve sufficient separation. In that case, a combination of techniques may be able to achieve the desired separation. The particle-size ranges shown in Table 4-3 can be used to determine which separation technique(s) should be used.

Table 4-3. Particle-Size Range for Application of Separation Techniques

Separation Process	Particle-Size Range
Size Separation	
Dry screen	>3,000 μm
Wet screen	>150 μm
Hydrodynamic Separation	
Elutriator	>50 μm
Hydrocyclone	5 to 150 μm
Mechanical classifier	5 to 100 μm
Density Separation	
Jig	>150 μm
Spiral concentrator	75 to 3,000 μm
Shaking table	75 to 3,000 μm
Bartles-Mozley Table	5 to 100 μm
Froth flotation	5 to 500 μm

Adapted from Perry and Chilton (1984) and Wills (1985).

The performance of physical separation techniques depends on the size range and density difference of the feed material. The berm soil should be characterized to determine the particle-size distribution of the soil and the metal concentration in each size range. Size distribution can be determined readily in a laboratory by passing a small sample of air-dried soil from the site through a series of standard sieves. At some sites that have wet, sticky clay, attrition scrubbing and wet sieving are required to ensure that clay balls do not roll off with the oversize fraction. Each size fraction is then subjected to a chemical (metals) analysis to determine the distribution of the metals among various size fractions.

If the metals are present as particulate, the density difference between the soil and metal particles is determined. If the density difference is significant, classification followed by gravity concentration techniques will perform well. Actual recoveries cannot be predicted without tests on site-specific soils; however, the efficiency of separation can be estimated by the following concentration criterion (cc) (Wills, 1985):

$$cc = \frac{S_h - S_f}{S_l - S_f} \qquad 4\text{-}1$$

where S_h = specific gravity of heavy particles (usually metals)
S_f = specific gravity of separation fluid medium (usually water)
S_l = specific gravity of light particles (usually soil)

If cc is greater than 2.5, gravity separation can be expected to perform well. Between 1.25 and 2.5, separation should still be feasible; below this the separation may not be feasible. Calculated concentration criteria for various elements and compounds typically found in small-arms range soils are shown in Table 4-4. As seen from the high cc values in the table, the particulate metal oxides and carbonates considered are amenable to gravity separation.

Table 4-4. Illustration of Calculated Concentration Criteria for Gravity Concentration

Heavy Material	Heavy Material Specific Gravity (S_h)(a)	Concentration Criteria for Various Combinations of Specific Gravity Light Material Specific Gravity(S_l)(a)		
		2.2	2.4	2.6
Copper metal, Cu	8.96	6.6	5.7	5.0
Cupric oxide, CuO	6.4	4.5	3.8	3.4
Cuprous oxide, Cu_2O	6.0	4.2	3.6	3.1
Lead metal, Pb	11.3	8.6	7.4	6.4
Cerussite, $PbCO_3$	6.5	4.6	3.9	3.4
Lead oxide, PbO(b)	9.3	6.9	5.9	5.2

(a) Specific gravity values used to illustrate light silica soil particles.

(b) Amorphous form.

The efficiency of gravity separation also increases with particle size, because larger particles respond better than smaller particles. For a given value of the concentration criterion, the size fraction containing most of the metals will control the separation performance. Good size control through the judicious use of screens and classifiers before gravity concentration will enhance the efficiency of the separation. Small particulate size solids reduce the processing rate and/or separation efficiency of gravity separation and should be removed prior to gravity separation.

Other equipment-related variables can be adjusted to improve performance. For example, one of the most important variables is the water balance in the separation scheme. Most gravity concentrators have an optimum solids level for the feed slurry. Good solids level control is important, especially for the initial feed. As the material travels through the separation scheme, water can be added or removed as required with the use of washwater lines or thickeners and hydrocyclones.

In jigs, the density effect can be accentuated compared with the size effect by using a short jigging cycle (i.e., short, fast strokes). The short cycle allows smaller, denser particles to be affected more by initial acceleration (mass effect) rather than by terminal velocity (size effect). For coarser particle sizes, longer, slower strokes are better.

Similarly, separation in spiral concentrators can be improved by selecting a spiral with a suitable channel slope. Manufacturers of spiral concentrators produce equipment with different channel slopes. For most applications, the purchaser can select an optimum slope from the standard equipment. Gentler slopes are provided for smaller density differences, but with a concomitant drop in capacity. Steeper slopes are for larger density differences and larger throughputs.

The performance of shaking tables is most affected by particle size. The wider the particle size range of the feed, the lower the performance. Table performance can be affected also by adjusting the stroke. A shorter stroke with higher speed improves the separation of finer particles; a longer stroke with slower speed is suitable for coarser particles.

Particle size also is important in froth flotation, because air bubbles will not lift particles when the particle weight is sufficiently high to overload the forces of adhesion at the bubble-particle interface. Another factor affecting flotation performance is pH. A higher pH generally is more suitable to flotation, because most collectors are stable in this range. Alkalinity is maintained by the addition of lime.

4.3 Acid Leaching Process Description

After physical separation, most of the coarse particulate metals have been removed from the bulk soil. Lead and other metals are still present in the soil either as fine particulates or as molecular or ionic species bound to the soil matrix. Fine particulates could consist of either elemental lead or precipitates of lead salts. Lead species could be bound to the soil by ion exchange, sorption, or complexation with organic matter. Because sorption and ion exchange are surface phenomena, molecular or ionic lead species often are concentrated in the finer size fraction (silts and clays), which have a high surface area.

Soil washing is a generic term for a group of techniques used to mobilize the lead from the soil into a solution by one or more of the following means:

- ☐ Changes in pH (e.g., acid leaching)
- ☐ Changes in system ionic strength (by addition of a suitable salt)
- ☐ Changes in redox potential (by addition of a suitable reducing agent)
- ☐ Formation of complexes (by addition of a ligand such as ethylenediaminetetraacetic acid [EDTA]).

Soil washing was first used in the Netherlands in the early 1980s and is widely used in Europe (Valenti, 1992). Soil washing starts with physical separation techniques to separate the coarse from the fine particles. The coarse fraction may be subjected to density separation to remove particulate metals. The fine fraction is mixed with a suitable wash solution (e.g., acid) to remove the lead bound to the soil. The coarse soil may or may not need washing depending on the amount of leachable lead associated with this fraction.

4.3.1 Acid Leaching and Metal Chemistry

Acid leaching helps to mobilize much of the fine particulate and soil-bound lead into solution by lowering the pH of the wash solution. Lowering the pH increases the supply of H^+ ions, which are consumed in a multitude of reactions that increase soluble lead concentrations. Figure 4-6 shows how the solubility of lead compounds changes with pH. Except for lead sulfate ($PbSO_4$), the solubility of the compounds shown increases with decreasing pH.

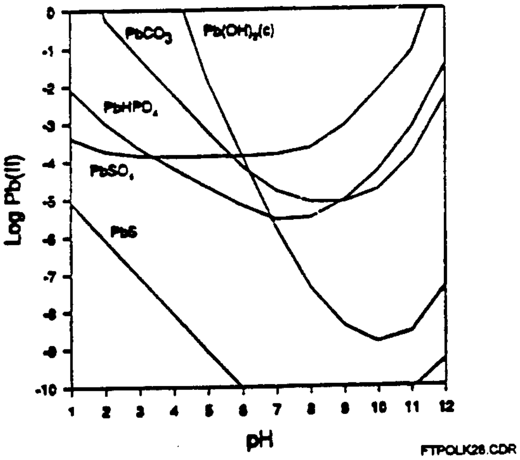


Figure 4-6. Pb solubility diagram: calculations made assuming solid phase always to be present, with total chemical component concentrations [e.g., Pb_T, $(SO_4)_T$, $(PO_4)_T$, C_T] varying depending on amount of solid phase that was dissolved (van Benschoten et al., 1997)

Acetic acid and hydrochloric acid have been commonly used to remove lead because both acids produce water-soluble salts. Acetic acid is weak and is expected to be effective at some sites where lead is mostly in the form of carbonate minerals (cerussite, hydrocerrusite, etc.). At small-arms range sites, lead carbonates may be formed from the weathering of elemental lead in the presence of native soil alkalinity (carbonates and bicarbonates). Other forms of lead, such as lead dioxide and lead sulfates, are more recalcitrant to solubilization by acetic acid. Lead sulfates are more common at lead acid battery sites. When lead sulfates or phosphates are present, the pH would have to be lowered to well below 3 to solubilize the lead. Extremely high molar concentrations of acetic acid (> 0.1M) would be required to attain a pH below 3, because of its low dissociation constant. As the concentration of acetic acid is increased, the percent dissociated decreases. Based on previous studies (Wozniak and Huang, 1982), pH 2 appears to be a threshold for lead and copper solubilization, whereas zinc was more easily solubilized, even at pH 3.

In general, solubilization rates are dependent on pH, liquid-to-solid ratio, type of metal, and contact time. Of these parameters, pH and liquid-to-solid ratio are the limiting factors for a given metal. The pH determines the equilibrium solubility (concentration) achievable, and the liquid-to-solid ratio determines the total mass of metal removed. As far as contact time is concerned, solubilization generally reaches a maximum in a relatively short time and then levels off (Wozniak and Huang, 1982), as long as relatively coarse metal particulates are absent. Metallic lead dissolves very slowly and, therefore, physical separation is desirable before leaching at small-arms range sites. A contact time between 10 to 60 minutes should be economically acceptable for a field leaching operation of the type conceived for small-arms ranges.

A stronger acid, such as hydrochloric or nitric acid, is more economical when the lead species requires much lower pH. A 0.1M solution of HCl, for example, has a pH of 1 and is more aggressive. Nitric acid may generate toxic oxides of nitrogen and is difficult to handle. Hydrochloric acid is therefore preferred. However, mineral acids such as hydrochloric acid are likely to be more corrosive on equipment and more aggressive on the native soil matrix.

4.3.2 Acid Leaching Process Configuration

Acid leaching is often performed as a continuous process and involves at least four vessels, as shown in Figure 4-7. In the leaching tank the acid solution is mixed with the soil to leach out the metals. The contact time between the leachant and soil can be set by designing the volume of the tank to achieve the required throughput rate. For a given volume of the tank, slowing down the throughput is the only way of achieving longer contact. Contact time requirements vary based on the type of soil and type of metal encountered. Small-arms range berms tend to be highly variable in terms of soil texture and the level of metals accumulation. Therefore, some degree of overdesign is advisable to maintain the desired processing rate for the plant.

The soil slurry is pumped from the leach tank to the clarifier, where the solids settle out and are discharged from the bottom. A flocculant may be added to enhance settling. The overflow from the clarifier is the leachate containing the solubilized metals. This overflow goes to a metal recovery tank, where the solubilized metals usually are recovered by precipitation or sometimes by electrowinning.

Precipitants used for metals recovery include hydroxide, phosphate, carbonates, sulfate, and sulfide. The pH maintained in the precipitation process is an important determinant of the precipitation efficiency. The optimum pH is determined by the type of metal, type of precipitant, and presence of potential complexing agents, such as ammonia or EDTA. Figure 4-8 shows the theoretical precipitation curves for various metals as hydroxides (Lanouette, 1977). Lead, zinc, and chromium hydroxides have an optimum

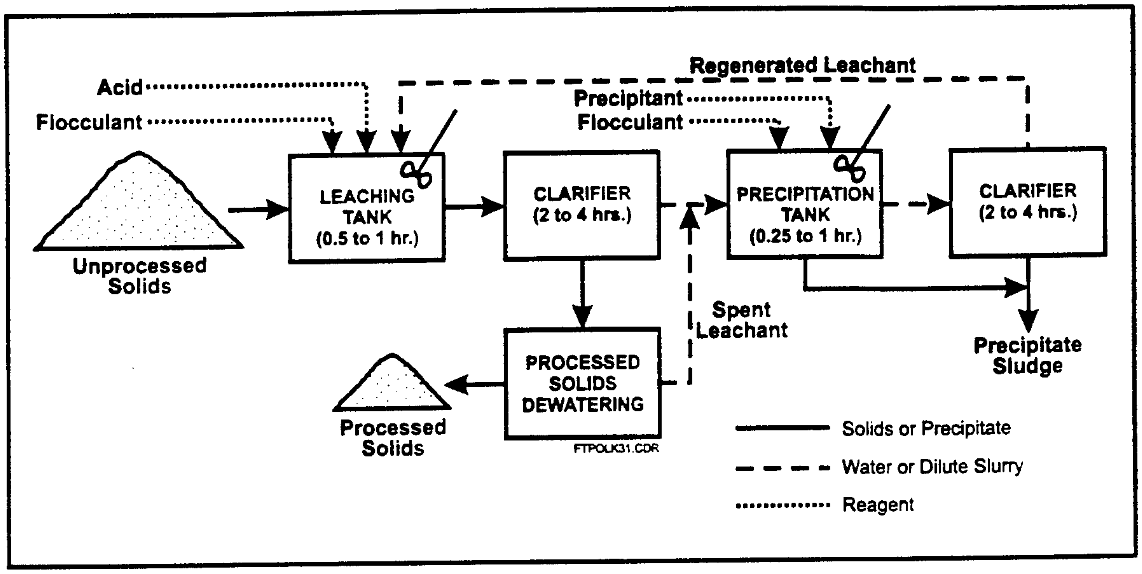


Figure 4-7. Continuous leaching process flow

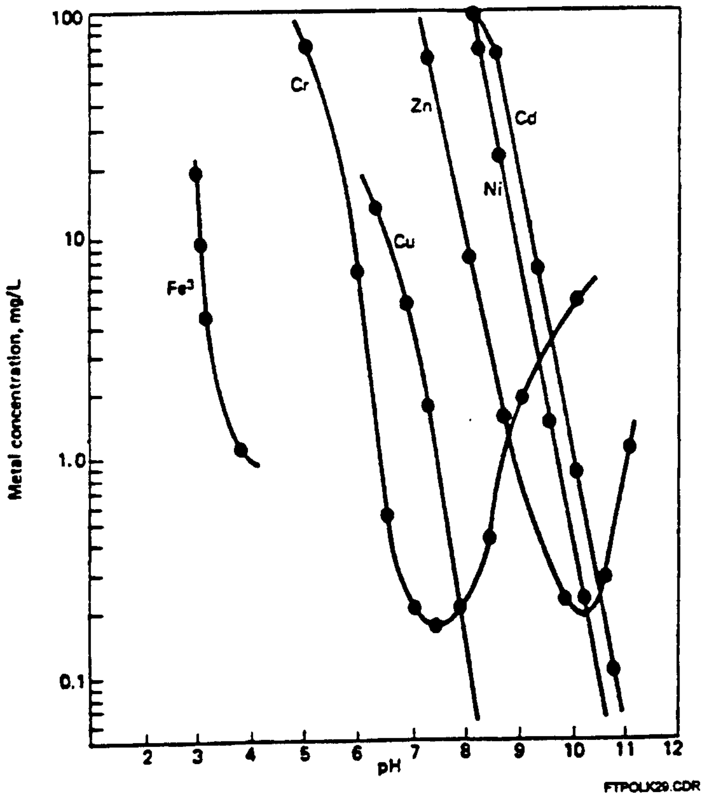


Figure 4-8. Precipitation of heavy metals as hydroxides (Source: Lanouette, 1977)

pH. As the pH is raised, solubility decreases up to a point. Beyond a certain pH, solubility starts increasing again. Therefore, pH control during precipitation is important. Also, if two or more metals are present in the solution, the optimum pH for each metal may be different from that for the same metals in individual solutions. Bench-scale tests should be used to determine a satisfactory pH, the use of polymers to aid in coagulation, the mixing and settling times needed, and the amenability of the precipitate to dewatering.

The treated leachate may then flow into a separate clarifier tank for settling of the precipitate. As shown in Figure 4-7, mixing of precipitant and coagulant with the leachate is fairly fast (15 to 60 min). Settling may require 2 to 4 hours at overflow rates of 300 to 700 gal/ft^2 of surface area per day (Lanouette, 1977). The respective tanks are sized accordingly. Some of the initial precipitate formed may be recirculated to the mixing tank, where the older precipitate particles provide a seed on which new precipitate can grow.

In the clarifier, the precipitate floc often settles down to form a sludge with only 1 to 2% solids. This sludge has to be dewatered before it is hauled away for disposal or recycling. The sludge can be dewatered in centrifuges, rotary vacuum filters, or plate-and-frame filters. Centrifuges require less floor space but may not dewater to the extent that the filters can. Plate-and-frame filters provide a drier cake and occupy less floor space, but require more operator attention than do rotary vacuum filters. A filter aid, such as diatomaceous earth, may be required to prevent clogging of the filter cloth with fine precipitate particles. Bench-scale tests should be used to determine appropriate dewatering equipment and parameters.

The dewatered sludge can be sent to an off-site smelter for recycling if it is acceptable to the smelter operator. The overflow from the clarifier is recycled back to the leach tank after being refortified with acid. An effective precipitation step assures the return of a good quality leachant containing low levels of soluble metals. This is important to maintain the performance of the entire acid leaching process.

4.4 Acetic Acid Versus Hydrochloric Acid for Small-Arms Range Soils

Acetic acid (HOAc) and hydrochloric acid (HCl) have both been found effective for removing lead from soils. However, the efficacy and soil degradation/environmental impact of these acids vary with soil type and lead specie. Although equimolar solutions of HOAc and HCl have the same neutralizing power, for example, as might be used to neutralize caustic solutions between pH 6 and 8, these acids perform very differently in leaching metals in the pH <7 region due to their markedly different acid and buffering activity, metal complexing characteristics, and metal oxidation catalysis capability. Generally speaking, HCl is an aggressive leachant that is a corrosive and low-cost acid, whereas HOAc is more selective, far less corrosive, but significantly higher in cost relative to HCl.

Based on the Fort Polk demonstration (Battelle, 1997a), further pursuit of an acetic acid process will require additional bench- and pilot-scale demonstrations prior to implementation. However, the hydrochloric acid process is ready for implementation and does not require further development or demonstration.

4.4.1 Acid Activity Effect on Leaching Rate

Acid strength can be understood as the product of total acid concentration and hydrogen ion "activity," i.e., the fraction of the available hydrogen ion that is not already strongly bonded to something other than water (as "free" hydrogen or as H^+ dissolved in water). Bonded H^+ is not available to directly attack lead compounds (see below) to leach the Pb^{2+} contained in them, or to exchange with Pb^{2+} ions held by soil ion exchange sites. Therefore an acid, HX, dissociates partially when added to water to produce free H^+ according to the following reversible reaction.

$$HX \overset{K_a}{\longleftrightarrow} H^+ + X^- \qquad 4\text{-}2$$

HCl (where $X^- = Cl^-$) and HOAc (where $X^- = OAc^-$, or acetate) differ enormously (more than five orders of magnitude) in the extent to which Equation 4-2 occurs in solutions of these acids. For example, when these acids are added to water and the resultant pH is <3.5, for HOAc the solution is composed of >90% neutral (un-ionized) HOAc molecules (Reaction 4-2 lies far to the left for HOAc). For HCl this same condition results in 100% of the HCl to be in ionized form, H^+ and Cl^- (that is, Reaction 4-2 lies far to the right for HCl). Therefore K_a (= $[H^+][X^-]/[HX]$, where [ ] = concentration) is very large (essentially infinite, i.e., HCl molecules are never present to a measurable extent in the pH >0 range). For HOAc, however, K_a is very small, $10^{-4.56}$ M (Martell and Smith, 1974), indicating that at about pH 4.5, 50% of the HOAc is present as the neutral molecule. Equation 4-3 can be used to estimate how the ratio of ionized to un-ionized concentrations of HOAc, $[OAc^-]/[HOAc]$, varies with pH.

$$\log\left(\frac{[OAc^-]}{[HOAc]}\right) = \log K_a + pH = pH - 4.56 \qquad 4\text{-}3$$

The exponential relationship between the $[OAc^-]/[HOAc]$ ratio and pH (Equation 4-3) results in major changes in the fraction of HOAc ionized near where pH ~ $-\log K_a$ (or "pK_a"). Using Equation 4-3, these percentages are listed in Table 4-5.

Table 4-5. Molecular and Ionized Forms of Acetic Acid Dependence on pH

pH	[OAc]/[HOAc] Calculated from Equation 4-3	% HOAc Ionized to OAc^-	$[H^+]_{free}$ M
1.56	0.001	0.00099	2.8×10^{-2}
2.56	0.01	0.0099	2.8×10^{-3}
3.56	0.1	0.099	2.8×10^{-4}
4.56	1.0	50	2.8×10^{-5}
5.56	10	91	2.8×10^{-6}
6.56	100	99	2.8×10^{-7}

On the other hand, HCl is 100% ionized over this same pH range. Note that as the $[H^+]$ is increased (decreasing pH), the fraction of acetic acid in ionized form becomes extremely small. Also note that the $[H^+]$ achievable from HOAc is always small. This last result is better shown by Table 4-6.

From Table 4-6, it is clear that to achieve high percent dissociation of acetic acid into H^+ ions, e.g., ≥15%, only very dilute acetic acid concentrations can be used (≥0.001 M). However, at these high dilutions the acidity is very low (pH ≥3.8). Therefore, optimum acid activity (H^+ activity with minimum total HOAc concentration) will occur around pH 3.3 to 3.8. HCl has no such limit. HCl solutions will increase in acid activity with increasing total HCl concentration to the HCl solubility limit, about 12M or 37%.

Table 4-6. Estimates of H^+ Activity vs. Total Acetic Acid Concentrations Using Equation 4-3

Total Acetic Acid Concentration C_T^{HOAc} (M)	$[H^+]_{calc}$ ($=[OAc^-]$)	Calculated pH	[HOAc] M	% HOAc Ionized to H^+ and OAc^-
1	5.2×10^{-3}	2.28	0.99	0.53
0.1	1.6×10^{-3}	2.8	0.098	1.6
0.01	5.2×10^{-4}	3.3	0.0095	5.5
0.001	1.5×10^{-4}	3.8	0.00085	15
0.0001	3.6×10^{-5}	4.4	6.4×10^{-5}	36

4.4.2 Relative Lead Ion Complexation (Solubilization) Chemistry of Acetic and Hydrochloric Acids

Complexation reactions tend to solubilize metal ions in water. Both acetate and chloride ions display Pb^{2+} complexation capability but with much different strength and pH dependencies. Although chloride and acetate salts of most metals are highly water soluble, this does not always occur with complete dissociation of the ions of the salt by the water. Lead(II) is in fact a good example of this phenomenon where the anion associates with (bonds to) the metal ion while in solution. These reactions are given in Table 4-7.

Table 4-7. Complexation Reactions Involving Lead

Reaction	Total Complexation Reaction	Formation/Solubility Constants		
		Symbol	log K (OAc^-)	log K (Cl^-)
4-4	$Pb^{2+} + X^- \rightarrow PbX^+$	K_1	2.15	0.90
4-5	$Pb^{2+} + 2X^- \rightarrow PbX_2^0$	B_2	3.5	1.3
4-6	$Pb^{2+} + 3X^- \rightarrow PbX_3^-$	B_3	3.18	1.4
4-7	$Pb^{2+} + 4X^- \rightarrow PbX_4^{2-}$	B_4	3.4	0.7
4-8	$PbX_{2(s)} \rightarrow Pb^{2+} + 2X^-$	K_{sp}	Very soluble	-5.0

Note: Interestingly, dialkyl lead(III) also forms mono and bischloro complexes with formation constants similar to those given in Table 4-7.

Although the formation constants for OAc are some 10 to 100 times those of Cl for Pb, Reactions 4-4 to 4-8 in Table 4-7 depend on the concentration of free anion, X, such that comparisons need to be made carefully (see below).

4.4.2.1 Acetic Acid

For HOAc the anion concentration can be very low in the pH 3.5 range (Tables 4-5 and 4-6). Note also that $Pb(OAc)_2$ is very water soluble, but $PbCl_2$ is not (Reaction 4-8). Therefore in the pH range of about 3.0 to 4.5, acetic acid provides both significant levels of available acidity (as HOAc) and some amount of complexing anion (OAc^-), which combine to help solubilize lead from lead compounds in the soil. At higher pHs much less HOAc exists, and lead dissolution reactions that involve carbonates, bicarbonates, hydroxide, oxide, or organic acids are not leached as rapidly, e.g., Reaction 4-9.

$$PbCO_{3(s)} + 2HOAc \xrightarrow{\text{pH 3.5-4.5}} \underset{\substack{\text{Soluble}\\ \text{complex}}}{Pb(OAc)_2} + H_2O + CO_2 \uparrow \qquad 4\text{-}9$$

Critically, acetic acid can supply sufficient acid capacity (~0.01M) while still maintaining the pH window needed for Pb^{2+} solubilization by complexation (Table 4-7, columns 3 and 4).

Interestingly, if acidity is not needed to release the lead from the soil, and if it is not present as a highly insoluble, low-pH-sensitive salt (e.g., $PbSO_4$), lead complexation to form soluble acetate complexes can occur up to pH 7 to 8, above which hydroxide precipitation (to pH ~10 to 11) occurs, followed by redissolution by anionic hydroxide complexes at still higher pHs (pH 11 to 14) (Kragten, 1978).

4.4.2.2 Hydrochloric Acid

In comparison, HCl provides Cl^- which forms much weaker Pb^{2+} complexes, and $PbCl_{2(s)}$ solubility is only a little more than $PbSO_4$ solubility. HOAc is mostly present as neutral molecules in the 3.0 to 4.5 pH range (Table 4-6); HCl is 100% dissociated over this same pH range. Therefore, a 0.01M HCl solution would have a pH of ~2, resulting in nonselective and substantial dissolution of many more materials. Also, the low solubility limits the total dissolved lead concentration to ~200 ppm, requiring large aqueous leach-phase (lixivient) volumes for heavy lead accumulations. Higher Cl^- levels would depress this solubility still further unless sufficient $[Cl^-]$ exists to promote the formation of soluble complex species, remembering that even 0.1M Cl^- increases Pb solubility only to a small extent.

Therefore HCl at mild pH (≥3) (and therefore dilute conditions such as might be found with acid rain) has too little acid capacity ($\leq 10^{-3}$ M) to dissolve much Pb^{2+} from large acid-demanding solids such as lead carbonates (unless the pH is maintained with concentrated HCl additions). Therefore, relatively speaking, HCl has very little pH buffering or acid activity at pHs ≥3. The associated chloride from HCl does too little by complexation to promote Pb^{2+} solubilization and in fact could actually retard lead leaching through formation of low-soluble $PbCl_2$ particles. As $PbCO_3$ is more insoluble than lead(II) hydroxides and oxides (Kragten, 1978), this compound can play a dominant role in soils exposed to environmental conditions. The acetate complexes of Pb(II) are sufficiently strong to compete with carbonate and therefore mobilize Pb(II) in the pH 3 to 9 regime. Ten times higher concentrations of chloride ion are needed to impart similar effects (Kragten, 1978). The chloride ion effects, however, extend down to the strong acid region, e.g., to pH 1.

4.4.3 Aggressive Leach Conditions

Certain forms of Pb^{2+} ion are highly insoluble because the matrix in which the Pb^{2+} ion is trapped is highly insoluble. Ferrites, iron(III) hydroxides, and aluminum hydroxides, manganese dioxide (MnO_2), and $PbSO_4$ are such examples. The hydroxides and oxides can be amorphous or crystalline. Amorphous materials normally dissolve at faster rates due to larger surface areas, water content, and larger inter-atomic spacings (weaker bonds). The high stability of these materials results in slow rates of dissolution by acid. What is more, ferric hydroxide is already essentially completely precipitated by pH 2.5 (Baes and Mesmer, 1986). Hence, high H^+ activity is often required for rapid dissolution, and metals other than lead also need to be dissolved to leach the lead. Therefore, both high H^+ activity and high acid concentration are needed to achieve rapid leach rates. Normally only HCl can provide both of these conditions, whereas HOAc can provide acid quantity but not the needed H^+ activity.

4.4.4 Catalysis of Oxidation

Chloride ion catalyzes electron transfer between metals and metal ions that are capable of oxidation reduction reactions. Chloride accomplishes this by bridging between two metal ions, thereby connecting their atomic orbitals for ease in electron transfer. Acetate ion is far less capable of electron transfer catalysis chemistry. Hence if Pb^0 is to be dissolved, or if ferrous iron-enhanced dissolution of ferric and

MnO solids is to be used, then Cl^- addition may help promote dissolution rate. Increased acid activity promotes this reaction but it is not required. This same catalysis phenomenon is responsible for the high corrosive action of chloride, especially HCl to carbon steel equipment.

4.5 Factors Affecting Cost and Performance of Physical Separation and Acid Leaching

Table 4-8 summarizes the factors that influence the effectiveness, implementability, and costs for application of physical separation and acid leaching to remediation of small-arms ranges.

The proportion of fine materials in the soil is an important factor determining the effectiveness and cost of physical separation and acid leaching operations. The surface area is larger and settling velocity is lower for fine particles in comparison to larger particles of similar shape and density. Increased surface area increases the capacity of the soil for adsorbing metals, particularly if the fine particles are clay or humic materials. Lower settling velocity increases the residence time required to perform physical separations. Both factors tend to cause processing of fine particles to limit the throughput of a physical separation and acid leaching plant. It is important to design equipment used for separation and leaching operations based on the measured content of fine particles in the soil. If the actual fine particle content is higher than the content measured in site characterization or treatability studies, the system capacity and performance will suffer. For example, a system with a clarifier designed to process 5 tons per hour of fine particles has a throughput of 50 tons per hour for soil containing 10% fines. If the soil contains 50% fines, the same system can process only 10 tons of soil per hour.

The chemical form of the metals strongly influences the selection of acid leaching chemical and operating conditions. The bullets enter the berm as elemental metals, but the actions of weather and chemicals in the soil alter the chemical state of the metals. Factors such as soil pH and the availability of anions (e.g., PO_4^{3-}, CO_3^{2-}, SO_4^{2-}, and NO_3^-) strongly affect the final equilibrium state and the rate of transformation. Therefore, design of the leaching and leachant regeneration system is site specific.

The ability to conduct required unit operations with off-the-shelf equipment increases process reliability, flexibility, and ease of maintenance. Physical separation and acid leaching processes use well-established, mature unit operations. Commercial equipment is available in a wide range of sizes and construction materials from many manufacturers. Alternatively, an entire processing plant can be leased if the processing is contracted to a vendor.

Selection of the required throughput for the separation and leaching system is site specific. The system capacity should be sufficient to complete soil processing quickly so that the maintenance or remediation project does not interfere with the range mission at an active range, or allows expeditious closeout of an inactive range. However, there are economic and performance limits on the maximum system size. High throughput requires large equipment that has higher capital costs and takes more time and expense to mobilize. If processing occurs very quickly, there will not be time to detect and adjust for processing problems such as inadequate metal removal. A processing rate sufficient to complete on-site processing in about 4 to 8 weeks typically is desirable.

4.6 Previous Testing of the Technology

This subsection summarizes previous bench- and pilot-scale tests, commercial processes, and a full-scale demonstration.

Table 4-8. Factors Affecting Performance and Costs of Separation/Acid Leaching Technologies

Factor Influencing Selection	Basis	Data Needs
Equilibrium partitioning of metal between matrix and extraction fluid	Low partitioning of metal into the extraction fluid increases fluid volumes required to attain cleanup goal	• Equilibrium partitioning coefficient • Jar testing
Metal solubility	Soluble compounds can be removed by water flushing	Metal solubility as a function of pH and anion content
Complex waste mixture	Complex mixture increases difficulty in formulation of a suitable extraction fluid	• Metal composition • Priority pollutant analysis
Type and size of debris	Presence of debris increases pretreatment requirements	Waste composition
Particle-size distribution	• Particles >2 mm require pretreatment • Particles in the range from 0.063 to 2 mm are optimum for acid leaching • Acid leaching difficult with particles <0.063 mm (up to 20% clay may sometimes be tolerable). Soils with high clay content will limit the throughput of the plant.	• Sieve-size analysis of waste • Distribution of metals to various solid and liquid phases
Total metals concentration and distribution	Determine concentration targets or interfering constituents, pretreatment needs, and extraction fluid	Total metal concentration in various size fractions
Leachable metals concentration and distribution	Determine extractability of target constituents and posttreatment needs	Leachable metal concentration in various size fractions
Extraction fluid characteristics	• Toxicity increases both health risks and regulatory compliance costs • Expensive or nonreusable fluid increases costs	• Fluid characterization • Jar testing • Pilot-scale testing
Waste buffering capacity and pH	High buffering capacity or pH increases acid consumption	Alkalinity
Presence of cyanides, sulfides, and fluorides	Determine potential for generating fumes at low pH	Waste composition
Matrix-specific surface area	High surface area increases sorption on soil	Specific surface area of matrix
Cation exchange capacity (CEC)	High CEC indicates the matrix has a high affinity for metal sorption	CEC of matrix
Clay content of waste	Clay increases sorption onto the waste matrix	Waste color, texture, and composition
Humic content of waste	Humic material increases sorption	Waste color, texture, and composition

Adapted from U.S. EPA, 1995, EPA/540/R-95/512.

4.6.1 Previous Bench-Scale Studies

A number of bench-scale studies that address separation/leaching of lead and other heavy metals from soil have been reported recently.

4.6.1.1 Acetic Acid Leaching Study

The EPA conducted a bench-scale study (Krishnamurthy, 1992) using acetic acid and other leachants to treat a sample of Louisiana soil that was artificially spiked with various lead species. In the three-step process used, lead sulfate was first converted to lead carbonate with ammonium carbonate. Acetic acid (0.1 M) was then used to leach the carbonate species. Lead dioxide (PbO_2) was converted to lead acetate using manganese acetate. Sodium sulfate was used as a precipitant to recover the lead in the leachate as a sulfate.

About 80 to 89% of the total lead was removed from the soil by this three-step process. The treated soil passed the TCLP test for lead. Lead dioxide was the most difficult to dissolve, even with manganese acetate. Dissolution of elemental lead was highly dependent on the particle size of the metal. One hour of contact time with acetic acid resulted in 95% dissolution of lead powder, 65% dissolution of granular lead (30-50 mesh), and only 25% dissolution of lead shot (0.09-inch diameter).

4.6.1.2 Hydrochloric Acid Leaching Studies

A recently completed bench-scale study examined the ability of hydrochloric acid leaching to reach cleanup goals for lead in seven soils (van Benschoten et al., 1997). The soils were wet-sieved into two fractions: coarse sand (−4 +20 mesh) and fine sand (−20 +200 mesh). The fine sand was processed by tabling and the coarse sand was processed by jigging. Tabling and jigging are size/density separation methods used to remove high-density particles (see Section 4.1.3). The lighter fractions or tailings from tabling and jigging were combined and used in the leaching tests.

The results of physical separation and leaching are shown in Tables 4-9 and 4-10. For the seven soil types, physical separation collected about 30 to 80% of the total lead in the soil as a dense fraction from the table and jig. Removing the dense fraction also reduced leachable lead in the soil by about 40% to 70%, except in soil 2, where the TCLP lead increased slightly in the tailings. Characterization of the unleached tailings consisted of scanning electron microscope (SEM) analysis and sequential extraction methods to identify the chemical speciation of lead. Leaching with HCl was effective in reducing the lead concentrations for most soils, but low pH was essential. The percent lead removed by acid leaching ranged from 22% to 93% for the seven test soils. All of the leached tailings passed the TCLP test criteria, indicating that HCl can successfully treat most lead species.

Table 4-9. Total Metals Content from Hydrochloric Acid Leaching Study[(a)]

Soil	Predominant Lead Species	Treatment Goal Lead Content (mg/kg)	All Soil Lead Content (mg/kg)	Unleached Tailings Lead Content (mg/kg)	Leached[(b)] Tailings Lead Content (mg/kg)
1	Carbonates	250	11,933	2,185	203
2	Associated with metal oxides	1,000	2,307	1,401	611
3	Oxides and carbonates	1,000	5,913	1,535	200
4	Sulfate	250	3,199	2,195	1,218
5	Oxides and carbonates	1,000	4,808	1,369	98
6	Sulfates, carbonates, oxide	1,000	1,394	500	391
7	Iron sulfate and lead oxide	1,000	4,249	2,755	1,033

(a) van Benschoten et al., 1997.

(b) Treatment conditions are HCl at a pH of 1, 25°C, leachant to solid ratio of 20:1, and 24-hr contact time.

Table 4-10. TCLP Test Results from Hydrochloric Acid Leaching Test[a]

Soil	Treatment Goal (mg/L)	All Soil TCLP Lead (mg/L)	Unleached Tailings TCLP Lead (mg/L)	Leached[b] Tailings TCLP Lead (mg/L)
1	0.5	29.5	10.6	0.3
2	0.5	1.27	2.0	0.5
3	0.5	134	41.7	0.8
4	0.5	6.46	4.0	Not done[c]
5	0.5	98.8	40.0	1.5
6	0.5	3.5	0.9	Not done[c]
7	0.5	19.7	11.7	0.7

(a) van Benschoten et al., 1997.
(b) Treatment conditions are HCl at a pH of 1, 25°C, leachant to solid ratio of 20:1, and 24-hr contact time.
(c) Untreated sample passed TCLP.

4.6.1.3 Other Acids

The Bureau of Mines (Wethington et al., 1992) and RSR Corporation (Prengaman and McDonald, 1990) are independently developing similar acid leaching processes to recover lead from soils, and battery wastes such as casings and sulfate-oxide sludge from scrap batteries. The process converts lead sulfate and lead dioxide to lead carbonate, which is soluble in fluorosilicic acid. Lead is recovered by electrowinning and the acid is recycled back to the leaching process. The fluorosilicic acid leach may be followed by nitric acid leaching to increase the lead removal. The process generally involves seven steps performed in the following order:

- Water wash to remove lead sulfate sludge
- Screening and water elutriation to remove metallic lead, rocks, and foreign material
- Size reduction of oversize pieces
- Carbonation treatment to convert lead sulfate in the ebonite casing to lead carbonate
- Ammonium bisulfite may be added to convert lead oxide to lead sulfate
- Acid washing to dissolve the lead carbonate
- Electrowinning to recover lead metal from solution.

The results of this testing are summarized in the literature and shown in Table 4-11.

4.6.2 Pilot Testing by NFESC and Bureau of Mines

Over the last 5 years, the NFESC and the Bureau of Mines Research Center (BMRC) have studied remediation of lead-bearing soils associated with small-arms ranges using physical separation and leaching methods developed for mineral processing (Johnson et al., 1994). NFESC wanted to explore the possibility of using physical separation to remove particulate lead before using stabilization or soil washing to treat the molecular or ionic lead. BMRC used its knowledge of mining techniques to develop a separation scheme that, in pilot studies, recovered a significant amount of lead from soils taken from various sites. For one of the sites where the lead was predominantly particulate, physical separation was able to recover lead to a level where the soil passed the TCLP test without having to undergo further chemical treatment.

Table 4-11. Results of the Bureau of Mines Treatability Tests on Lead-Bearing Soils

Site/Matrix	Untreated Material		Treated Material		
	Predominant Lead Species	Average Total Lead (mg/kg)	Leaching Treatment Method	Total Lead After Treatment (mg/kg)	EP Toxicity Leachable Lead After Treatment
United Scrap Lead/Soil	Pb, $PbSO_4$, PbO_2	8,000 - 18,000	HNO_3	200	<1
United Scrap Lead/Soil	Pb (2%), $PbSO_4$, PbO_2	8,000 - 18,000	H_2SiF_6/HNO_3	203	<1
Arcanum/Soil	Pb (6.6%), $PbSO_4$	71,000	H_2SiF_6/HNO_3	330	0.26
Arcanum/Soil	Pb (6.6%), $PbSO_4$	71,000	HNO_3	<250	<1
C&R Battery/Soil	Pb, $PbSO_4$, $PbCO_3$, PbO_2	17,000	HNO_3	29	<0.1

Source: U.S. EPA, 1991, EPA/540/2-91/009.

The separation scheme arrived at by BMRC after trying different combinations is shown in Figure 4-9. Although many users could probably achieve acceptable results with less complex operations, this flowchart shows how each piece of equipment was optimized to do what it does best. The plant operation is as follows:

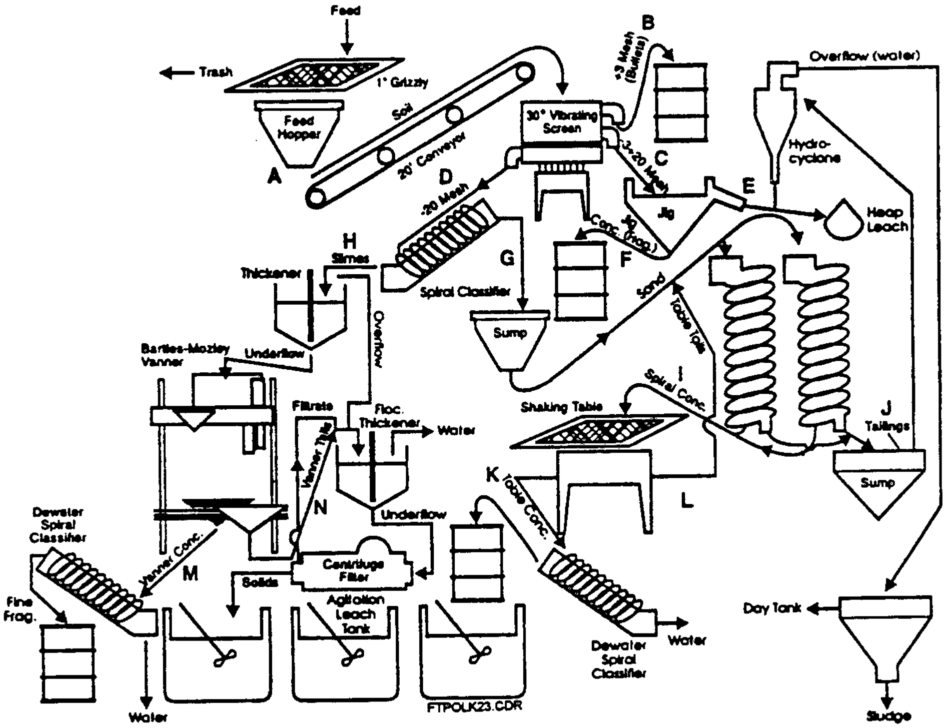


Figure 4-9. Bureau of Mines process for treating small-arms range soils

- ☐ The lead-bearing soil first is loaded into a feed hopper through a 1-inch grizzly. The grizzly removes rocks, branches, etc. The soil is fed via a conveyor belt to a two-deck (3-mesh and 20-mesh) vibrating screen. Water is added at the screen for wet screening; alternatively, a 20% slurry of the soil in water could be prepared separately and fed to the screen. The +3-mesh fraction containing a combination of bullets, bullet fragments, and pebbles is collected in a drum. This fraction can be sent to a lead smelter for recycling.
- ☐ The −3+20-mesh fraction is sent to a jig, and the jig concentrate (consisting of lead fragments) is drummed for recycling. The overflow from the jig goes to chemical treatment (heap leaching in this case).
- ☐ The −20-mesh fraction from the screen goes to a spiral classifier to remove slimes. The slimes (ultrafine particulate) go to the thickener for dewatering. The sludge from the thickener is fed to a Bartles-Mozley Table. The concentrate from the table is dewatered in a spiral classifier and drummed for recycling. The tailings are dewatered, first in a thickener (with addition of flocculant), and then in a centrifuge. The solids from the centrifuge are further treated chemically.
- ☐ The bulk of the −20 mesh fraction coming out of the screen and through the first spiral classifier is collected in a sump, from which it is pumped to the top of two spiral concentrators. The tailings from the spirals are dewatered in a hydrocyclone and sent to chemical treatment. The overflow water from the hydrocyclone is clarified and sent to a day tank for storage and reuse.
- ☐ The concentrate from the spirals is sent to a riffled shaking table. The table concentrate is dewatered in a spiral classifier and collected in a drum for recycling. The table tailings are recirculated back to the top of the spiral concentrators.

All the equipment in the flowchart is expected to fit on two or three 40-ft × 8-ft trailers. A throughput of 1.5 tons/hr of untreated soil is possible with relatively small equipment. The advantage of using physical separation to remediate lead-bearing soils is the ability to recover large amounts of lead without the use of large volumes of extraction fluid. Very little lead is left in the soil that goes on to chemical treatment. Because the following chemical treatment is heap leaching, the use of wet separation is justified and the water added to the soil forms part of the extractant liquid.

The performance of the various stages in the separation scheme shown in Figure 4-9 is given in Table 4-12. Starting with 1.5 tons of lead-bearing soil, Table 4-12 shows the distribution of the feed into various fractions and the amount of lead in each fraction. The "overall operation" columns show the product weight and lead content as percentages of their total values in the initial feed. The "unit operation" columns show the product weight and lead content as percentages of the feed to a particular unit process. The last two columns indicate the water balance maintained at various stages of the operation.

Interestingly, a simple screening step at 3 mesh results in 59.44% of the lead in the original feed being removed. A second screening step at 20 mesh (−3+20 mesh) removes another 29.64% of the lead in the original feed. Thus, almost 90% of the original lead in the soil from this particular site is removed just by screening. Jigging concentrates the −3+20 mesh stream from the screen from 12.73% lead to 31.67% lead, possibly making the material easier to sell to a recycler, and reduces the quantity, and therefore the shipping costs, of material shipped to a recycler.

4.6.3 Commercial Processes

Several vendors, including COGNIS, Inc. (TerraMet™), Earth Treatment Technologies, Inc., and BESCORP have developed and commercialized acid leaching processes to recover lead from soils.

Table 4-12. Performance of Separation Unit Processes for Lead Removal
(Source: U.S. EPA, 1995, EPA/540/R-95/512)

Stream Number[a]	Dry Wt (ton)	Overall Operation Soil Wt Dist (%)	Overall Operation Pb Wt Dist (%)	Wt Pb in Stream (lb)	Stream Assay, Pb (%)	Unit Operation Wt Dist (%)	Unit Operation Pb Dist (%)	Percent Solids of Stream	Water (gpm)
Feed (a)	1.5	100	100	316.2	10.54	100	100	100	0
+3 (B)[b]	0.127	8.46	59.44	187.95	74.07	8.46	59.44	70	0.22
-3+20 (C)[c]	0.368	24.53	29.64	93.72	12.73	24.53	29.64	70	0.63
-20 (D)	1.005	67.01	10.92	34.53	1.72	67.01	10.92	25	12.05
JIG T (E)	0.22	14.68	0.03	0.09	0.036	59.84	0.1	10	7.92
JIG C (F)	0.148	9.85	29.61	93.63	31.67	40.16	99.9	60	0.39
CLS SAN (G)	0.7	46.66	6.38	20.17	1.44	69.63	58.43	75	0.93
CLS SLI (H)	0.305	20.35	4.54	14.36	2.35	30.37	41.57	9	12.33
SPRL C (I)	0.026	1.73	3.57	11.29	9.35	3.7	55.9	65	0.06
SPRL T (J)	0.674	44.93	2.81	8.89	0.283	96.3	44.1	23	9.02
TBL C (K)	0.002	0.13	2.98	9.42	80.8	7.5	83.5	40	0.01
TBL T (L)	0.024	1.6	0.59	1.87	1.3	92.5	16.5	5	1.82
BM C (M)	0.016	1.07	1.5	4.74	13.65	5.24	33.09	15	0.36
BM T (N)	0.289	19.28	3.04	9.61	1.53	94.76	66.91	6	18.1

(a) T = tailings; C = concentrate; CLS = classifier; SAN = sands; SLI = slimes; SPRL = spiral; TBL = table; BM = Bartles-Mozley Table. Letters following stream description indicate stream location on Figure 4-9.

(b) +# = Retained on screen size #.

(c) -# = Passes through screen size #.

These processes use an acid leachant to remove metals from the soil and are reported to treat most types of lead, including metallic lead, soluble ions, and insoluble lead oxides and salts.

Physical separation is the first step in the commercial processes. Simple dry screening removes oversize materials. More complex physical separation can be used, if required. The lead-laden fines are then processed by acid leaching. The fines are acid-leached by at least two contacts with fresh acid. The treated solids are then separated from the leaching solution. The spent leaching solution is treated by ion exchange or reduction to recover lead and regenerate the leaching solution for reuse.

The BESCORP/COGNIS system was used for full-scale remediation of about 20,000 tons of lead-bearing soil at the Twin Cities Army Ammunition Plant, New Brighton, Minnesota. The average total lead concentration in the untreated soil was 17,000 mg/kg. The total lead residual in the treated soil was less than 300 mg/kg. The lead was recovered as part of solvent regeneration (Fix and Fristad, 1993; Lewis et al., 1995). The Earth Treatment Technologies system treated soils containing as high as 44,000 mg/kg of lead. The treated residual is reported to have contained less than 300 mg/kg and passed the TCLP test (DuGuay, 1993).

Physical separation followed by acid leaching has also been tested or applied for cleanup of metals-contaminated soils at Superfund sites. These tests are summarized in Table 4-13.

4.6.4 Fort Polk Demonstration

The physical separation and acid leaching technology was demonstrated on soils from Range 5 at Fort Polk, an Army Base near Leesville, Louisiana. Range 5 is an active 300-meter small-arms range that has

Table 4-13. Application Potential of Physical Separation Techniques to Waste Sites

Site	Application	Vendor/ Technology	Separation Equipment	Performance
Alaskan Battery Enterprise, Superfund Innovative Technology Evaluation (SITE) demonstration	Soil contaminated by broken lead batteries	Brice Environmental Service Corp/ BESCORP Soil Washing System	Wet screen, hydraulic separators, spiral classifier, clarifier	61-85% lead removal; sand fraction passed TCLP test, gravel fraction failed TCLP test
Twin Cities Army Ammunition Plant, Minnesota, ordnance waste	Soil contaminated with lead from priming compound manufacturing waste	Brice Environmental Service Corp/ BESCORP Soil Washing System	Physical separation as pretreatment prior to chemical leaching	No data
Gould, Portland, Oregon, battery recycling site	Soil and battery casings contaminated with lead	Canonie Environmental	Attrition scrubbing, washing, gravity separation	Lead concentration reduced from 100 to 200 mg/kg to ND to 5 mg/kg
United Scrap Lead, Ohio, battery recycling site	Soil and battery casings contaminated with lead	Canonie Environmental	Attrition scrubbing, washing, gravity separation	No data
Tonolli Corp., Pennsylvania, battery recycling site	Soil and battery casings contaminated with lead	Canonie Environmental	Attrition scrubbing, washing, gravity separation	No data

Sources: U.S. EPA, 1994, EPA/540/R-94/526 and U.S. EPA, 1994, EPA/542/R-94/003.

been used mainly for M-16 rifle training. The range has three berms, the last of which runs along the edge of a wetland. Fort Polk was selected for the demonstration because it is environmentally proactive and has active ranges that contain soil and metals accumulation of the type and quantity typically found at several DoD ranges. The demonstration was conducted in an old parking lot approximately 2 miles away from the range by road. The demonstration site was located some distance from the range to avoid closing adjacent ranges, whose cones of lethal fire (surface danger zones) extend into Range 5. Also, the demonstration site was located near an available power supply.

The separation/leaching technology demonstration at Range 5, Fort Polk was a joint effort between the Naval Facilities Engineering Service Center (NFESC) and U.S. Army Environmental Center (USAEC). The field activities related to the demonstration were conducted between August and December 1996. During this period, two vendors demonstrated their variations of the technology. At the request of USAEC and NFESC, Vendor 1 used acetic acid leaching and Vendor 2 used hydrochloric acid leaching. Battelle, under contract to NFESC, conducted the independent evaluation of the technology and its application at Fort Polk, as documented in the Final Technology Evaluation Report (Battelle, 1997a) and the Technology Application Analysis (Battelle, 1997b).

The goal of the demonstration was to evaluate physical separation and acid leaching for small-arms range soil processing. The demonstration had the following objectives:

- Design and mobilize the vendors' respective plants at Fort Polk and process up to 1,000 tons of Range 5 soil at an average continuous rate of 5 tons/hr.
- Evaluate the efficiencies of two potentially effective acids for leaching. Vendor 1 was asked to use acetic acid leaching and Vendor 2 was asked to use some acid other than acetic acid for leaching.
- Make a good faith effort to process the range soil to meet the TCLP criterion of 5 mg/L or less of lead. No criteria were set for other metals, but the removal of copper, zinc, and antimony by the process was also tracked.
- Achieve the TCLP criterion through metals removal, without the use of stabilization agents. The two vendors were therefore given total metals targets for the processed soil. Vendor 1's target was 1,000 mg/kg. The target was reduced to 500 mg/kg for Vendor 2 to better meet the TCLP criterion.
- Ensure that the processed soil would be physically and chemically suitable for reuse in an active berm.

A detailed characterization was performed on a representative 30-gallon composite sample of berm soil collected from Range 5. Table 4-14 contains the particle size analysis results obtained from wet screening of the sample. At Fort Polk, dry screening tended to underestimate the fines content of the soil because balls of fine clay were retained on the coarse screens. Figure 4-10 shows the results of additional characterization conducted by Battelle to determine the particle size and lead distribution in various fractions and the amenability of the lead in these fractions to physical separation:

- The raw soil from the berm (feed) had a lead assay of almost 0.5%.
- The +10-mesh coarse fraction constituted 2.3% of the berm material, but contained almost 80% of the original lead. Therefore, the majority of the lead in the range soil is recoverable by relatively simple size or gravity separation equipment, such as screens or jigs. About 3% of the

Table 4-14. Particle Size Analysis of the Raw Range Soil (30-gallon sample)

Raw Soil (Total Weight = 142.5 kg)			**Fraction Weight %**		
Mesh size	**Micron size**	**Fraction Weight (kg)**	**Retained (%)**	**Cumulative Passing (%)**	**Cumulative Retained (%)**
Organics	N/A	0.08	0.1	99.9	0.1
+10	1,680	3.13	2.2	97.7	2.3
+14	1,190	0.22	0.2	97.6	2.4
+20	841	0.33	0.2	97.4	2.6
+28	595	0.94	0.7	96.7	3.3
+35	425	2.23	1.6	95.1	4.9
+48	297	6.54	4.6	90.6	9.4
+65	210	22.1	15.5	75.0	25.0
+100	149	26.9	18.9	56.2	43.8
+150	105	22.3	15.6	40.5	59.5
+200	74	10.8	7.6	32.9	67.1
-200	-74	46.9	32.9	N/A	N/A

N/A = Not applicable.

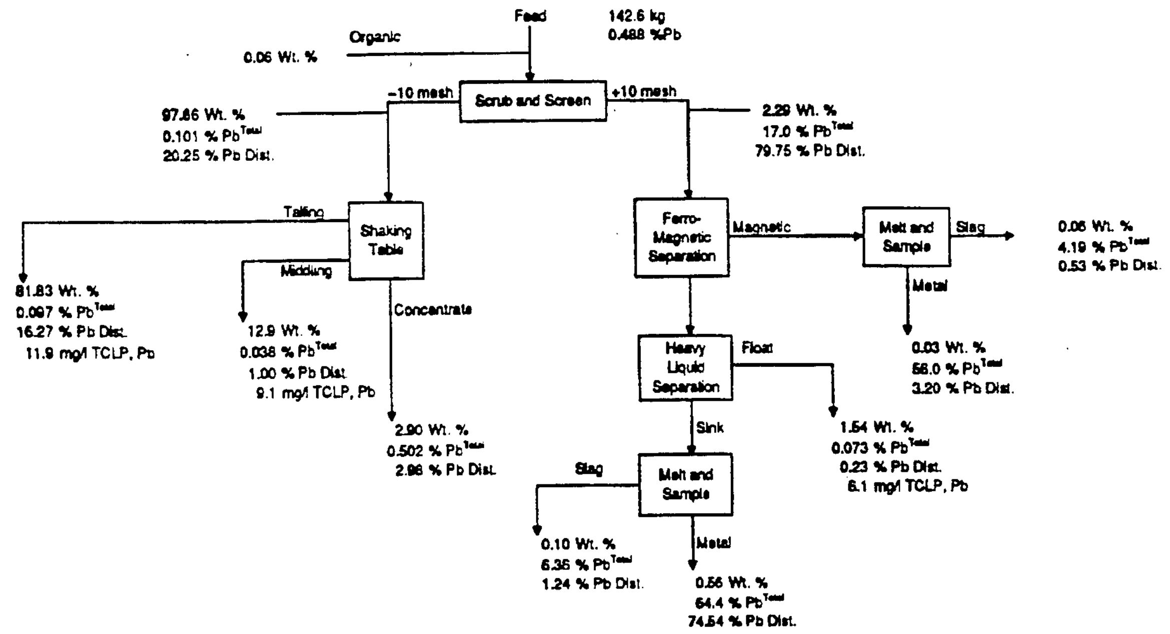


Figure 4-10. **Characterization of a 30-gallon sample of Range 5 soil to evaluate lead distribution and amenability to physical separation (conducted by Hazen Research for Battelle)**

lead was amenable to magnetic separation, by virtue of its association with the ferromagnetic fraction.

- When the coarse fraction was further separated into metals (magnetic and nonmagnetic) and gravel (float), the gravel was found to contain enough leachable lead to fail the TCLP test. This indicated that the coarse fraction also needed to be leached.
- The -10 mesh fraction constituted 98% of the berm material, but contained only 20% of the lead. The -10-mesh fraction was processed on a shaking table to see if this material was amenable to gravity separation. Although gravity separation isolated a concentrate stream that had an assay of 0.5% lead, this constituted less than 3% of the lead in the original range material. The middlings and tailings (predominantly soil) fractions retained most of the lead and both streams failed the TCLP test. The -10-mesh fraction did not contain much lead amenable to gravity separation.

Physical separation alone was not sufficient to meet target criteria. The -10-mesh material contained sufficient fine particulate and/or ionic lead to require removal by leaching.

4.6.4.1 Vendor 1 Performance

Vendor 1 assembled an on-site plant and processed 263 tons of Range 5 soil by physical separation and acetic acid leaching.

Process Efficiency

Table 4-15 shows the results of Vendor 1's processing. On the first day of processing the processed soil met the total and TCLP lead targets. Approximately 93% of the total lead, 93% of the total copper, 77%

Table 4-15. Overall Removal of Total and Leachable Lead with the Acetic Acid Process

Date	Total Lead Raw Soil (mg/kg)	Processed Soil (mg/kg)	Removal (%)	TCLP Lead Raw Soil (mg/L)	Processed Soil (mg/L)
15-Sep	1,854	122	93	34.6	3.07
21-Sep	1,407	208	85	21.0	5.99
25-Sep	3,347	330	90	22.0	10.3
2-Oct	2,741	404	85	40.5	11.2
4-Oct(a)	208 - 330	269(b)	None	5.99 - 10.3	7.80(b)
10-Oct	4,789	839	82	106	21.7
12-Oct	4,789	1,443	70	106	48.0
Statistics					
n	5	N/A	N/A	5	N/A
Avg.	2,828	N/A	N/A	45	N/A
Std. Dev.	1,331	N/A	N/A	35	N/A
80% C.I.	2,828±792	N/A	N/A	45±21	N/A

(a) This sample is a combination of the processed samples from September 21 and 25 that failed TCLP testing.
(b) These sampling data are the results of reprocessing of soil that failed TCLP on September 21 and 25.
N/A = Not applicable. The process did not reach steady state and the distribution is not normal.
C..I. = confidence interval.
n = Number of independent measurements.

of the total zinc, and 70% of the total antimony were removed during this initial processing effort, indicating that acetic acid has the potential to remove heavy metals to target levels. Subsequently however, both total and leachable lead levels rose incrementally. This decline was due to increasing lead levels in the raw soil and a buildup of lead in the regenerated leachant caused by inadequate precipitation.

Table 4-16 shows the lead assays and pH ranges of various process streams in the plant. Most of the oversize material (O) accumulated in the basin of the blade mill rather than on the screen and was

Table 4-16. Distribution of Lead in Acetic Acid Process

Process Stream	Stream Description	pH Range	Total Lead Result (mg/kg) Sep. 15	Oct. 1-3	Oct. 7-11	TCLP Lead Result (mg/L) Sep. 15	Oct. 1-3	Oct. 7-11	Avg. Total Lead Conc. (mg/kg)
U	raw soil	4.0-4.8	1,854	2,741	4,789	34.6	40.5	106	2,828
T	processed soil	4.1-4.9	122	404	839	3.07	11.2	21.7	722
M	jig concentrate	4.8	N/A	484	N/A	N/A	17.6	N/A	484
O	oversize fraction	5.2	N/A	N/A	239,000	N/A	N/A	N/A	239,000
P	precipitate sludge	3.2-3.6	N/A	N/A	11,990	N/A	N/A	321	11,990
Z	organic matter	N/A	6,457	N/A	N/A	11.1	N/A	N/A	6,457
C	coarse processed fraction	4.9-5.5	N/A	252	N/A	N/A	6.49	N/A	252
F	fine processed fraction	4.0-4.3	N/A	947	N/A	N/A	15.1	N/A	947
L	leach circuit feed	4.4	832	5,347	N/A	21.3	49.9	N/A	3,090
Q(a)	regenerated leachant	2.9-3.3	N/A	627	29.3	N/A	N/A	N/A	328

(a) Leachant concentration measured in units of mg/L.
N/A = Not applicable/available.

collected at the end of the demonstration. The jig concentrate (M) did not contain much lead, indicating that the coarse soil fraction may not have contained much lead at the size fraction suited for the jig. Organic matter (Z) collected in the process contained high levels of lead, but this stream was very small in volume. Both coarse (C) and fine (F) processed fractions individually failed the TCLP test. This was because inadequate precipitation caused dissolved lead to build up in the regenerated leachant (Q), at times reaching levels as high as 627 mg/L. The pH levels of the regenerated leachant (Q) and precipitate (P) indicate that the precipitation step was being implemented at a very low pH, at which most precipitants may be expected to be inefficient.

The following factors contributed to the low plant reliability and inability to meet processing targets:

- ☐ Inadequate bench-scale testing. At bench-scale itself, Vendor 1 was unable to optimize the separation/leaching processes to attain the TCLP lead target. Precipitation efficiency was not optimized during the bench-scale tests and key operating parameters, such as precipitant dosage and effective pH range, wereinadequate.
- ☐ Inadequate process control. The problem with the buildup of lead in the leachant was not identified and corrected in time during the demonstration because the vendor's atomic absorption (AA) analyzer was not functional, and there was no other means to provide reliable on-site verification. Vendor 1 also appeared to be inadequately staffed. Additional operators (including an on-site process chemist) would have provided better process control.
- ☐ Inadequate attention to material handling and equipment sizing during plant design. Various material handling problems were encountered in the feed hopper, plate feeder, soil deagglomerator, sand screw, vacuum belt filter, and plate-and-frame filter press. These difficulties caused frequent bottlenecks and downtime.

4.6.4.2 Vendor 2 Performance

Vendor 2 assembled an on-site plant and processed 835 tons of Range 5 soil by physical separation and hydrochloric acid leaching.

Process Efficiency

As seen in Table 4-17, the processed soil from Vendor 2's plant consistently met total and TCLP lead targets. Total lead was reduced from an average of 4,117 mg/kg in the raw soil to an average of 165 mg/kg in the processed soil. Leachable lead levels as measured by TCLP were reduced to an average of 2 mg/L. Figure 4-11 shows the daily total metals removal performance of the process. Processing removed an average of 96% total lead, 97% total copper, 89% total zinc, and 60% total antimony from the range soil. Figure 4-12 shows the daily TCLP metals removal performance of the process.

Figure 4-13 shows the lead assays of the various process streams. Most of the metals that were removed by the process were collected in the jig bed (M′) and in the precipitate sludge (P). The organic matter separated from the classifier overflow showed high concentrations of lead. This organic matter was blended with the final processed soil.

Table 4-17. Overall Removal of Total and Leachable Lead with Vendor 2's Hydrochloric Acid Process

	Total Lead			TCLP Lead	
Date	Raw Soil (mg/kg)	Processed Soil (mg/kg)	Removal (%)	Raw Soil (mg/L)	Processed Soil (mg/L)
15-Nov	4,819	143	97	18.4	3.07
16-Nov	4,819	178	96	18.4	1.83
20-Nov	4,152	125	97	20.7	0.958
21-Nov	3,567	134	96	37.3	1.32
22-Nov	4,068	115	97	33.5	0.56
23-Nov	5,194	232	96	31.9	1.75
25-Nov	5,194	235	95	31.9	2.15
26-Nov	5,040	181	96	36.3	1.97
27-Nov	5,040	165	97	36.3	2.84
29-Nov	5,040	230	95	36.3	3.44
30-Nov	3,351	233	93	40.4	2.53
2-Dec	3,351	177	95	40.4	1.85
3-Dec	3,351	132	96	40.4	1.36
4-Dec	2,743	113	96	13.7	2.35
5-Dec	2,743	127	95	13.7	3.06
6-Dec	2,743	123	96	13.7	0.757
Statistics					
n	8	16	16	8	16
Avg.	4,117	165	96	29	2.0
Std. Dev.	869	46	1.0	10	0.86
80% C.I.	4,117±435	165±15	96±0.34	29±5.0	2.0±0.29

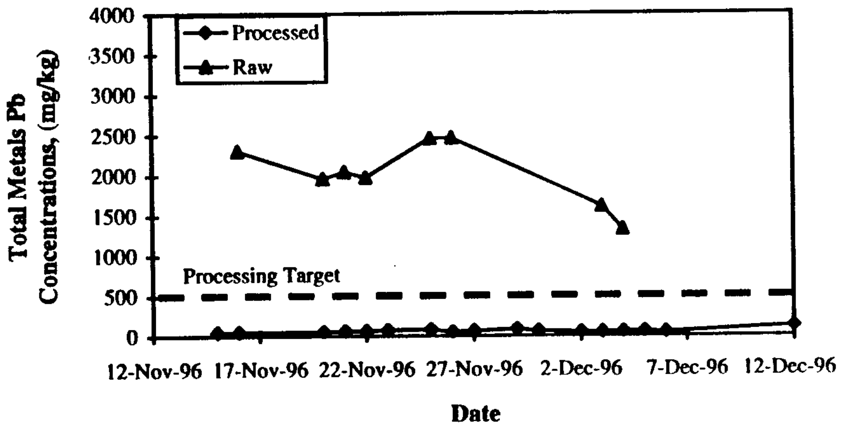
C.I. = confidence interval.
n = number of independent measurements.

The metals collected in the jig bed (M′) were an unexpected process stream that resulted from on-site modifications made to the plant by the vendor. Because of difficulties encountered in screening the raw soil, Vendor 2 eliminated the screening unit and the coarse material jig from the planned plant configuration. Instead, the raw soil was sent directly to the attrition scrubber and classifier. The coarse fraction from the classifier was sent to the fine material jig. In this jig, the metal fragments, instead of sinking into the jig concentrate, were retained on top of the jig sieve along with the ragging. These metal fragments were hand-sorted and removed by an operator.

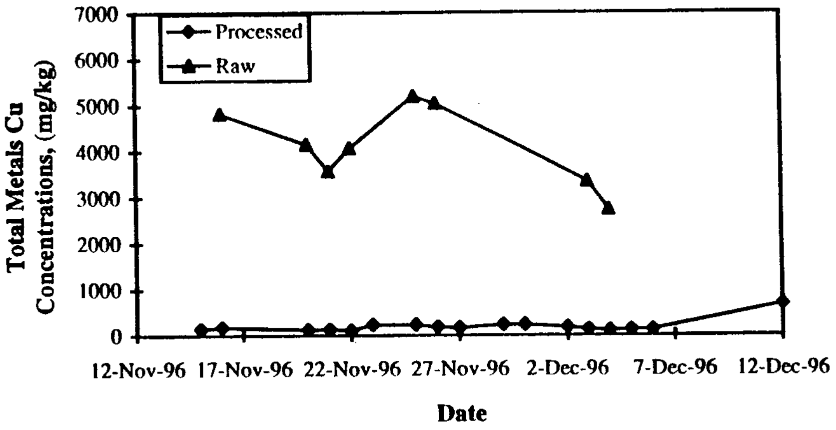
As seen in Figure 4-13, both coarse (C) and fine (F) processed fractions contained low levels of lead. These two fractions were combined to form the final processed soil (T) that was neutralized and returned to the range. The processed soil had a loose texture and appeared to be suitable for reuse in the active berm at Range 5. Precipitation was conducted efficiently at a pH of around 9.5 by adding sodium hydroxide. Precipitation reduced the lead content from 96 mg/L in the leachate (Q_f) to 11.5 mg/L in the regenerated leachant (Q_c).

The mass distribution of lead in the input and output streams in the plant is summarized in Table 4-18. Most of the lead was collected in the jig bed rather than in the jig concentrate. About 7% of the lead was collected in the precipitate sludge. The organic matter isolated from the soil contained a high concentration of lead but its mass was not significant. About 4% of the lead in the raw soil was residual in the processed soil. The mass balance is skewed mainly by the high variability of the lead concentration

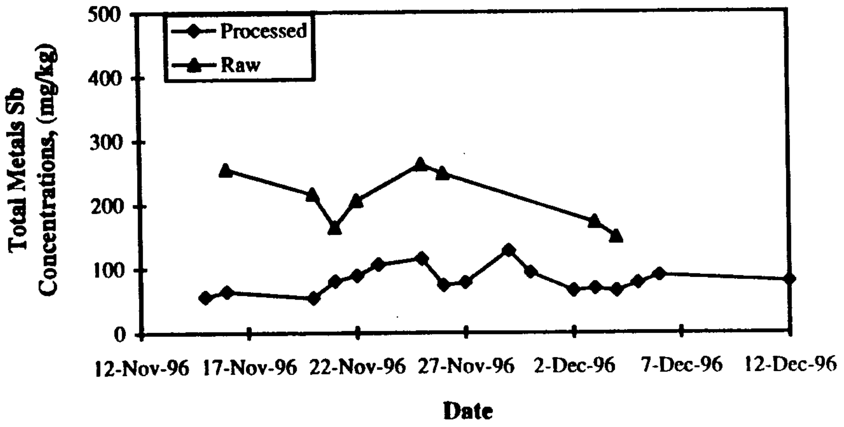
(a) Field Demonstration Total Metals Pb Concentrations for Processed and Raw Soil



(b) Field Demonstration Total Metals Cu Concentration for Processed and Raw Soil



(c) Field Demonstration Total Metals Sb Concentrations for Processed and Raw Soil



(d) Field Demonstration Total Metals Zn Concentrations for Processed and Raw Soil

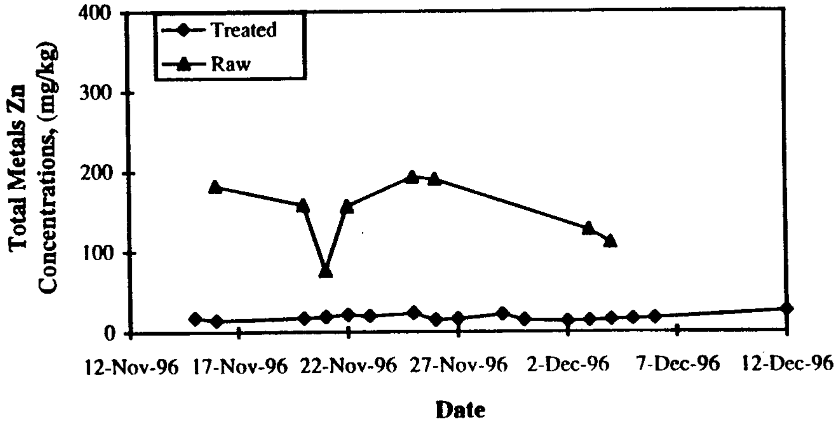
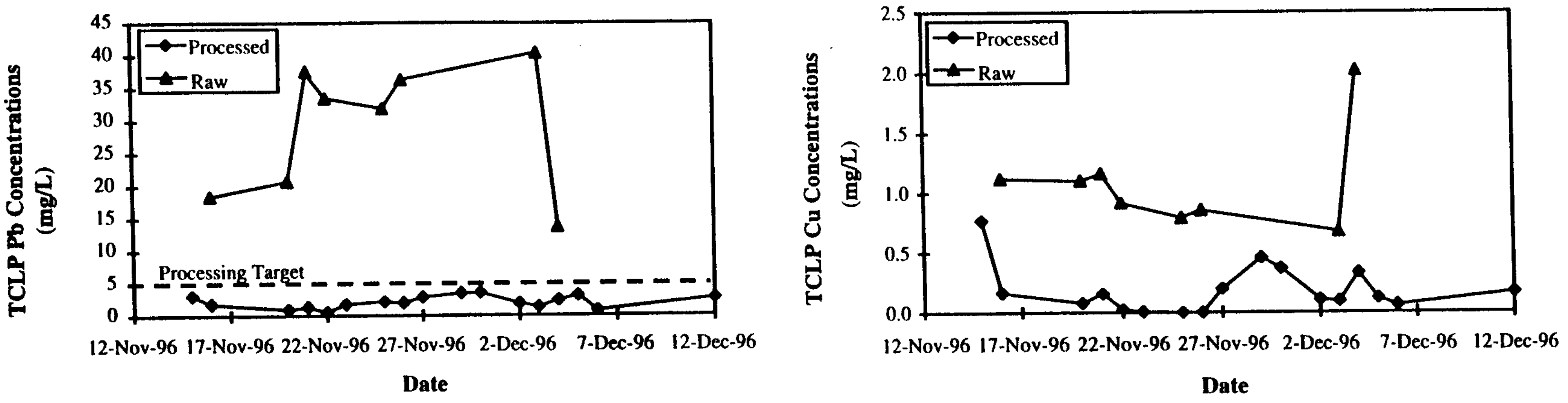
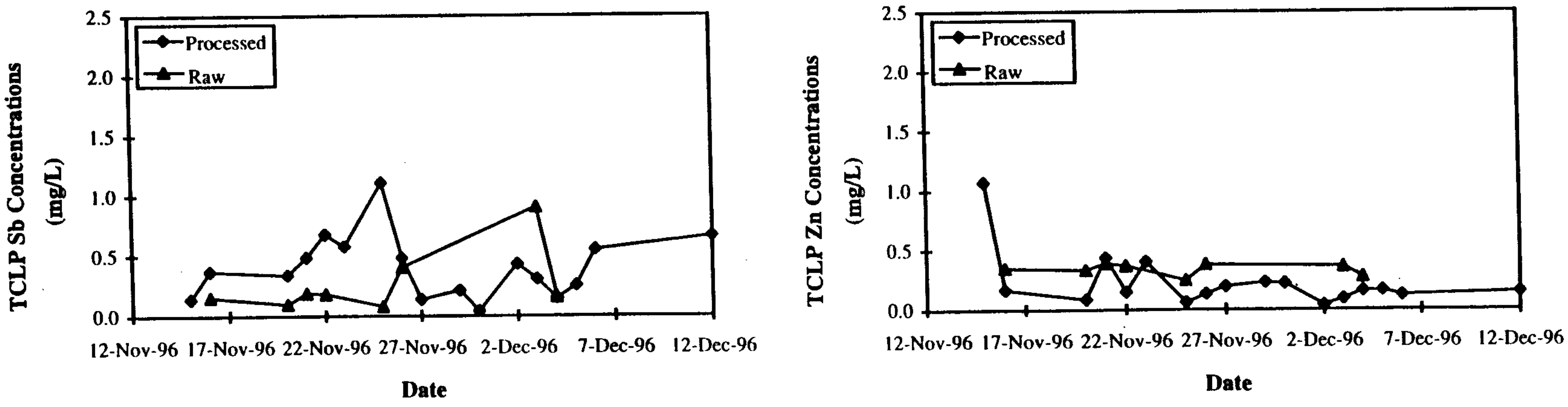


Figure 4-11. Total metals removed during the hydrochloric acid demonstration at Fort Polk



(a) Hydrochloric Acid Field Demonstration TCLP Pb Concentrations for Processed and Raw Soil

(b) Hydrochloric Acid Field Demonstration TCLP Cu Concentrations for Processed and Raw Soil



(c) Hydrochloric Acid Field Demonstration TCLP Sb Concentrations for Processed and Raw Soil

(d) Hydrochloric Acid Field Demonstration TCLP Zn Concentrations for Processed and Raw Soil

Figure 4-12. TCLP performance during the hydrochloric acid demonstration at Fort Polk

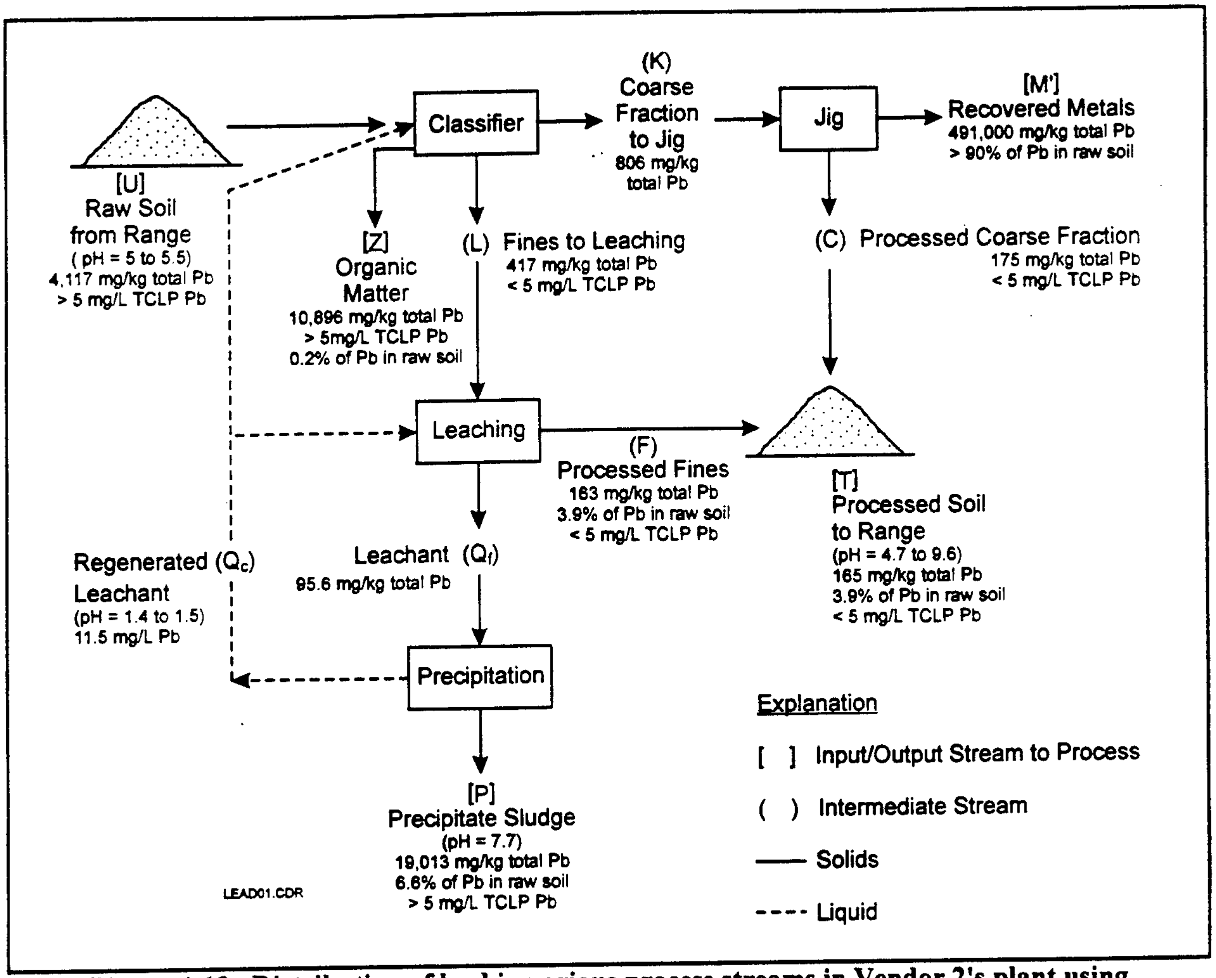


Figure 4-13. Distribution of lead in various process streams in Vendor 2's plant using hydrochloric acid leaching.

in the jig bed metals (M′). The lead content of this stream was estimated by analyzing three grab samples of the oversize material, which contained whole bullets, bullet fragments, bullet casing, and gravel. These three grab samples were analyzed by special pyrometallurgical techniques to obtain average lead, copper, zinc, and antimony contents that were used as an estimate of the metals in this fraction for all the samples during the demonstration.

Process Residuals

The residuals from Vendor 2's processing are shown in Table 4-19. Both the jig bed metals (M′) and the precipitate (P) were sent to an off-site smelter for recycling of their lead content. The smelter did charge a recycling fee for accepting the material.

4.7 Advantages and Limitations

Physical separation and acid leaching provide long-term effectiveness by recovering much of the lead and returning it to commercial use. Conventional alternatives, such as S/S treatment or disposal, rely on chemical and physical containment to immobilize the metals. Both of these containment methods have demonstrated effectiveness over periods of years or decades, but effectiveness beyond this time frame cannot be predicted.

Table 4-18. Mass Distribution of Lead in Various Process Streams for Vendor 2

Process Stream	Stream Description	Moisture Content (%)	Mass of Process Stream (kg)(a)	Average Lead Concentration (mg/kg)	Mass of Lead (kg)	Mass Percentage of Lead (%)(b)
U	raw soil	9.1	757,507	4,117(c)	2,836	100
T	processed soil	22.8	868,825	165	111	3.9
P	precipitate sludge	62.9	26,672	19,013	188	6.6
Z	organic matter	40.0	800(d)	10,896	5.2	0.2
M′(e)	jig bed metals	5.0(e)	7,859(f)	491,900(g)	3,673	129.5(h)

(a) Total mass of process streams are on a wet weight basis.

(b) Overall balance equation : U = T + P + Z + Metals.

(c) Concentration of total lead in the raw soil varied considerably from day-to-day.

(d) Mass of material in this stream was estimated to be 1 % of the total feed.

(e) This stream contained particulate metals collected from the jig bed and a small amount of soil; moisture content was assumed to be 5 %.

(f) Mass of material in this stream was estimated from the weights of the drums reported by the off-site recycling facility.

(g) Concentration of lead in the recovered metals stream was measured by pyrometallurgical analysis conducted on three samples collected from this stream.

(h) This number has the highest uncertainty because of the high variability of this stream and the limitations of the analytical methods.

Table 4-19. Residuals Disposal for the Vendor 2 Demonstration

Process Stream	Stream Description	Average Lead Concentration (mg/kg)	Hazardous/ Nonhazardous	Disposal Method	Mass of Stream (kg)(a)	Unit Cost ($)	Total Cost ($)
T	Processed soil	165	Nonhazardous	Returned to range	745,968	$0.00	$0
P	Precipitate sludge	19,013	Hazardous	Recycled	26,672	$0.18	$4,850
Q_c	Process solution	< 5 mg/L(b)	Nonhazardous	Discharged to POTW	22,000 gal	$0.00	$0
Z	Organic matter	10,896	Nonhazardous	Reblended with process soil(c)	800(d)	$0.00	$0
M′	Particulate metals	491,900	Hazardous	Recycled	7,859(e)	$0.53	$4,158

(a) Total mass of process streams are on a wet weight basis.

(b) The lead concentration measured during the demonstration was 11 mg/L. The final concentration measured prior to discharge was less than 5 mg/L due to additional processing of the discharge by the vendor and the influx of rainwater into the containment pond.

(c) In the future, this stream should be reblended with the precipitate sludge, or disposed of as hazardous waste.

(d) The mass of material in this stream was estimated to be 1% of the total feed.

(e) Mass of material in this stream was estimated from the weights of the drums reported by the off-site recycling facility.

Reduction of the toxicity, reduction of mobility, and reduction of the volume of contaminants are the three principal measures of a cleanup alternative's overall performance. The 1986 Superfund Amendments and Reauthorization Act (SARA) emphasizes that the preferred alternative should reduce (1) the level of toxicity of contaminants at the site, (2) the spread of contaminants away from the source, and/or (3) the volume or amount of contaminants at the site. Treatment using physical separation and acid leaching is responsive to the SARA criteria because the toxicity of the waste is reduced by removing metals. Both the total and leachable metal concentrations in the waste are reduced.

Physical separation and acid leaching processing presents some potential hazard sources for operating personnel. Processing requires soil transfer and mixing equipment and involves chemical handling and material transfer operations. However, this is done with standard construction and chemical handling equipment and does not pose any hazards beyond those normally encountered during industrial activities. The potential hazards can be mitigated using standard safety procedures and equipment (see Section 8.0 and Appendix A).

Physical separation and acid leaching operations use commercial off-the-shelf equipment and technology. Application of acid leaching to small-arms range soils is an innovative technology, but is approaching full commercial maturity. A variety of vendors are available to implement the technology (USAEC, 1997).

5.0 Treatability Testing

Treatability testing should be planned to acquire information for evaluating the technology and providing a basis for design and implementation, if the technology is selected. This section describes methods for structuring treatability tests to efficiently collect the information required for physical separation and acid leaching to process small-arms range soils.

5.1 Prescreening Characteristics

Historical records and site characterization results should be reviewed to collect as much information as possible about the nature and extent of metals accumulation and the engineering properties of the matrix. A review of historical information provides design basis data and identifies data gaps that must be filled by the treatability testing.

Maps and plans showing the number of firing points; the height, width, and length of the berm; width and length of the firing range; and width and length of the overflight area usually are available. If they are not available, a survey should be performed. Dimensional data are essential for estimating the volume of material to be treated and for selecting excavation equipment. Other important historical aspects are the use patterns and maintenance history of the range. The types of ammunition used at the range should be determined to define the expected size, shape, and composition of the bullets. Records indicating the age of the range and the amount of ammunition expended annually for practice at the range, if available, allow estimation of the total amount of lead in the berm. Prior maintenance activities have important effects on the distribution of bullets in the berm. Some ranges periodically scoop bullet accumulations out of the bullet pockets for recycling. The recycling operation reduces the total lead inventory in the range but can spread bullets around and into the berm. Resurfacing, another approach to correcting a ricochet problem, buries bullets inside the berm. At old, heavily used ranges there may be several layers of bullets many feet below the existing surface of the impact berm.

Site characterization results should be reviewed to establish the types of metals and the metal concentrations and distribution. The chemical analysis results should be reviewed for completeness. For example, analysis for antimony should be included for at least a few samples. In addition, samples should come from inside the berm as well as from the surface. In shotgun shotfall areas, a few samples should be analyzed for arsenic and PAHs.

The bulk chemistry and engineering properties of the soil are important to the design of the system. Site characterization programs often focus mainly on determining metals concentrations. Data such as soil classification, bulk density, metals speciation, pH, particle-size distribution, and CEC can be useful in the preliminary assessment of the applicability of the technology and for planning the treatability test.

The proportion of fine materials in the soil is an important factor determining the effectiveness and cost of physical separation and acid leaching operations. The surface area is larger and settling velocity is lower for fine particles in comparison to larger particles of similar shape and density. Increased surface area increases the capacity of the soil for adsorbing metals, particularly if the fine particles are clay or humic materials. Lower settling velocity increases the residence time required to perform physical separations. Both factors tend to cause processing of fine particles to limit the throughput of a physical separation and acid leaching system. The capacity of separation and leaching operations usually is controlled by the content of fine particles in the soil. If the actual fine particle content is higher than the content measured in the site characterization or treatability studies, the system capacity and performance will suffer. For example, a system with a clarifier designed to process 5 tons per hour of fine particles has a throughput of 50 tons per hour for soil containing 10% fines, but if the soil contains 50% fines, the same system can process only 10 tons of soil per hour. Because physical separation and acid leaching are wet processes, the fines content should be determined by wet sieving.

The chemical form of the metals strongly influences the selection of acid leaching chemical and operating conditions. The bullets enter the berm as elemental metals, but the actions of weather and chemicals in the soil alter the chemical state of the metals. Factors such as pH and the concentration of anions (e.g., PO_4^{3-}, CO_3^{2-}, SO_4^{2-}, and NO_3^-) strongly affect the final equilibrium state and the rate of transformation. Therefore, the design of the leaching and leachant regeneration system is site specific.

5.2 Establishing Testing Goals and Data Quality Objectives

The goals of treatability testing performed to support a project using physical separation and acid leaching to clean up small-arms range soils are as follows:

- Determine process feasibility
- Select physical separation approach
- Optimize leaching system parameters
- Determine design parameters.

Process feasibility is determined by the ability to meet the site-specific limits established on total and/or leachable metals remaining in the soil. The testing approach and analytical methods should provide at least 95% confidence that the measured mean is 20% of the true mean for the total or leachable metal content, as applicable.

Selecting the physical separation approach, optimizing leaching parameters, and determining design parameters require interpretation of a series of soil characterization and treatability tests. In general, the data quality objectives applied to each individual test need not be highly demanding. Moderate data quality is acceptable for treatability testing because of the following factors:

- Decisions are developed using a weight-of-evidence approach that applies several sources of overlapping information to arrive at a conclusion
- Design of the process should be developed to allow for flexibility in operation.

The selection of the physical separation method is an example of the weight-of-evidence approach. The decision is based on testing to determine particle-size distribution along with results from several bench-scale tests using different separation methods.

The process must be sufficiently flexible to accommodate the expected variations in soil conditions and metal content determined by the treatability testing. Factors such as the proportion of fine particles, the total metal content, or the size and shape of metal particulate in the soil may be different at different points in the soils being treated. The process should be designed to allow the flexibility to adapt to soil conditions through changes such as adjustment of soil feed rates or water flowrates, contact between the soil and the acid, and number of repeated cycles of contact with fresh acid.

Collecting a sample that accurately represents the soil to be treated is a requirement fundamental to developing and performing a meaningful treatability test. Both the sample collection approach and the size of the sample should be carefully designed to support good data quality (see Section 5.3.1). In particular, the sample must accurately represent the proportion of fine particles in the soil.

The capabilities of standard methods should be considered when establishing data quality objectives. Examples of test methods are provided to assist in planning tests and setting data quality objectives. Methods to determine matrix physical parameters, total and leachable metals in soils, and metals in water for small-arms range treatability studies are presented in Tables 5-1, 5-2, and 5-3, respectively. Table 5-2 summarizes methods to determine chemical properties of soils or to extract total metal content or leachable metals for subsequent analysis. Table 5-3 summarizes methods to determine chemical properties of aqueous samples including process water or leachate from extraction methods described in Table 5-2. Method numbers are provided as examples of applicable procedures. Equivalent methods may be available at lower costs depending on the capabilities of the analytical laboratories used for the study.

Table 5-1. Summary of Analytical Methods for Small-Arms Range Physical Properties

Analysis	Method	Method Characteristics
Particle-size distribution	ASTM D 422	Determines particle-size distribution by sieve size separation on a dry soil sample.
Particle-size distribution	ASTM C 117	Determines quantity of fines (-200 mesh) by wet sieving
Soil classification	ASTM D 2487	Determines the soil type as defined by the Unified Soil Classification based on laboratory measurements.
Soil classification	ASTM D 2488	Determines the soil type as defined by the Unified Soil Classification based on visual observations.
Bulk density	ASTM D 4531	Determines the weight per unit volume of an oven-dried soil sample.
In situ bulk density	ASTM D 2937	Determines mass per unit volume of an intact soil sample collected by a driven cylinder method.
In situ bulk density	ASTM D 1556	Determines mass per unit volume of an intact soil sample collected by a sand cone method.
Porosity	ASTM D 2434	Determines the pore space in a soil sample by dividing its bulk density by the particle density.
Moisture content	ASTM D 2216	Determines the weight percent free water by oven drying at 110°C.

5.3 Test Planning

This section describes how to efficiently collect the data needed to evaluate and design a physical separation and acid leaching system.

5.3.1 Sample Selection

The sample selection process should be designed to give a representative sample that is large enough to allow testing but not so large that the laboratory is unable to handle the material or excessive amounts of material are wasted. Table 5-4 indicates approximate sample weights needed to provide a representative sample based on the largest diameter piece in the sample for uniform, medium, and heterogeneous materials. Range soils typically contain lead particles less than 3/8 inch in diameter and can be considered as medium uniformity or heterogeneous samples. Using these parameters indicates that a sample in the range of 300 to 1,800 lb is adequately representative. Assuming the excavated mixture of soil and lead has a density of 4,000 lb/yd^3, a 55-gal drum contains about 1,080 lb, so one or two drums of soil typically will give a sufficient amount of sample.

Table 5-2. Summary of Analytical Methods for Metals in Small-Arms Range Soils

Analysis	Method	Method Characteristics
pH	EPA SW-846 Method 9045	Determines pH of soil or waste by mixing the sample with reagent water and measuring the resulting aqueous solution with a pH electrode.
Cation exchange capacity	EPA SW-846 Method 9081	Determines available sites for exchange of cationic metals using the sodium acetate methods. One factor in assessing sorption of metals in soils.
Total organic carbon	EPA SW-846 Method 9060	Approximates the nonpurgeable organic carbon content. One factor in assessing sorption of metals in soils.
California Waste Extraction Test	California Code of Regulations Title 22 Section 66262	Determines status as hazardous waste in California based on Total Threshold Limit Concentration (TTLC) and Soluble Threshold Limit Concentration (STLC).
Toxicity Characteristic Leaching Procedure	EPA SW-846 Method 1311	Determines the mobility of both organic and inorganic analytes present in liquid, solid, or multiphase wastes through liquid extraction and analysis of the extracts. This test is the basis for RCRA leachable toxicity hazardous waste characteristic.
Acid digestion[(a)]	EPA SW-846 Method 3050	Nitric acid treatment to extract a solution from sediment, sludge, or soil samples for total metal analysis by flame or furnace atomic absorption (AA) spectroscopy or inductively coupled plasma (ICP) spectroscopy.
Generalized acid neutralization capacity	Isenburg and Moore, 1992	• Determines soil pH response or buffering capacity. • Determines mobility or solubility of lead at different pH levels (Igwe et al., 1994).
Sequential extraction	Isenburg and Moore, 1992	Helps to indicate the chemical form and leaching characteristics of the lead
Particle size and metal distribution analysis	Igwe et al., 1994	Determines distribution of metal in various particle size fractions. The sample is separated into size fractions by screening and each fraction is analyzed to determine the metal content.
Loss on ignition	EPA Water and Waste Method 160.4	Determines weight of materials that are volatile at 550°C.

(a) Method 3050 does not include Sb as a target analyte, but acceptable recoveries have been demonstrated in practice (U.S. EPA, 1990, EPA/540/5-89/005a).

The upper limit on sample size is controlled by the needs and capabilities of the laboratory. A mineral processing laboratory will have equipment to handle 55-gal drums of soil. A chemistry laboratory that might be used to perform leaching tests may be unable to process samples larger than a few pounds. A few pounds of soil can be used for preliminary studies if the laboratory cannot handle drum-sized quantities. A better approach is to ship a large sample to a mineral preparation laboratory for preprocessing to prepare a sample for the chemistry laboratory.

Obtaining a representative sample of an impact berm is a difficult challenge. For proper sampling, a heterogeneous mixture of solids should be arranged to approximate a one-dimensional configuration (Gy, 1982; Pitard, 1992). For example, a full cross section of soil should be collected at random times at a point on a conveyor belt. This ideal cannot be achieved without excavating the entire berm, which is not practical. An acceptable alternative is to collect many composites from random locations through the berm. Sampling should be designed so that any point in the full depth of the expected excavation has an equal probability of being sampled. Single samples should be collected to the full depth of the planned excavation at 5 to 15 points (see Table 5-5). The single samples are mixed and then reduced to the required sample size using a riffler, quartering methods, or subsampling with a sampling thief.

Table 5-3. Summary of Analytical Methods for Metals in Surface Water, Groundwater, and Extracts for Small-Arms Range Sites

Analysis	Method	Method Characteristics
pH	EPA SW-846 Method 9040	Determines pH of water using a combination pH electrode.
Eh	ASTM D 1498	Determines the oxidation-reduction potential of aqueous media using a combination oxidation-reduction electrode.
Acid digestion[(a)]	EPA SW-846 Method 3010	Nitric acid digestion to prepare aqueous samples for analysis by flame AA spectroscopy or ICP spectroscopy.
Acid digestion (Pb - furnace AA)	EPA SW-846 Method 3020	Nitric acid digestion to prepare aqueous samples for lead or thallium analysis by furnace AA.
Acid digestion (As - furnace AA)	EPA SW-846 Method 7060	Nitric acid digestion to prepare aqueous samples for arsenic analysis by furnace AA.
Pb, Cu, Sb, As	EPA SW-846 Method 3020	Determines metal content, simultaneously or sequentially, using ICP
Pb (by furnace AA)	EPA SW-846 Method 7421	Determines lead content by drying, charring, and atomizing an aliquot of aqueous sample in a graphite tube furnace in an AA. Furnace methods are used when low detection limits are required.
As (by furnace AA)	EPA SW-846 Method 7060	Determines arsenic content by drying, charring, and atomizing an aliquot of aqueous sample in a graphite tube in an AA. Furnace methods are used when low detection limits are required.

(a) Method 3010 does not include Sb as a target analyte but acceptable recoveries have been demonstrated in practice (U.S. EPA, 1990, EPA/540/5-89/005a).

AA = atomic absorption.

Table 5-4. Required Sample Size as a Function of Sample Heterogeneity

Diameter of Largest Piece (inch/mesh)	Sample Weight Need for Various Ore Types		
	Uniform Ore Sample Size (lb)	Medium Ore Sample Size (lb)	Heterogeneous Ore Sample Size (lb)
0.500	250	556	3,200
0.375	141	313	1,800
0.3125	98	217	1,250
0.250	63	139	800
0.1875/4	35	78	450
0.131/6	17.2	38.1	220
0.093/8	8.65	19.2	111
0.065/10	4.3	9.5	55
0.046/14	2.16	4.8	28
0.0328/20	1.075	2.37	13.76
0.0232/28	0.539	1.2	6.90
0.0164/35	0.269	0.59	3.44
0.0116/48	0.135	0.30	1.73
0.0082/65	0.067	0.15	0.86
0.0058/100	0.034	0.075	0.43
0.0041/150	0.017	0.038	0.215
0.0029/200	0.009	0.019	0.107

Source: Adapted from Taggart, 1945.

Table 5-5. Number of Samples Needed to Achieve Various Confidence Levels ([1-α]×100) and Relative Precisions (r) as a Function of Coefficient of Variation (C)

Coefficient of Variation	Relative Precision	Confidence Level			
		60%	80%	90%	99%
0.15	0.2	2	2	3	6
	0.1	2	3	5	15
0.20	0.4	2	2	2	5
	0.2	2	2	4	9
	0.1	2	4	8	25
0.65	0.4	2	3	6	18
	0.2	2	9	19	60
	0.1	3	31	70	229
1.0	0.4	2	6	12	37
	0.2	2	19	42	135
	0.1	7	72	164	541
2.0	0.4	2	19	42	135
	0.2	7	72	164	541
	0.1	26	284	657	2,164

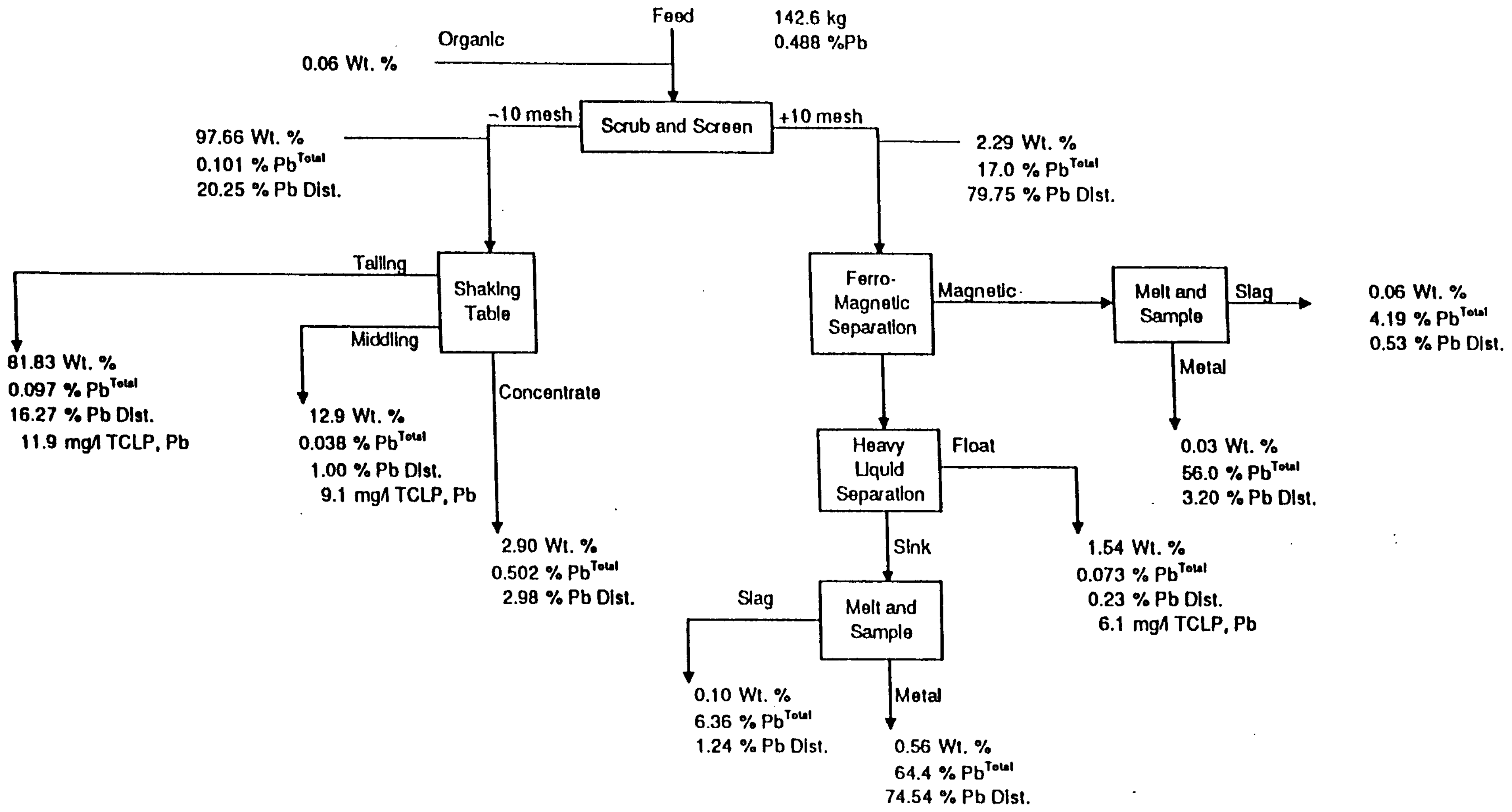
A small backhoe or a skid-steer loader (Bobcat™) are ideal for collecting treatability study samples. Using a mechanical excavator allows exposure and sampling of a significant fraction of berm soils. Hand excavation is possible but much less desirable than mechanical excavation. Hand methods do not expose a cross section of the berm and are labor intensive.

Where gross heterogeneity exists (e.g., bullet pockets as compared to the remainder of the berm), treatability study samples should be collected to allow testing of materials that limit process performance as well as materials that reflect average conditions. In general, testing should consider at least two types of material: (1) bullet pocket soil and (2) general area soil. The soil in bullet pockets will present significant challenges to the treatment process because of higher lead concentration, a higher proportion of lead as metal, and a different particle-size distribution compared to soil in the areas around and beneath the bullet pockets. The general area soil cannot, however, be ignored because it represents the largest volume of soil to be treated at most ranges.

Most berms are constructed from nearby soils and are at least partially mixed by the excavation and construction activities, but variations of soils are seldom completely removed. Initial characterization results should be examined to identify soils with high clay or organic content. Treatability study sampling should be planned to ensure that representative amounts of these problem soils are included in treatability samples. If the soils are very heterogeneous, it may be desirable to provide separate samples of each soil type.

5.3.2 Process Development

To provide direction to the treatability tests, it is necessary to determine the particle-size distribution of the berm soils, coupled with the metal concentrations in each size range. This work can be performed by a metallurgical laboratory and should use large drum-sized representative samples. If leachable metal criteria are involved, the relationship between total metal concentrations and leachable metal levels should be determined. Once the distribution of the metals is known by particle size and leachability, the bench-scale studies can be focused on removing metals from the various size fractions using equipment and techniques best suited for the task. An example of this type of characterization from the Fort Polk demonstration is shown in Figure 5-1.



Hazen Research, Inc.

Figure 5-1. Lead distribution across various fractions of raw soil

Treatability testing should be developed to simulate at bench scale the performance of the full-scale system. An example is shown in Table 5-6.

Table 5-6. Comparison of Bench-Scale and Full-Scale Process Steps

Bench-Scale Procedure	Related Full-Scale Function
Attrition scrubbing (hand-held power mixer)	Attrition scrubbing (blade mill)
Physical separation (wet screening)	Physical separation (vibrating sieve, blade mill, hydrocyclones, sandscrew)
Removal of particulate lead (panning)	Removal of particulate lead (jigs)
Acid leaching and attrition scrubbing of sands (beakers)	Acid leaching and attrition scrubbing of sands (blade mill, sand screw)
Acid leaching of fines (beakers)	Acid leaching of fines (leaching tanks)
Flocculation of suspended particles (beaker)	Flocculation of suspended particles (leaching tanks)
Dewatering of fines (centrifuge)	Dewatering of fines (vacuum belt filter)
Precipitation of lead (beaker)	Precipitation of lead (precipitation tank)

The treatability testing should include providing potential recycling processors with a sample of the material that will be recycled. For example, the main concern for primary lead smelters is the slagging properties of the matrix in their furnace. Therefore, most of the recyclable streams leaving a physical separation/acid leaching plant will be tested for their silica and calcium content – not lead. The smelter will do their own testing before committing to accept a material for processing or providing a cost quotation. The smelter will typically perform the acceptance testing at no cost.

5.3.3 Process Optimization

Depending on the particle size of the metals and the goals for processing, the bench-scale tests may need to be more elaborate than those shown in Table 5-6. For example, bench-scale jigs and hydrocyclones may need to be tested to optimize the process.

If acid leaching is required to meet processing goals, all aspects of the leaching cycle (see Section 4.3.2) need to be fully tested and optimized. Acid leaching tests should include:

☐ Leaching
  — pH
  — Solid:leachant ratio
  — Contact time and number of contacts
☐ Metal recovery
  — Precipitation
  — Flocculation
☐ Solid-liquid separation
  — Settling tests (clarifier design)
  — Filtration tests (filter design)
☐ Re-acidification of leachant.

Depending on the needs of the particular site or application, process optimization can be performed either independently by the site or deferred to the vendor. Whether or not detailed treatability tests are performed by the site, the vendor will need and want to perform its own tests.

5.4 Data Analysis and Interpretation

Because physical separation and acid leaching are specialized technologies, analysis and interpretation should be performed by those familiar with these areas. The data gathered should be used to generate a process flow diagram with a material balance. This flow diagram should present each piece of equipment, the flows (solid and liquid) of various streams in and out of each equipment, and the metal concentrations expected in each stream. This flow diagram provides a representation of the process required and the streams that will be generated. It also provides the data needed to plan for utilities, site preparation, schedule, etc.

5.5 Schedule

Planning for the treatability tests should allow time for an initial set of tests (Section 5.3.2), including time to obtain analytical results, followed by at least a few days to interpret the results and plan a second set of testing (Section 5.3.3). The first set of tests should be planned to cover a wide range of possible operating conditions. The second set can be focused on a narrower range of conditions to confirm results from the first set and to allow for optimization and better determination of design parameters.

The treatability testing schedule should allow 3 weeks of turnaround time for chemical analysis, whenever possible. The analytical results can be obtained in less time, but it is better to allow ample time when planning the tests. Priority processing increases costs (e.g., reducing the turnaround time to 1 week can double the cost of the analytical service).

6.0 System Conceptual Design Basis

This section outlines the functional requirements and design bases to assist in scoping a conceptual design for applying physical separation and acid leaching to cleanup of small-arms range soils.

6.1 Site Planning and Preparation Considerations

The functional requirements for site preparation are to provide adequate administrative support, utility support, and infrastructure to allow efficient operation of the project.

The range of work elements that must be defined for planning an environmental project is as follows:

- ☐ Regulatory requirements and interface
- ☐ Site preparation
- ☐ Site security
- ☐ Mobilization
- ☐ Excavation
- ☐ Spill and discharge control
- ☐ Treatability testing
- ☐ Air monitoring and modeling
- ☐ Surface water management
- ☐ Groundwater management
- ☐ Environmental resource protection
- ☐ Erosion control
- ☐ Emissions control
- ☐ Transportation
- ☐ Project management
- ☐ Operations and maintenance
- ☐ Site sampling and closure
- ☐ Demobilization
- ☐ Quality assurance (QA)
- ☐ Health and safety.

The documentation defining and controlling work activities for most small-arms range maintenance or remediation projects can be adequately covered by a maintenance or remedial action work plan, a treatability study plan, a QA plan, and a health and safety plan (HASP). Sections of the work plan will provide the required content for the planning elements listed above. Appendix B contains an example outline for a work plan. If one or more of the work elements is particularly important or complex, a separate plan covering those aspects may be required. Preparing brief, site-specific addenda for generic project or corporate plans can be a cost-effective approach for meeting the requirements of the QA plan and HASP. Appendix C presents an example QA plan.

The treatment contractor will need a work area for soil handling and processing. Preparation of the work area is normally the responsibility of the facility where the range is located. The work area should be a level surface with provision for spill control and stormwater runoff collection. A location as close as possible to the range should be selected to minimize the time and cost required for soil handling and to meet requirements of the EPA Military Munitions Rule if performing range maintenance. The level area should be large enough to accommodate a stockpile of untreated soil, the treatment equipment, a stockpile of treated soil, and a storage area for recyclable and waste materials, e.g., PPE. The area required will depend on the amount of soil to be processed and logistic arrangements at the site. A paved area surrounded by a low berm to control runoff and runon is preferred.

The site owner should provide basic utility services to the work area. Utility requirements should be determined by discussions with the treatment contractor. An electrical power source capable of providing 440-volt, 3-phase power, a service water source of 50 gpm, and a sewer inlet discharging to the site water treatment plant will be adequate for most applications.

6.2 Soil Excavation and Handling

The functional requirements for soil excavation and handling are to remove metal-bearing soil from the berm and other areas and place the soil in an appropriate, contained holding area in preparation for treatment. Locations at small-arms ranges that contain soil that may need treatment includes impact berms, side berms, shotfall areas, and general range areas. The specific arrangement, dimensions, and features of the ranges vary from site to site. Impact berms generally fall in two major classes: (1) constructed piles and (2) natural hillsides. The shotfall area of a shotgun range will typically be flat, grassy fields, but scrub land, lightly wooded areas, or bodies of water have also been used. For marksman type ranges, the area in front of targets will be a broad, flat, and well maintained field. Combat training and simulation ranges will be more rugged. The areas behind impact berms may be flat fields, but are more likely to be rugged, wooded, and poorly maintained compared to the area in front of the impact berms.

The planned depth of excavation should be tailored to site conditions and cleanup or maintenance goals; however, excavating 1 foot or less is often adequate to capture much of the lead. As indicated by the site characterization summaries in Section 2.3, lead rarely moves more than 1 foot, even in sandy soils with low pH.

For range maintenance to correct a ricochet problem, excavation should be planned to remove lead accumulations in the bullet pockets, and a surface layer from the rest of the front and top of the berm. The surface excavation approach corrects the ricochet problem and removes the bulk of the total lead at the site, but leaves any bullets buried by past berm refacing. Lead remaining inside the berm is isolated from the environment and adds little incremental risk in comparison to the bullets collecting in the bullet pockets during use of the range.

Site restoration to release the range for unrestricted use will require more extensive excavation. The practice of refacing bullet pockets is so prevalent that the entire berm should be excavated unless the range history is known and clearly documents that there are no bullets buried in the berm. For excavations at the firing line, in front of the targets, and beyond the berm, the low mobility of lead should be recognized. Excavation in areas away from the berm can be limited to less than 1 ft for most conditions.

During the excavation and reconstruction, range soil can be found in one of four conditions: (1) bank, (2) loose, (3) compacted, or (4) stabilized. The four conditions can be defined as follows:

☐ The bank condition is soil in its original undisturbed state prior to project activities.

☐ The loose condition is soil in a pile, bin, or truck bed after excavation or treatment.

☐ The compacted condition is loose soil that has been densified by physical methods.

☐ The stabilized condition is loose soil that has been treated with a binder, such as portland cement, lime, or lime and fly ash to increase density and strength.

The soil volume to be excavated in the bank condition can be estimated based on the dimension of the berm or area to be treated and the planned excavation depth. The resulting volumes of soil should be corrected for changes in density due to handling. Excavation increases the void space in the soil mass, reducing the density. Voids can be removed by mechanical compaction, such as pressure or vibration, resulting in a soil density equal to or greater than the bank density. Table 6-1 gives examples of typical soil densities to indicate approximate expected volumes. The planner should note that soils from the bullet pockets will contain significant quantities of lead metal, so their density will be higher than normal bank run soil. Solidification/stabilization (S/S) binders may be added to the soil to reduce metals leachability, if the acid leaching is unable to reach required leachable residual levels. More detailed discussion of S/S treatment is beyond the scope of this handbook.

Table 6-1. Approximate Soil Densities(a)

Soil Type	Bank Density (lb/yd^3)	Loose Density (lb/yd^3)	Compacted Density (lb/yd^3)
Clay, dry	2,650	2,100	2,940
Clay, wet	3,575	2,700	3,970
Earth, dry	2,850	2,215	3,170
Earth, moist	3,080	2,410	3,420
Earth, wet	3,380	2,750	3,750
Sand, dry	2,920	2,600	3,070
Sand, wet	3,520	3,100	3,700

(a) The actual values will vary with grain size, moisture content, and compaction methods. Lead metal mixed with the soil will significantly increase the density of the mixture. Site-specific data should be used, if available.

Source: Ringwald, 1993.

Excavation and soil handling can be accomplished with standard construction equipment. The maximum required reach height to excavate a berm is usually less than 20 ft and rarely over 30 ft (Heath et al., 1991). Subsurface excavation depth rarely exceeds 2 ft. A combination front-end loader and backhoe is the most efficient equipment for most applications. For small jobs, a skid-steer front-end loader (e.g., Bobcat™) will be adequate (Ringwald, 1993).

If scrub land and lightly wooded areas must be remediated, clearing and grubbing will be needed prior to soil excavation. A bulldozer is efficient for moderate to large jobs. Small or lightly overgrown areas can be cleared by hand or with a skid-steer loader (Ringwald, 1993).

6.3 Physical Separation

The functional requirements for physical separation are to remove oversize debris (if any) and separate bullets and bullet fragments from soil to allow recycling of the metals and more efficient treatment of the soil. Screening, the simplest form of physical separation, will be required as a pretreatment step in all cases. Two stages of screening with decreasing opening size can be used to separate debris, bullets, and soil. The bullets will usually be sent to a lead smelter for recycling. More complex physical separation approaches such as jigging, tabling, or hydrocycloning (see Section 4.0) may improve metal recovery and reduce the quantity of material to be recycled, and thus the cost. The effectiveness of different physical separation methods depends on the size and density characteristics and the concentration of lead in different size ranges of the soil. These parameters are site specific and must be determined by characterization and treatability testing using site soils (see Section 5.0).

6.4 Acid Leaching

The functional requirements for acid leaching are to remove metals from the soil to meet total and leachable metal concentration requirements while producing the minimum possible amount of process residuals.

For acid leaching to succeed, the leaching solution must be able to accomplish the following:

- ☐ Remove metals to the required cleanup level
- ☐ Reach the required cleanup level with a minimum number of contacting cycles
- ☐ Produce a minimum volume of waste leaching solution
- ☐ Selectively dissolve the metals of concern but not the matrix
- ☐ Provide compatibility with moderate cost materials of construction (e.g., austenitic stainless steel).

To achieve these goals the leaching solution needs to balance aggressive dissolution and high solubility for the target metals with limited attack on the matrix and normal materials of construction (see Section 4.0). Prior experience and a knowledge of equilibrium chemistry can narrow the range of leaching chemicals and conditions to be tested for a particular small-arms range soil, but treatability tests must be performed using site soils (see Section 5.0).

Development of the acid leaching system must not ignore management of the leaching solution after it has removed the metals from the soil. The ability to efficiently manage leachate is a major factor in the implementability and cost-effectiveness of acid leaching. The leachate management method must minimize the cost and adverse environmental effects of process residuals. The treated leachate properties should be consistent with local water treatment plant permit requirements or NPDES discharge requirements, including low dissolved metals content, low suspended solids content, and pH between 6 and 9. The process used to clean up the leachate should produce a metal or metal salt that can be separated from the leachate and that is compatible with a metal recovery process, usually treatment in a lead smelter.

Increasing the pH to precipitate metal hydroxides is the standard method for treating the metal-containing leaching acid. The precipitated hydroxide can be separated from the leachate using gravity settling in a clarifier. The precipitate sludge exiting the bottom of the clarifier is further dewatered by filtration and expression. The precipitation process must be developed to give low dissolved metal and suspended solids content and to precipitate particles that are sufficiently large to settle and filter well.

6.5 Residuals Management

The functional requirement for residuals management is to provide appropriate options for managing the streams produced by the physical separation and acid leaching process. Typical residual management approaches are recycling of bullets and bullet fragments, recycling or disposal of sludge from leaching solution treatment, disposal of treated leaching solution, disposal of PPE, and management of other wastes resulting from physical separation. Recycling is strongly favored over disposal as a management option.

Recovered lead can be processed in a commercial lead smelter. Bullets and bullet fragments may have high enough lead content and low enough impurity levels to allow processing in a secondary smelter. However, the metals separated from range soil will usually be more suitable as feed for a primary smelter. The precipitate collected when the leaching acid is regenerated can contain between 1% and 5% lead. This precipitate is also typically more suitable for recycling in a primary smelter. Facilities near the site should be contacted early in the process to determine their requirements for material properties, processing volumes, shipping modes and schedules, and toll fees. Prospective recycling facilities will require a sample of the material (~500 grams) for their analysis.

Table 6-2 indicates the locations of smelters in the United States that may accept bullets or soils from small-arms ranges. This tabulation outlines the local availability for smelters and gives a place to start making contacts when trying to locate a recycler. The listing is not intended to be comprehensive nor is it an endorsement or approval of these facilities. Users are encouraged to research the compliance status of any processor they select. A fee in the range of $100/ton to $300/ton (plus shipping at $0.07/ton-mile to $0.15/ton-mile) would be charged to accept low-grade materials at any of these processing facilities.

Table 6-2. Locations of Pyrometallurgical Plants for Processing Bullets or Soils from Small-Arms Ranges

Company	Location	Smelter Type	Process Bullets	Process Soils
ASARCO, Inc.	Glover, MO	Primary	No	Yes
ASARCO, Inc.	East Helena, MT	Primary	No	Yes
Doe Run Company	Buick, MO	Secondary	Yes	No
Doe Run Company	Herculaneum, MO	Primary	Yes	Yes
East Penn Mfg. Company, Inc.	Lyon Station, PA	Secondary	Yes	No
Exide Corporation	Muncie, PA	Secondary	Yes	Yes
Exide Corporation	Reading, PA	Secondary	Yes	Yes
Gopher Smelting and Refining	Eagan, MN	Secondary	>25%	No
Naranda Metallurgy, Inc.	Belledune, New Brunswick	Primary	Yes	Yes
RSR Corporation	Middletown, NY	Secondary	Yes	No
RSR Corporation	Indianapolis, IN	Secondary	Yes	No
RSR Corporation	City of Industry, CA	Secondary	Yes	No
Schuylkill Metals Corporation	Baton Rouge, LA	Secondary	>50%	No
Schuylkill Metals Corporation	Forest City, MO	Secondary	>50%	No

Source: Adapted from Lead Industries Association, 1992; U.S. EPA, 1995, EPA/540/R-95/512.

Primary smelters provide a first stage of processing that increases the lead content and reduces impurity levels. The product from the primary smelter goes to a secondary smelter to produce the final high-purity soft lead and hard lead alloys. Soils containing as little as 500 mg/kg lead would be compatible with primary smelters. In primary smelting, lead content is of minor importance because the soil acts more as a silica, calcium, and iron source to assist in slag formation than as a major contributor of lead. Granular sandy soils are more favorable, whereas a high proportion of finer particle size silt and clay would make soil unfavorable for use in a primary smelter. For more information on transferring materials to primary smelters contact, Cliff Asberry, Doe Run Company, Herculaneum, Missouri (314-933-3164) or Glendon Archer ASARCO, Inc., New York (212-510-2215).

The Center for Hazardous Materials Research and Exide/General Battery Corporation are demonstrating the use of secondary lead smelting to reclaim usable lead from waste materials containing between 1 and 50% lead. Waste containing 1 to 25% lead is treated in a reverberatory furnace to produce slag containing about 70% lead. The slag and other high-lead-content materials are fed to a blast furnace to produce lead metal products. SITE Program testing has been performed on a variety of waste materials including battery cases, slags, lead dross, and lead paint chips (U.S. EPA, 1993, EPA/542/N-93/005). Low-grade materials from Superfund or other sites could be mixed with higher grade lead material to allow processing in a secondary smelter (U.S. EPA, 1994, EPA/540/R-94/526).

6.6 Berm Reconstruction

The functional requirement for berm reconstruction is to prepare an acceptable backstop for the range using the treated soil. The required berm dimensions vary widely depending on the site-specific factors such as topography, range size, and range mission. Recommended characteristics for small-arms range berms are provided by DoD (1992) and Whiting (1989). Soil used to construct impact berms should be free of hard particles that could cause impacting bullets to ricochet. The finished berm slope should be as steep as possible but not less than 45 degrees (i.e., rise over run ratio of 1:1). Sand bags or old tires can be used to stabilize the slope, if needed. If a 45-degree or steeper slope cannot be achieved, a ricochet catcher should be provided along the top of the berm (DoD, 1992). The soil in the berm should be compacted to 95% of the maximum laboratory dry density.

6.7 Site Restoration and Demobilization

The functional requirements for site restoration and demobilization are to remove treatment equipment, repair any damage resulting from treatment operations, and return the range to full operation.

The range must be returned to usable condition prior to acceptance for closeout of a maintenance project for an active range. Visual inspection by the range manager or another knowledgeable authority should suffice as the acceptance criteria for the configuration and physical condition of the range. Chemical analysis for metal content of soils may not be required to closeout a maintenance project for a range that will continue in active service.

If the range is closing, project closeout will require confirmation sampling to ensure that cleanup goals have been met. Sample locations should be determined using probability methods (Gilbert, 1987; U.S. EPA, 1983, EPA/600/4-83/020; U.S. EPA, 1989, EPA/600/8-89/046) so that statistical analysis can be applied to interpreting the results.

Turf areas will be damaged by earth moving and soil treatment operations. The damaged areas should be reseeded and mulched to reestablish appropriate ground cover. Control measures should be provided to reduce the potential for erosion during the initial growth phase for the ground cover. Fertilization of grassy areas with lime and phosphate to the maximum levels consistent with the local vegetation and soil conditions should be considered. High phosphate concentration and less acid soil conditions help reduce lead mobility in the environment.

6.8 Environmental Considerations

The level of environmental consideration will depend on whether the small-arms range soils are being processed to support a maintenance or remediation activity. The team responsible for planning and implementing physical separation and acid leaching for cleanup of small-arms range soils must assess the environmental resources at the site, identify potential adverse effects to those resources, and provide methods to eliminate or reduce any adverse effects. Environmental aspects that should be considered when planning and implementing physical separation and acid leaching for small-arms range cleanup include surface and groundwater resources, actual and planned land use, natural and depletable resources, wetlands and sensitive ecosystems, and historic and cultural resources.

Outdoor small-arms ranges will be exposed to natural precipitation. Water runoff and erosion are the most significant metals transport processes in the overland environment. When rainfall occurs, some amount of the bullet metals will dissolve into the water and then partition between the aqueous and sorbed phases. The water may then transport metals to the environment around the range as dissolved metals, sediment with sorbed metals, and metal particulates.

Runoff is that portion of precipitation that eventually appears as flow water on the ground surface (i.e., overland flow). Runoff occurs when the precipitation supply rate exceeds the water demands of sinks such as interception by vegetation, storage in depressions (e.g., ponds, puddles, or playas), evaporation to the air, and infiltration into the ground.

Although individual raindrops seem insignificant, the combination of mass and impact from rain exerts a significant erosive force. For example, the combined weight of 1 inch of rainfall on 1 acre of ground is more than 110 tons, and the raindrops impact at a velocity of about 25 feet/second. The force of rainfall breaks soil agglomerations into smaller units and, on sloped terrain such as an impact berm, moves with sufficient velocity to carry sediments with sorbed metals or fine metal particulates.

Runoff may carry metals into nearby bodies of water such as rivers, lakes, estuaries, wetlands, or groundwater. The effects of runoff on the quality of local surface and groundwater depend on site-specific conditions. The seriousness of potential environmental effects depends on factors such as the following:

☐ The climate at the site
☐ The topography, geology, and hydrogeology of the site
☐ The chemistry, type, size, and hydrology of the surface water body or aquifer
☐ The location of wetlands or sensitive ecosystems
☐ The existing and planned uses for the surface water or groundwater.

Soil processing will generate aqueous process residuals. Many physical separation processes use water to carry the soil and assist in the separation. Acid leaching produces a treated spent acid solution. The process design must include sufficient cleaning of the aqueous residuals to allow discharge to a treatment plant or NPDES permitted release point, as appropriate.

The ecology for small-arms ranges usually will be consistent with that of rural or suburban upland fields. Small-arms ranges, due to their noise level, are more likely to be located in sparse population areas. The range area usually is a flat, grassy field, but there are exceptions. Special-purpose facilities that are used for combat assault training courses may be located in moderately rugged terrain or wooded areas. The overflight area behind the berm may have rugged terrain and mature vegetation. In the past, some shotgun ranges used water bodies as the shotfall area; however, environmental regulations have limited this practice in recent years.

At a small-arms range, the biota of concern typically would consist of vegetation, birds, small mammals (primarily rodents), insects, and earthworms. In some areas, large game such as deer also may use the range area. If the range is located near any aquatic habitats, aquatic species such as fish, macroinvertebrates, or waterfowl also may be of concern. Local regulatory and conservation agencies should be contacted to determine the potential presence of any threatened or endangered species or critical habitat at or adjacent to the range. A preliminary site survey can be performed to provide an overview of the biota at the range. This survey would include observation and mapping of vegetation types; observation and mapping of animals and their tracks, trails, burrows, or other signs; mapping any aquatic or marine habitats that might be located in the proximity of the range and noting any aquatic species of concern; and photographing ecological features on site and in the vicinity of the range. Survey techniques should take into account diurnal/nocturnal variations and seasonal variations.

A review should be conducted to identify potential historic and cultural resources at or near the range. The review should include examination of historical records and a site walkover.

7.0 Costs

A budget estimate of the cost to process the soil is an important factor in evaluating the technology. This section describes the methods of preparing budget cost estimates (+30% to − 15% accuracy) for separation and acid leaching to process small-arms range soils based on the Fort Polk demonstration.

7.1 Cost Performance

For the cost performance evaluation of the two physical separation and acid leaching technologies demonstrated at Fort Polk, the costs during site setup, mobilization, operation, and demobilization were categorized as either fixed costs or variable costs. Fixed costs are incurred irrespective of the amount of soil processed. Examples of fixed cost items are environmental assessment, regulatory permitting, site characterization, bench-scale treatability testing, engineering and administration, site preparation, process plant lease (vendor), transportation, mobilization, and demobilization. Variable costs are dependent on the total amount of soil processed. Variable costs in the two demonstrations included costs for chemicals used, utilities (power and water) required, operating labor, sampling and analysis, consumables and supplies, soil excavation and hauling, and residual disposal. Any recycled metals recovered from processing were considered as a credit to the residual disposal variable cost. Appendix I of the final demonstration report (Battelle, 1997a) contains details of the cost-estimating basis used.

7.1.1 Hydrochloric Acid Process Cost

The hydrochloric acid process costs incurred during the Fort Polk demonstration provided the best basis for projecting the costs for a routine range maintenance or full-scale remediation operation. Table 7-1 shows the costs incurred during the Fort Polk demonstration and the projected costs for a routine range maintenance operation for the same volume of range soil with similar soil characteristics and similar processing targets. The total cost for the range maintenance demonstration at Fort Polk that processed 835 tons of berm soil was around $1.17M, at an average cost of around $1,400/ton. The requirements for a technology demonstration added significant costs to the project. Fixed costs accounted for two-thirds of the total cost of the range maintenance and therefore the unit cost (per ton) remains high. At larger sites, the unit cost per ton of soil processed by hydrochloric acid is expected to be much lower, especially under nondemonstration conditions.

Because some small-arms range sites have as much as 10,000 tons of soil or more, a cost projection for a hydrochloric acid remediation of that size is shown in Table 7-2. It is assumed that the same size plant (20-tons/hr quoted capacity) will be used for the routine maintenance of sites up to 10,000 tons. Inherent in this assumption is the projection that the performance of the processing plant will be maintained at a higher throughput rate of 20 tons/hr. The maximum throughput rate measured during the second demonstration was about 7.5 tons/hr, but the processing rate was limited more by the availability of storage space for the processed soil awaiting verification than by the processing equipment capacity. Implicit in the scale-up cost projection is the assumption that the plant will be required to meet similar processing targets (5 mg/L TCLP lead and 500 mg/kg of total lead). The projected unit cost for remediation of 10,000 tons of berm soil is around $170/ton.

An additional cost consideration when using hydrochloric acid for leaching is its corrosive effect on equipment. Analysis of the precipitate sludge showed that this sludge contained over 4% iron. Although some of this iron may have leached out of the soil, it is likely that some of it was from the carbon steel equipment itself. Use of hydrochloric acid at a very low pH (below 2) may reduce the life of the equipment. Alternatively, the plant may have to utilize more expensive stainless steel equipment, which will increase capital costs.

Table 7-1. Incurred and Routine Costs of the Hydrochloric Acid Demonstration

Item	Basis	Demonstration Costs 835 tons
Fixed Costs		
Permitting and Regulatory (Site)	NEPA, HASP, & other permitting	$73,199
Site Characterization (Site)	Planning, sampling, and analyses	$56,171
Vendor Selection (Site)	Selection and contracting, plan preparation	$135,686
Bench-Scale Testing (Vendor)	1 representative sample	$17,739
Site Preparation & Support (Site)	Pad construction and accessory rentals	$150,839
Engineering & Administrative (Vendor)	Administrative and assessment	$41,571
Transportation (Vendor)	Plant and personnel mobilization	$173,692
On-site Mobilization (Vendor)	Equipment procurement and shakedown	$23,825
Equipment (Vendor)	25% depreciation over 4 cleanups	$233,075
Decontamination and Demobilization (Vendor)	Disassembly, decontamination, and demobilization	$20,000
Total Fixed Costs		$925,797
Variable Costs		
Soil Excavation/Hauling (Vendor)	Backhoe equipment, excavation/hauling	$12,419
Labor (Site)	1 site superintendent for 300 hours	$18,000
	1 health and safety officer for 300 hours	$15,000
Utilities (Site)	Electricity, 5,000 kWh/month @ $0.075/kWh	$750
	Water, 49,300 gal @ $8.07/kgal	$398
	Phone, $220/month	$440
Labor (Vendor)	1 supervisor for 300 hours	$51,845
	2 engineers for 300 hours each	
	1 chemist for 300 hours	
	5 technicians for 300 hours each	
Chemicals (Vendor)	HCl acid, 5,200 gal @ $0.60/gal	$3,141
	NaOH, 5,850 gal @ $0.60/gal	$3,517
	Diatomaceous earth, 11,300 lb @$0.53/lb	$6,044
	Flocculant, 1,000 gal @ $3.31/gal	$3,311
	Hydrated lime, 1,275 lb @ $0.40/lb	$510
Consumables / Supplies (Vendor)	PPE, gloves, tarps, accessories	$8,235
Sampling & Analyses (Site)	Accessories, other equipment rentals	$19,983
- Labor (Site)	1 supervisor for 300 hours	$18,000
	2 technicians for 300 hours each	$18,000
- Analyses (Site)	240, sample prep & TCLP analyses	$57,000
	529, sample prep & total metals analysis	
Residuals, Waste Shipping/Handling (Vendor)	Bulk solid waste & recovered metals credit	$9,008
Effluent Treatment (Site)	Wastewater, 0 gal @ $1.25/gal	$0
Total Variable Costs		$245,601
Total Project Costs		**$1,171,398**
Total Cost/Ton of Soil		**$1,402**
Variable Cost/Ton of Soil		**$294**

Table 7-2. Scaleup Costs of the Hydrochloric Acid Process

Item	Basis	Scale-Up Costs 10,000 tons
Fixed Costs		
Permitting and Regulatory (Site)	NEPA, HASP, other permitting	$73,199
Site Characterization (Site)	Planning, sampling, and analyses	$56,171
Vendor Selection (Site)	Selection and contracting	$135,686
Bench-Scale Treatability Tests (Vendor)	1 representative sample	$17,739
Site Preparation and Support (Site)	Pad construction and accessory rentals	$150,839
Engineering and Administrative (Vendor)	Administrative and assessment	$41,571
Transportation (Vendor)	Plant and personnel mobilization	$173,692
On-site Mobilization (Vendor)	Equipment procurement and shakedown	$23,825
Equipment (Vendor)	25% depreciation over 4 cleanups	$233,075
Decontamination and Demobilization (Vendor)	Disassembly, decontamination and demobilization	$20,000
Total Fixed Costs		$925,727
Variable Costs		
Site Excavation / Hauling (Vendor)	Backhoe equipment, excavation & hauling	$124,190
Labor (Site)	1 Superintendent/HSO for 480 hours	$28,800
Utilities (Site)	Electricity, 5,000 kWh/month @ $0.075/kWh	$1,125
	Water, 80,000 gal @ $8.07/kgal	$646
	Phone, $220/month	$660
Labor (Vendor)	1 supervisor for 480 hours 1 engineer for 480 hours each 1 chemist for 480 hours 3 technicians for 480 hours each	$134,400
Chemicals (Vendor)	HCl acid, 62,275 gal @ $0.35/lb	$21,796
	NaOH, 70,060 gal @ $0.44/lb	$30,826
	Diatomaceous earth, 50 tons @ $800/ton	$40,000
	Flocculant, 7,200 gal @ $2.20/gal	$26,347
	Hydrated lime, 8 tons @ $89/ton	$712
Consumables / Supplies (Vendor)	PPE, gloves, tarps, accessories	$50,994
Sampling & Analyses (Site)	Accessories, other equipment rentals	$34,873
- Labor (Site)	1 supervisor for 480 hours	$28,800
	1 technician for 480 hours	$14,400
- Analyses (Site)	360, sample prep & TCLP analysis 800, sample prep & total metals analysis	$86,040
Residuals, Waste Shipping / Handling (Vendor)	Bulk solid waste & recovered metals credit	$110,180
Effluent Treatment (Site)	Wastewater, 22,000 gal @ $1.25/gal	$27,500
Total Variable Costs		$726,289
Total Project Costs		**$1,688,086**
Total Cost/Ton of Soil Processed		**$168**
Variable Cost/Ton of Soil		**$73**

7.1.2 Physical Separation Costs for Routine Maintenance

Routine maintenance may involve only physical separation techniques to remove bullets and bullet fragments from the impact berms. Most of the bullets can be separated from berm soils by simply screening them out. However, for a 10,000-ton quantity of berm soil, the amount of rock present in the oversize fraction from the screening operation can be significant. The cost of shipping this fraction to a lead smelter is also significant, but it can be reduced by concentrating the lead using gravity separation techniques. The projected costs for a physical separation process that involves gravity separation of coarse (oversize) and sand fractions (not the fines) are presented in Table 7-3.

The cost projections presented in this report do not take into account any profit or fee that the vendor may charge. They are meant to serve only as a reasonable estimate for the incurred costs, should a full-scale small-arms range maintenance action or remediation be undertaken. Section 7.1.3 provides a comparison of the costs of common alternatives to physical separation/acid leaching.

7.1.3 Comparison of Costs of Alternative Technologies

The cost criterion refers to the fixed (capital) cost to design, purchase, and install the remediation option as well as the variable cost of operating and maintaining the option. A detailed cost comparison of fixed and variable costs for landfill disposal, stabilization/solidification, and physical separation/leaching is provided in Table 7-4. The costs used for the alternative technologies chosen are based on figures obtained from the R.S. Means Environmental Restoration Unit Cost Books (R.S. Means, 1996). The detailed cost basis used to generate Table 7-4 can be found in Appendix I of the final demonstration report (Battelle, 1997a). These figures provide reasonably accurate costs for the associated equipment and items used for these types of remedial activities. The costs of the hydrochloric acid full-scale operation have been projected from the Fort Polk demonstration costs incurred for Vendor 2's activity and for site preparation and sampling.

Figure 7-1 is a graph of the unit processing cost versus the total soil tonnage processed with the competing technologies. As can be seen from the graph, it is cheaper to utilize landfill disposal when dealing with small sites (2,600 tons or less). S/S-treatment technology becomes more cost effective than landfill disposal at sites larger than 2,600 tons. Hydrochloric acid leaching with physical separation (as conducted by Vendor 2) becomes more cost effective than landfilling at about 5,000 tons. S/S-treatment is cheaper than physical separation/acid leaching regardless of the size of the site. The acetic acid process with physical separation (as conducted by Vendor 1) was not considered in this evaluation because processing difficulties encountered during this demonstration made cost estimation for the scaleup operation difficult.

An off-site technology, such as landfilling, is always cheaper than on-site technologies at smaller sites mainly because on-site technologies have higher fixed costs for site preparation, plant equipment, etc. At larger sites, as the fixed costs are spread out over a larger tonnage of soil processed, on-site technologies become cheaper. Among on-site technologies, stabilization is cheaper than physical separation/acid leaching regardless of the amount of soil processed because stabilization uses simpler equipment and therefore incurs lower capital costs. Residence times of the soil required in stabilization equipment are also lower than those for leaching. This enables much faster processing by stabilization using equivalently sized equipment.

Table 7-3. Projected Costs for Physical Separation Only

Item	Basis	Soil Screening Costs 10,000 tons
Processing Duration		2 months
Fixed Costs		
Permitting and Regulatory (Site)	NEPA, HASP, & other permitting	$20,000
Site Characterization (Site)	Planning, sampling, and analyses	$1,000
Vendor Selection (Site)	Selection and contracting, plan preparation	$25,000
Bench-Scale Treatability Tests (Vendor)	1 representative sample	$1,500
Site Preparation and Support (Site)	Pad construction and accessory rentals	$30,000
Engineering and Administrative (Vendor)	Administrative and assessment	$18,000
Transportation (Vendor)	Plant and personnel mobilization	$28,000
On-site Mobilization (Vendor)	Equipment procurement and shakedown	$20,000
Equipment (Vendor)	25% depreciation over 4 cleanups	$75,000
Decontamination and Demobilization (Vendor)	Disassembly, decontamination, and demobilization	$20,000
Total Fixed Costs		$238,500
Variable Costs		
Site Excavation/Hauling (Vendor)	Backhoe equipment, excavation/hauling	$125,000
Labor (Site)	1 site superintendant for 160 hours	$9,600
	1 health and safety officer for 160 hours	$9,600
Utilities (Site)	Electricity, 5,000 kWh/month @ $0.075/kWh	$800
	Water, 25,000 @ $8.07/kgal	$200
	Phone, $200/month	$400
Labor (Vendor) - Operations Crew	1 supervisor for 320 hours	$9,600
	2 technicians for 500 hours	$30,000
Consumables and Supplies (Vendor)	PPE, gloves, tarps, accessories	$2,000
Sampling and Analyses (Site)	Accessories, equipment rental	$4,000
- Labor (Site)	1 technician for 160 hours	$12,800
- Analyses (Site)	50, sample prep and analyses	$12,000
Residuals, Waste shipping and handling (Vendor)	Bulk solid waste & recovered metals credit	$110,000
Effluent Treatment (Site)	Wastewater, 20,000 gal @ $1.25/gal	$25,000
Total Variable Costs		$351,000
Total Project Costs		**$589,500**
Total Cost/Ton of Soil		**$59**
Variable Cost/Ton of Soil		**$35**

Table 7-4. Cost Comparison of Alternative Technologies

Technology	Landfill Disposal Costs	S/S Costs	HCl Acid Washing Costs
Soil to be Processed	**10,000 tons**	**10,000 tons**	**10,000 tons**
Processing Duration	**1 month**	**2 months**	**3 months**
Fixed Costs			
Permitting and Regulatory (Site)	$73,199	$73,199	$73,199
Site Characterization (Site)	$56,171	$56,171	$56,171
Vendor Selection/Contracting (Site)	$25,000	$135,686	$135,686
Bench-Scale Treatability Tests (Vendor)	$0	$17,739	$17,739
Site Preparation and Support (Site)	$15,400	$75,400	$150,839
Engineering and Administrative (Vendor)	$12,000	$41,000	$41,571
Transportation (Vendor)	$52,125	$98,120	$173,692
On-Site Mobilization (Vendor)	$16,500	$22,228	$23,825
Equipment (Vendor)	$55,250	$138,125	$233,075
Decon and Demob (Vendor)	$12,000	$20,000	$20,000
Total Fixed Costs	$317,645	$677,668	$925,797
Variable Costs			
Site Excavation / Hauling (Vendor)	$1,909,651	$124,190	$124,190
Labor (Site) - Superintendent/HSO[(a)]	$14,400	$14,400	$28,800
Utilities (Site) - Electricity	$750	$750	$1,125
Utilities (Site) - Water	$323	$4,035	$646
Utilities (Site) - Phone	$440	$440	$660
Labor (Vendor) - Operations Crew	$46,525	$86,600	$134,400
Chemicals (Vendor) - HCl Acid	$0	$0	$21,796
Chemicals (Vendor) - Acetic Acid	$0	$0	$0
Chemicals (Vendor) - ThioRed®	$0	$0	$0
Chemicals (Vendor) - NaOH	$0	$0	$30,563
Chemicals (Vendor) - Cement	$0	$204,897	$0
Chemicals (Vendor) - DE	$0	$18,000	$40,000
Chemicals (Vendor) - Flocculant	$0	$0	$26,347
Chemicals (Vendor) - Lime	$0	$0	$712
Consumables and Supplies (Site)	$12,749	$25,497	$50,994
Sampling and Analyses (Site)	$17,437	$17,437	$34,873
- Labor (Site) - Supervisor	$7,200	$14,400	$28,800
- Labor (Site) - Technician	$3,600	$7,200	$14,400
- Analyses (Site) - TCLP/Totals	$6,480	$42,960	$86,040
Residuals, Waste Shipping and Handling (Vendor)	$0	$87,500	$110,180
Effluent Treatment (Site)	$22,250	$44,500	$27,500
Total Variable Costs	$2,040,085	$692,806	$762,289
Total Project Costs	$2,357,730	$1,370,474	$1,688,086
Total Cost/Ton of Soil Processed	$235.77	$137.05	$168.81

(a) HSO is Health and Safety Officer.
DE is diatomaceous earth.

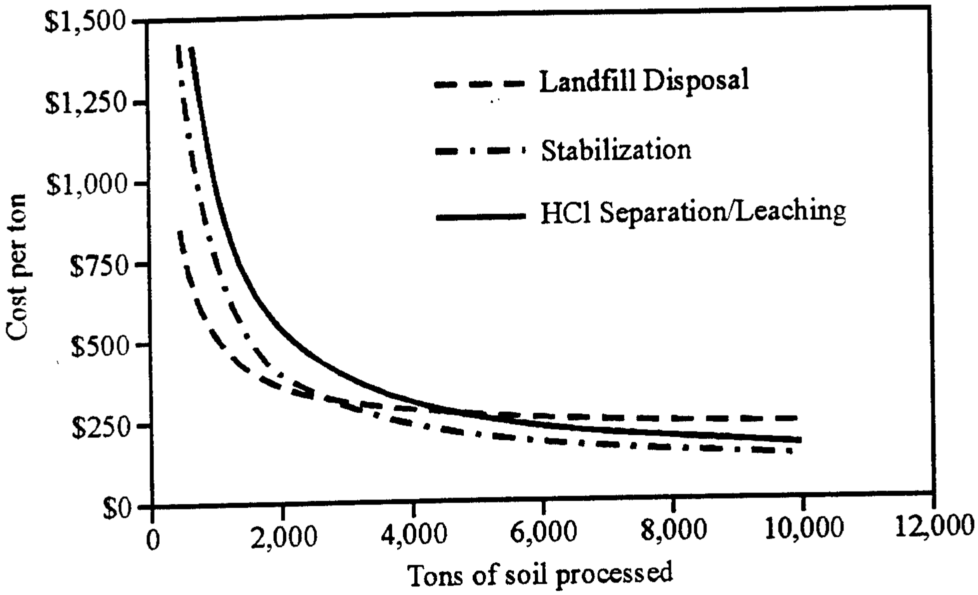


Figure 7-1. Cost comparison of competitive technologies

If a true cost-benefit analysis is undertaken, however, several tangible and intangible benefits of physical separation/acid leaching emerge that may outweigh the cost advantage of landfilling or stabilization irrespective of the amount of soil that requires processing. The following are some of the benefits of physical separation/acid leaching that should be considered by sites trying to identify the best alternative:

- ☐ With landfilling and stabilization, although the metals have been immobilized or contained, the liability remains. With physical separation/acid leaching, over 95% of the lead may be removed, recovered, and reused.
- ☐ Stabilization of an active range may result in a hardened treated material that is physically unsuitable for reuse in the berm. The processed soil from physical separation/acid leaching still retains its loose texture and can be put back in an active berm.
- ☐ Even at an inactive range, with stabilization and on-site disposal, the site may be put to only limited use, because the metal source remains and is best left undisturbed. On the other hand, if the stabilized material is sent off site for disposal, the cost of this option will increase considerably. With physical separation/acid leaching, the potential uses that the site can be put to increase because most of the metal is gone.

8.0 Health and Safety Considerations

A job hazard analysis should be performed to ensure potential risks are identified and all possible mitigation measures are in place. Examples of the hazard sources and mitigation measures for small-arms range remediation are summarized in Appendix A.

Metals accumulation in soils is a potential chemical hazard source at small-arms ranges. Table 8-1 summarizes the exposure limits and health hazards for bullet metals. Applicable employee 8-hr permissible exposure limits (PELs), action levels (ALs), and threshold limit values (TLVs) are tabulated. The PELs are defined by the United States Department of Labor, OSHA. Table 8-2 shows the exposure level

Table 8-1. Exposure Limits and Primary Health Hazards of Metals in Small-Arms Range Soils

Metal Specie	PEL/AL (mg/m^3)	TLV (mg/m^3)	Primary Health Hazards
Lead	0.05[a]	0.05	Wide range of reproductive system, nervous system, gastrointestinal, blood, and kidney damage; learning disability in children; animal carcinogen
Copper fume	0.1	0.2	Skin, eye, and respiratory irritant
Zinc oxide fume	5.0	5.0	Irritant, low toxicity
Antimony and compounds	0.5	0.5	Wide range of nervous system, cardiovascular, gastrointestinal, blood, liver, and kidney damage
Arsenic and inorganic compounds	0.01[b]	0.01	Wide range of nervous system, cardiovascular, gastrointestinal, blood, liver, and kidney damage; skin abnormalities; carcinogen

(a) Medical monitoring required for workers spending 8 hours per day for 30 or more days a year in an area where lead levels exceed 0.03 mg/m^3. If the blood lead level exceeds 40 micrograms per deciliter, the worker should be removed from the area where lead exposure is occurring.

(b) National Institute for Occupational Safety and Health (NIOSH) calculates the limit for arsenic as 0.002 mg/m^3 when considering carcinogenic effects.

Table 8-2. Potential Exposure to Metals in Dust with a Total Dust Concentration of 5 mg/m^3

Metal	Assumed Maximum Concentration (mg/kg)	Potential Exposure[a] (mg/m^3)	AL/PEL/TLV[b] (mg/m^3)
Lead (high)	50,000	0.25	0.03
Lead (typical)	3,000	0.015	0.03
Copper	400	0.002	0.1
Zinc	200	0.001	5.0
Antimony	300	0.0015	0.5
Arsenic	50	0.00025	0.01

(a) The potential exposure is estimated using the assumed concentration in soil that is dispersed as dust at a concentration of 5 mg/m^3 in air.

(b) The value shown is the lower of the OSHA AL or PEL and the American Conference of Governmental and Industrial Hygienists (ACGIH) TLV.

that would occur with typical metals concentrations in soils and an airborne dust concentration of 5 mg/m^3. A site-specific assessment should be performed when actual concentrations are known, but Table 8-2 provides a reasonable estimate of maximum exposures. Under the assumed scenario, only very heavy metals-laden soil from the bullet pockets has the potential to cause a chemical hazard greater than the irritation hazard from dust. Soil excavation, handling, screening, and treatment operations should provide methods such as water spray, foam coating, and/or covers to minimize dust generation. Monitoring should be provided to determine the dust and metal concentrations in air in the breathing zone, in work areas, and at the site perimeter.

9.0 Contract Implementation Approaches

This section describes methods to obtain and manage services for physical separation and acid leaching to process small-arms range soils.

9.1 Developing a Statement of Work for Contracting

The SOW should be developed to describe the technical requirements for the project and to define the basis for determining the proposal that offers the best value. Preparing the SOW requires careful thought and planning to define the key work elements that must be performed and the criteria that must be met without limiting the contractor's flexibility to provide their best value option. The criteria must be sufficiently demanding so that the product produced by the project gives the required level of quality, but not so demanding as to be uneconomical or unachievable. The concepts involved in preparing a good SOW are easy to understand but difficult to achieve in practice. The example SOW for a small-arms range berm maintenance project in Appendix D provides a possible starting point for SOW preparation.

The work elements and criteria should be stated without reference to how the work should be done. This performance-based specification should take advantage of the vendor's experience by not over-specifying the work (Dennis et al., 1992). The SOW often is prepared before criteria are quantified so that qualitative statements must be used. However, maximum possible use of specific numerical criteria is generally preferred. For example, "The treated soil shall contain less than 400 mg/kg lead and less than 5 mg/L TCLP leachable lead" provides a clearer definition than "The treated soil shall meet all applicable or relevant and appropriate requirements." Although the second statement is more inclusive, it provides a poor basis for the contractor to give an estimate and leaves the final performance requirements open to interpretation.

The SOW should clearly define the roles and responsibilities for the participants in the work. In particular, key decision points and interfaces must be clearly described so that all participants understand who is to perform the work, what is to be done, and where the authority lies for accepting the results.

The work area and the availability of utility services should be described in the SOW so that the proposals are consistent with site capabilities. For example if electricity is not available, the vendors can include costs for an auxiliary generator in their quotation. In particular, the capacity and permit restrictions of the local water treatment plant should be provided. Site characterization data should be made available to the bidders in a convenient format.

The SOW should require the bidders to provide information about the amount of time they will need between contract award and mobilization and the time and cost of performance for each major work element. A contractor's inability to mobilize quickly due to prior work commitments may be a factor in the ranking. Often, however, the vendors who are less available are the better vendors. Over-specification of the schedule may eliminate these vendors.

The SOW is usually prepared to cover the entire scope of the maintenance or remediation activities required, so that the remedial project manager (RPM) has a single contractor with responsibility for the work. Contractors responding to the SOW usually will subcontract some portion of the work. Treatment of small-arms range soil using physical separation and acid leaching involves a wide range of operations that may not be within the capabilities of one contractor. For example, recycling lead metal will be provided by a broker or smelter. Transport of residuals to a recycling or disposal facility is another operation that is likely to be subcontracted.

For a large or complex job, the RPM could act as the general contractor by preparing separate SOWs for each operation. Separating work elements gives the RPM greater flexibility for obtaining the best price for each work element but increases the effort required to coordinate range maintenance activities and creates more opportunities for interface issues and disputes. However, requiring one contractor to have overall responsibility normally provides the most efficient execution for a range maintenance or remediation job.

Each work element should be priced separately to facilitate comparison of the proposals and to allow direct correlation between work progress and payments. A variety of pricing approaches are available including fixed price, cost plus fixed fee, and fixed unit price with an indefinite quantity. A unit price, indefinite quantity approach allows the ability to adapt to field conditions, but should be used with some caution. The total cost can increase if the amount of soil is greater than expected.

9.2 Vendor Identification

The RPM should identify possible sources for obtaining the required services. The U.S. EPA has compiled useful treatment vendor identification resources in the Vendor Information System for Innovative Treatment Technologies (VISITT) and the Vendor-FACTS databases. The most current copies of these databases can be obtained by calling 800-245-4505 or 703-883-8448. Another option is to solicit information in the *Commerce Business Daily*. A number of commercial concerns or industry periodicals produce catalogs that contain information about environmental service firms. A few examples include *Thomas Register*, *Pollution Equipment News* (Rimbach, 1996), and *National Well Drillers Buyers Guide* (Faison, 1996). Yellow Pages directories from cities near the site are also useful sources for identifying potential bidders. If local Yellow Pages are not available, business phone directories for cities throughout the United States on CD-ROM can be used. The worldwide search from the Fort Polk demonstration (USAEC, 1997) is another resource.

9.3 Vendor Selection

Although there are a number of providers of this technology, the following guidance for procurement is offered to ensure successful maintenance or remediation.

The key to successful vendor selection will be to ensure the following:

- ☐ Vendor and proposal operators have had prior experience with physical separation and acid leaching processes for metals-bearing soils (lead experience is preferred)
- ☐ The vendor should provide information on site preparation needs and utilities support required from the site. It may be advisable for the site to overdesign site support facilities (such as power, water, pad size, etc.) to some extent to allow the vendor some flexibility in adding or changing equipment during the operation.
- ☐ The vendor should demonstrate that provisions have been made for adequate and appropriate operator support in terms of number of operators and qualifications. At least one of the operators should have enough knowledge of the process and its chemistry to be able to make on-site adjustments.
- ☐ The vendor should demonstrate that adequate process control has been built into the plant to allow verification and adjustment of key operating parameters, such as pH, contact time, metals concentrations, etc. An on-site AA analyzer and process chemist are suggested.

In response to the RFP, the vendors must provide (Dennis et al., 1992):

- ☐ An explanation of how their process will meet the site remediation requirements, and how their process will handle variations in metal accumulation levels and soil texture (e.g., clay content)
- ☐ A detailed description of the process, including a process flow sheet with the material balance for your site (all input, output, and intermediate streams, solid and liquid flows)
- ☐ A detailed description of the process layout
- ☐ A detailed schedule.

The vendor must perform meaningful bench-scale tests.

- ☐ The vendor should obtain representative samples (see Section 5.3.1) for bench-scale testing.
- ☐ The vendor should perform testing of all critical operations of the proposed process:
  - — Physical separation (e.g., screening density, hydrodynamic, magnetic, froth)
  - — Leaching (e.g., pH, contact time, number of contacts)
  - — Leachant regeneration and metals recovery (e.g., precipitation, solid-liquid separation)
  - — Dewatering of soil and precipitate effluent streams
  - — Neutralization of soil.

The proposals received in response to the SOW should be evaluated first strictly on their technical merits. The basis for evaluating technical quality includes factors such as understanding of the SOW requirements, effectiveness and implementability of the proposed approach, project experience of the proposed personnel, and project experience of the company. Some requirements of the SOW set conditions that must be met and can be used to eliminate unsuitable vendors. Other requirements are desirable but not essential, and can be used to rank candidates that meet the essential requirements. For example, experience with acid leaching of metals in soils may be required. In this case, any vendor that cannot demonstrate the required experience would be unacceptable. Specific experience with treatment of lead in soils at small-arms ranges may be desirable but not essential. Factors that indicate vendor technical competence include the following:

- ☐ Prior experience with physical separation and acid leaching processes for metal-bearing soils (experience with lead desirable)
- ☐ Capability to provide a supervisor with experience in field operation of chemical treatment of soils
- ☐ Capability to provide an experienced process chemist on site during treatment operations
- ☐ Provision of a detailed process flow sheet including a site-specific material balance with the proposal
- ☐ Discussion of methods to adapt to variations in soil texture (e.g., clay content) in the proposal.

The technical evaluation described above should be analyzed by someone familiar with the bench-scale tests performed, physical separation operations, acid leaching operations, process flow sheets, and material balances to ensure a successful site implementation

Cost-effectiveness can be considered after the acceptable candidates have been identified based on technical factors. The RPM can use this handbook and literature sources to estimate the expected project costs for evaluating the cost-effectiveness of proposed approaches.

9.4 Project Management and Quality Control

The RPM should ensure that meaningful treatability tests have been completed before initiating on-site processing. Project planning should allow time for two sets of treatability tests, because a second round of testing often is needed to confirm or refine testing results (see Section 5.0). Treatability test results provided by the vendor should indicate that factors required for design and operation of the physical separation and acid leaching system have been quantified. Treatability test results must be available to support the design of critical operations as follows:

☐ Screening (e.g., particle size and shape)
☐ Physical separation (e.g., particle density, settling rate, magnetic properties, surface properties)
☐ Leaching (e.g., leachant pH, contact time, and number of contacting cycles)
☐ Regeneration of leaching solution (e.g., precipitation conditions)
☐ Metals recovery (e.g., smelter identification and capabilities)
☐ Precipitate dewatering (e.g., solid-liquid separation method).

Treatability test results must be evaluated by someone familiar with these tests and unit operations. The RPM or authorized representative will have the responsibility to provide timely acceptance inspections and sampling and analysis results. For example, soil that has been processed will be sampled and analyzed to determine total and leachable lead content prior to replacement on the berm. The treated soil will be stockpiled during the time required to collect, ship, and analyze a sample. Sampling and shipping will require at least 2 days. Unless special provisions are made, the analytical turnaround time will be 2 to 3 weeks. Although the turnaround time can be reduced, the cost per analysis will increase (see Section 5.6).

Small-arms range maintenance or remediation requires quality assurance of both construction and chemical testing activities. An example QA plan is provided in Appendix C to indicate an approach to quality assurance covering the full range of activities that could occur during a project using physical separation and acid leaching to process small-arms range soils.

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APPENDIX A

HAZARD ANALYSIS FOR HEALTH AND SAFETY PLANNING FOR SMALL-ARMS RANGE SOIL TREATMENT

This appendix presents, in Table A-1, sources and mitigation methods for potential hazards during soil remediation at a small-arms range using physical separation and acid leaching treatment methods.

Table A-1. Hazard Sources and Mitigation during Soil Small-Arms Range Soil Treatment

Hazard	Typical Sources	Mitigation Methods
Small-arms fire	Inadvertently conducting operations during use of nearby ranges	• Obtain clearance from training personnel stating that the required work areas are closed. • Post boundary marking tape, fencing, and signs indicating that the range is closed.
Slips, trips, and falls	Working on top of or on the slope of the berm	• Use the buddy system and ensure that one person is specifically designated to actively watch the working crew and warn anyone approaching the edge. If the hazard seems excessive, install a warning line or barrier.
Slips, trips, and falls	General site area	• Maintain good housekeeping. • Limit range area with boundary marking tape and signs.
Contacting a utility line	Subsurface sampling or excavations	• Low probability because sampling and excavation typically involve berm soils. Obtain confirmation that there are no utility lines that could interfere with work areas.
Contact with Pb, Cu, Zn, As, or Sb	Soil handling and processing	• Level D personal protective equipment (PPE) typically adequate. • Workers should remain upwind whenever possible. • Wear coveralls and gloves. • Maintain good housekeeping. • No eating, smoking, or drinking on site.
Contact with polycyclic aromatic hydrocarbons	Soil handling and processing at shotgun ranges	• Level D PPE typically adequate. • Wear coveralls and gloves. • Maintain good housekeeping. • No eating, smoking, or drinking on site.
Respiration of potentially contaminated dust	Soil screening or other soil handling during dry conditions	• Provide real-time aerosol monitoring upwind, downwind, and in the work zone • Dusty conditions may require upgrading to Level C PPE. • Remain upwind whenever possible. • Water spray, polymer foam, or plastic covers may be needed for dust suppression. • Consider providing personal monitors and real-time dust monitors, particularly if soils are fine or have low moisture content.
Contact with chemicals	Soil processing	• Level D PPE typically adequate. • Wear coveralls and gloves. • Wear safety glasses with side shields when preparing and using solutions. • Maintain good housekeeping. • No eating, smoking, or drinking on site.

Table A-1. Hazard Sources and Mitigation during Soil Small-Arms Range Soil Treatment (Continued)

Hazard	Typical Sources	Mitigation Methods
Contact with steam, detergent, or solvent	Decontaminating equipment	• Level D PPE typically adequate. • Wear coveralls and gloves. • Wear safety glasses with side shields when preparing and using decontamination solutions. • Maintain good housekeeping. • No eating, smoking, or drinking on site.
Contact with hazardous flora or fauna	General site area and, in particular, the back of the berm	• Wear coveralls, steel-toed shoes, and gloves. • Perform periodic self-checks for ticks and insect bites.
Weather extremes	Work in inclement weather	• Use dress consistent with conditions. • Stop work in extreme heat, cold, or precipitation.
Traffic	Roadways near site	• Wear warning vests, if working near a road. • Provide flagman or barricades as appropriate, if working near a road. • Park vehicles well off of the road. • Use caution when approaching or crossing the road.

APPENDIX B

EXAMPLE CONTENTS OF A WORK PLAN FOR SMALL-ARMS RANGE SOIL TREATMENT

1.0 INTRODUCTION
  - 1.1 Site Description and Historical Information
  - 1.2 Previous Investigation
  - 1.3 Planned Program
    - Purpose of Work Plan
    - Planned Work Scope
    - Overview of Activities
    - Identify Stakeholders and Participants and Their Roles and Responsibilities

2.0 WORK ACTIVITIES
  - 2.1 Subcontractor Procurement
  - 2.2 Permitting and Notification
  - 2.3 Site Preparation and Mobilization
  - 2.4 Excavation
  - 2.5 Treatment
  - 2.6 Residuals Management and Transportation
  - 2.7 Sampling and Acceptance
  - 2.8 Site Restoration
  - 2.9 Demobilization

3.0 ENVIRONMENTAL MANAGEMENT ACTIVITIES
  - 3.1 Water and Biological Resources
    - Surface Water
    - Groundwater
    - Flora and Fauna
    - Sensitive Environments
    - Rare, Threatened, and Endangered Species
  - 3.2 Other Resources
    - Population and Land Use
    - Architectural and Archeological Protection
  - 3.3 Impact Pathways Analysis
  - 3.4 Regulatory Drivers
    - Regulatory Lead
    - Regulatory Requirements

4.0 PROJECT MANAGEMENT
  - 4.1 Project Responsibilities
  - 4.2 Project Cost and Schedule
  - 4.3 Document Control and Data Management
  - 4.4 Meetings and Reports

APPENDIX C

QUALITY ASSURANCE PLAN FOR PERFORMING MAINTENANCE OF THE BERM AT RANGE A-33

1.0 MANAGEMENT

This quality assurance (QA) plan sets forth the policy and requirements for the quality program during maintenance activities for the impact berm of small-arms Range A-33. (This QA plan is a hypothetical example; the range described does not exist.) Range A-33 is a 25-yd pistol range with 15 firing points. The range has been in use for more than 50 years. The berm is 120 ft long, 20 ft high, 50 ft wide at the base, and 10 ft wide at the top. The general arrangement of the site is shown in Figure C-1.

The objective of the project is to perform maintenance to correct a ricochet problem and improve the general condition of the berm. The scope of the work includes the following items:

1. Preparing project plans
2. Mobilization to the site
3. Soil excavation and processing
4. Berm reconstruction
5. Demobilization and site restoration.

The QA plan establishes a management system to assure that work activities are conducted to meet established quality standards in a planned and controlled manner and documented to demonstrate that the quality standards are met. This range maintenance activity involves excavation and treatment of impact berm soils and expansion and refurbishment of the range.

1.1 Quality Program

The purposes of this QA plan are to define standards for the materials and methods to be used during maintenance of Range A-33 and to provide methods to measure and document the quality of the maintenance activities with respect to those standards. This QA plan covers all activities that affect the quality of the work performed during maintenance of the impact berm at Range A-33.

Quality control of field operations will be ensured by adherence to the work plan, this project QA plan, and contractor corporate QA policies. All project and corporate policies concerning field activities, cost accounting, resource utilization, and performance monitoring in the field will be followed.

All staff involved in range maintenance are responsible for implementing the provisions of the quality program described in this plan. Quality achievement shall be verified by personnel who are not directly responsible for performing the work. All staff working on the project have the authority and responsibility to identify conditions adverse to quality, health and safety, and to recommend stopping any activity in question until the condition has been corrected. Final decision to "stop work" is the responsibility of the manager supervising the element of work. The project organization is shown in Figure C-2. The roles and responsibilities of specific personnel and organizations are summarized in Table C-1.

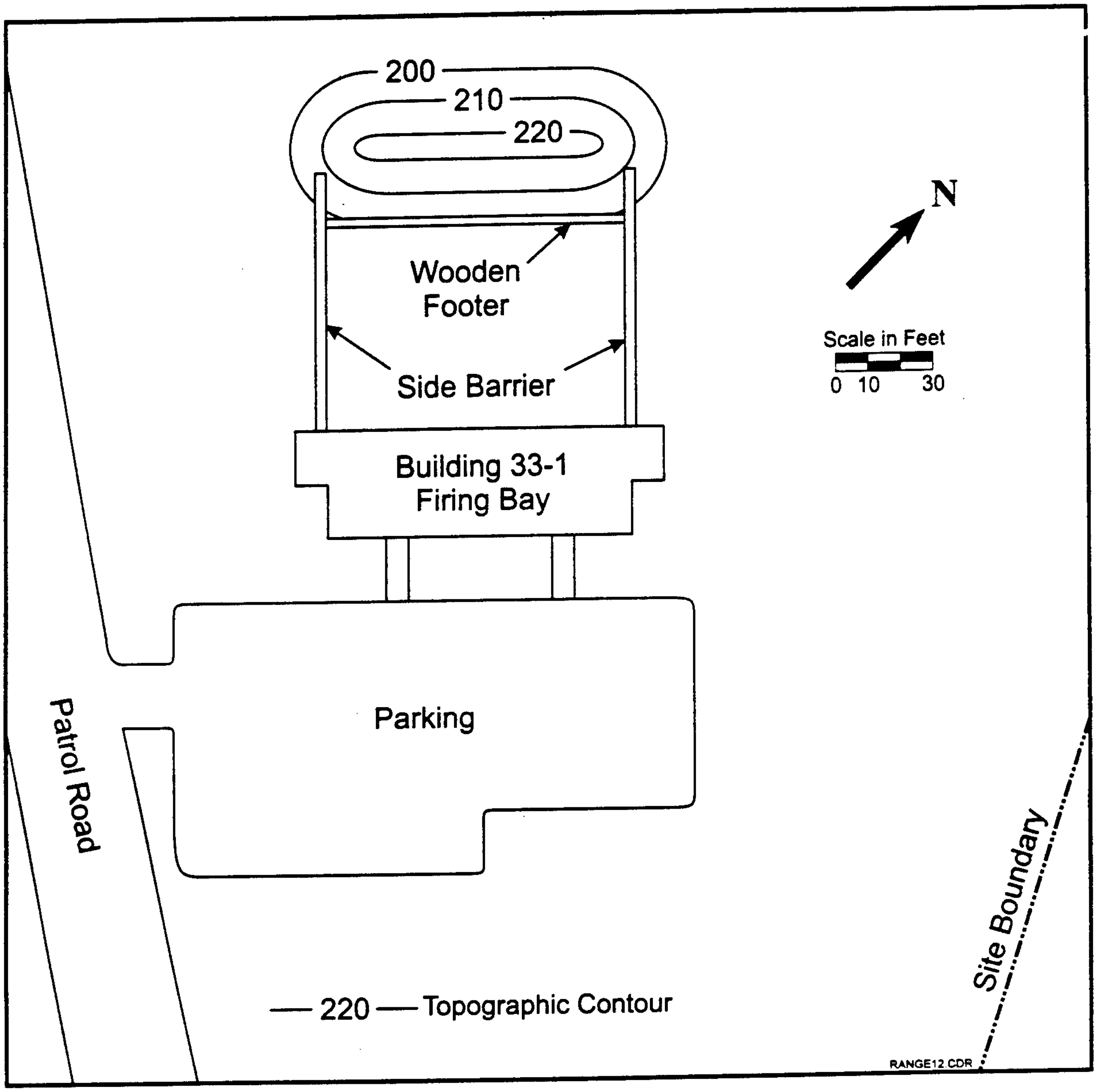

Figure C-1. Range A-33 General Site Features

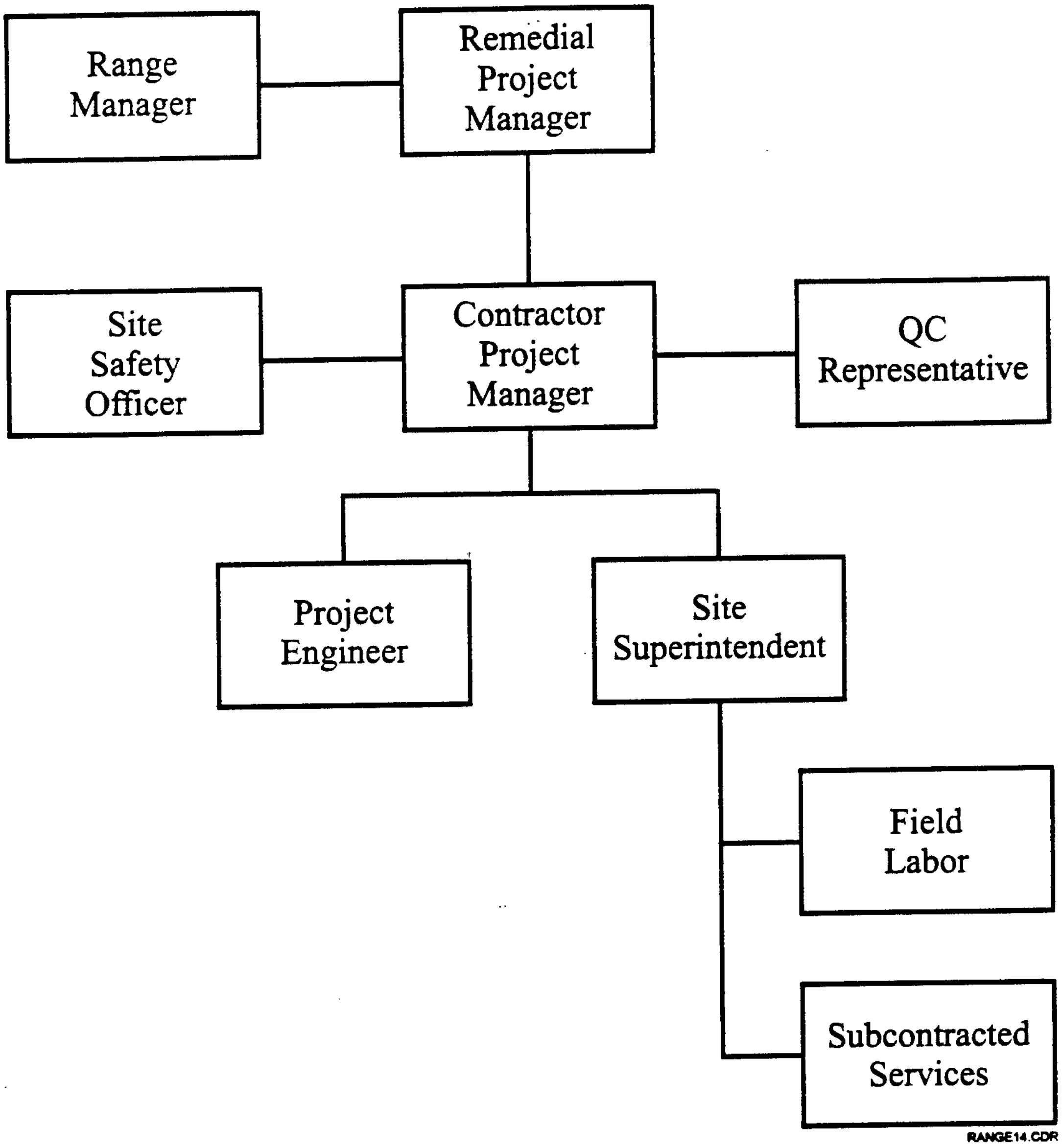

Figure C-2. Range A-33 Range Project Organization Chart

Table C-1. Responsibilities and Authorities of Key Personnel in Small-Arms Range Remediation

Key Position	Responsibilities	Authorities
Range manager	• Provide clearance to access the range • Arrange for access to water and electrical utility services • Review project plans	• Control access to the range • Approve/disapprove work plans • Approve/disapprove range acceptance
Remedial project manager	• Administer work effort • Review project planning, budgeting, scheduling, and overall performance • Assist project personnel in resolving support and interface issues • Ensure effective program communications	• Commit resources for the project • Approve/disapprove work plans • Approve/disapprove technical elements of work • Resolve schedule and resource conflicts • Monitor timely completion of work • Approve/disapprove project costs • Approve/disapprove range acceptance
Contractor's project manager	• Allocate and manage resources for work execution • Supervise preparation of plans and specifications • Manage project planning, budgeting, scheduling, and overall performance • Review of field logbooks and analytical data to ensure compliance with health and safety and quality standards • Identify and correct root causes of noncompliance	• Approve/disapprove work plans • Approve/disapprove technical elements of work • Resolve schedule and resource conflicts • Monitor timely completion of work • Select and manage project technical staff
Contractor's quality control representative	• Monitor and audit field and laboratory operations to ensure compliance with QA plan • Review all data • Ensure adequate documentation is developed and maintained • Monitor identification and correction of root causes of noncompliance	• Conduct unannounced audits of field or laboratory procedures • Review field logbooks • Approve/disapprove field or laboratory data • Stop field or laboratory work which is not in compliance with the QA plan
Contractor's health and safety officer	• Monitor and audit field and laboratory operations to ensure compliance with the Health and Safety Plan (HASP) • Conduct the daily site safety meeting at the start of each work day • Brief field personnel regarding special hazards • Monitor handling, labeling, shipping, and control of potentially hazardous substances • Conduct air monitoring	• Immediately shut down field or laboratory operations if a violation of the HASP exists • Immediately shut down field or laboratory operations if an unacceptable hazard level exists
Contractor's site superintendent	• Perform range maintenance in compliance with the SOW, work plan, QA plan, and HASP • Maintain field logbooks and analytical data to ensure compliance with health and safety and quality standards • Perform sampling and analysis for final acceptance testing • Identify and correct root causes of noncompliance	• Resolve site resource problems, if possible, and consult with the contractor's project manager to obtain needed resources • Immediately stop work that does not conform to the requirements of the SOW, work plan, QA plan, or HASP • Select equipment and methods to accomplish required work • Approve/disapprove material and labor costs for site operations
Subcontractors	• Perform range maintenance in compliance with the SOW, work plan, QA plan, and HASP	• Immediately stop work that does not conform to the requirements of the SOW, work plan, QA plan, or HASP • Select equipment and methods to accomplish work elements in their scope • Approve/disapprove material and labor costs for work elements in their scope

1.2 Personnel Training and Qualification

This section describes the responsibilities and requirements for training, indoctrination, and qualification of contractor staff working on maintenance at Range A-33. The contractor's project manager is responsible for ensuring that staff assigned to the project have the appropriate skills for the assignment. All personnel involved with the project shall read and be familiar with the contents of this QA plan. Personnel involved with soil treatment processes shall have demonstrated prior experience with the safe operation of physical separation and acid leaching equipment. All personnel working on site shall have successfully completed a 40-hr HAZWOPER health and safety training course and current 8-hr update in accordance with OSHA 29 CFR 1910.120.

1.3 Quality Improvement

This section establishes the requirement for efforts to promote continuing quality improvement in project activities. The contractor's project manager is responsible for ensuring that quality improvement is encouraged. Quality improvement will focus on improving work processes, identifying and correcting work that does not conform to quality standards, and determining and correcting the root cause of any nonconformance. Nonconformance shall be recorded in the field logbook. The contractor's project manager or site superintendent shall identify and document the root cause and corrective actions taken in the field logbook.

1.4 Document Control and Records Management

This section establishes the requirement for preparing, reviewing, and filing project documents. The field work area will be organized to provide a safe and efficient workplace for the project team. Information pertaining to the project, such as copies of the work plan and HASP shall be maintained within the field work area. The contractor's project manager is responsible for ensuring that project reports are prepared, reviewed, and maintained in accordance with this QA plan. The contractor's site superintendent is responsible for ensuring that copies of project plans, including a map showing the route to the hospital and a copy of the emergency contact phone numbers, are available on site. The contractor's site superintendent is responsible for ensuring that field logbooks, data sheets, and chain-of-custody forms are prepared in accordance with this QA plan. Project reports, field logbooks, and data sheets shall be transmitted to a records management office where the documents will be maintained and protected for 3 years after project completion.

2.0 PERFORMANCE

2.1 Work Processes

This section establishes the requirement for performing maintenance activities at Range A-33 in accordance with the project SOW, work plan, QA plan, and HASP.

2.1.1 Definable Features of Work

Work elements are grouped by similarity in their implementation requirements to allow definition, control, and documentation of the quality achieved. The definable features of work for the berm maintenance activity are as follows:

1. Preparing project plans
2. Mobilization to the site
3. Soil excavation and processing
4. Berm reconstruction
5. Demobilization and site restoration
6. Site acceptance testing.

These features will be managed for compliance with the work plan and project specifications by implementing visual inspections and laboratory testing. All inspections will be documented in accordance with document control and records management requirements established in this QA plan.

2.1.2 Preconstruction Conference

A preconstruction conference will be held to review site conditions, project approach, plans, required policies, procedures, and other quality-related issues prior to commencement of on-site activities. The meeting will be attended by the range manager, RPM, contractor's project manager, and subcontractor technical representatives. The team shall discuss the project execution plan, establish lines of communication, and address outstanding issues.

2.1.3 Project Plans and Submittals

All project plans and submittals prepared for this project will receive technical review by the contractor's project manager prior to final review and approval by the RPM. The RPM will obtain input from the range manager and other site personnel as appropriate.

2.2 Identification and Control of Items

This section establishes the requirement for identification and control of quality-affecting items during the maintenance activities at Range A-33. The contractor's site superintendent is responsible for recording the types of chemicals used for the treatment and their source of supply and lot number. The contractor's site superintendent is responsible for ensuring that samples collected for chemical analysis are identified with unique numbers and that the sample number and identification are recorded in the field logbook.

2.3 Handling, Storage, and Shipping

This section establishes the requirement for handling, storing, and shipping confirmation samples collected during the maintenance activities at Range A-33. The contractor's site superintendent is responsible for ensuring that all samples are properly handled, stored, and shipped.

2.3.1 Sample Container Labeling

A label will be applied to the sample container before the sample is collected. The label will be completely filled out with permanent ink and will contain the following information:

- Sample number
- Sample matrix
- Preservative used, if any
- Sampling location

- Analysis required
- Initials of the sampler
- Date and time of sample collection.

2.3.2 Sample Container Cleaning

Clean, empty sample containers will be provided by the analytical laboratory. The containers will be wide-mouth bottles made of glass or polyethylene. The outer surfaces of the sample containers will be cleaned by field sampling personnel after the sample container is filled.

2.3.3 Sample Container Packing and Shipping

The labeled, cleaned, and filled sample containers will be double-wrapped in plastic bags and placed in the shipping containers. Insulated chests will be used for sample shipping. Bubble pack or similar packing materials will be used to protect the sample containers. A chain-of-custody form will be placed in each shipping container and the containers will be sealed and protected by a chain-of-custody seal.

2.3.4 Sample Preservation

No preservative will be required for the samples. The maximum allowed hold-time between collecting the sample and analysis by the laboratory is 6 months.

2.3.5 Residuals Management

The waste materials generated by sampling activities will be excess soil collected during sampling, soapy water and solvent used to decontaminate sampling equipment, and protective clothing. The excess soil will be returned to the area sampled. The soapy water will be spread on the site and will be allowed to infiltrate into the soil. The solvent will be placed in a shallow pan and will be allowed to evaporate. The protective clothing will be placed in trash containers at the site.

Bullet metals will be transported to a recycling facility in accordance with an approved transportation plan. The recovered lead will be packaged and labeled by the treatment subcontractor with review and approval by the site superintendent. The recovered lead package will be labeled and shipped as a lead-bearing product, not as a RCRA hazardous waste.

Treated soils will be used on site to rebuild the berm. Treated soil will be sampled and will be determined to meet the total and leachable lead content requirements specified in the work plan prior to use on the berm. Sampling and analysis are the responsibility of the contractor's site superintendent.

2.4 Process Monitoring, Data Collection, and Test Equipment

This section establishes requirements and responsibilities related to the control, maintenance, and management of monitoring, data collection, and test equipment.

2.4.1 Laboratory Monitoring and Equipment

The contractor's program manager is responsible for ensuring that laboratory analytical equipment is calibrated in accordance with the manufacturer's instructions. The program manager will review the laboratory quality control, calibration, and analytical procedures to ensure compliance with project requirements. The program manager will review sample receipt records, holding times, and matrix spike and matrix spike duplicate results to evaluate the quality of laboratory results. On-site audits of the laboratory results may be performed to further assess and document quality.

2.4.2 Field Monitoring and Equipment

The assigned, full-time contractor's site superintendent will directly supervise and be responsible for all aspects of operations, health and safety, quality control, schedule, and budget for on-site activities. The site superintendent has the authority to stop work, if required, to correct failure to conform to quality or health and safety requirements.

The site superintendent, or authorized representative, will conduct field inspections and tests and document the results in the field logbook.

The contractor's site superintendent is responsible for ensuring that procedures are available in the field for calibrating measurement equipment used on site, that the personnel are trained using the procedures, and that calibrations are performed as required in the procedures. The frequency and results of site calibrations shall be recorded in the field logbook.

2.5 Design

This section establishes the requirements for maintaining quality during design of maintenance activities at Range A-33.

2.5.1 Project Submittals

Submittals will be prepared at appropriate times during project execution per the requirements of the project statement of work (SOW), as follows:

- Work plan
- QA plan
- HASP
- Final report
- Monthly progress reports.

2.5.2 Design Quality Assurance Records

Design documents that affect quality will be reviewed, stored, and maintained in accordance with this QA plan. Design documents considered to be QA records include, but are not limited to, the following:

- Design references, data sources, and design basis documents
- Design calculations
- Design verification records
- Workplans, test procedures, and inspection documents
- Design output such as drawings and specifications.

2.5.3 Submittal Review

Submittals will be reviewed, signed, and dated by the preparer, a technical reviewer, other project team members (as appropriate) and the contractor's project manager. The reviewed draft will be submitted to the RPM for review by the RPM. The submittals will be revised in accordance with comments from the RPM and issued as a final document.

2.5.4 Calculations

Calculations will be prepared with sufficient explanation and documentation to allow a technically qualified person to review and understand the assumptions, methods, and input data and to verify the results. The minimum required documentation in a calculation is, as follows:

- A statement of the purpose of the calculation
- A discussion of the calculation method
- A listing of the assumptions and the basis for using the assumption
- References for data and equations used
- Numerical calculations
- Results.

All calculations will be reviewed by an independent reviewer and will be maintained as quality-affecting records.

2.5.5 Drawing Verification

Each drawing will be issued a unique identification record which is maintained even if the drawing is revised. The drawing identification log is maintained by the drafting group. Drawings will be checked prior to issue by an independent reviewer and will be maintained as quality-affecting records. Each drawing will be signed by the preparer and the staff member who reviewed the drawing.

2.6 Procurement

This section establishes the requirements for maintaining quality during procurement of subcontracted services to perform maintenance activities at Range A-33. Project requirements will be documented in a SOW that is accepted by both the RPM and the contractor. The contractor may subcontract portions of the work to other organizations. The contractor's project manager is responsible for ensuring that technical and quality requirements and acceptance criteria for the subcontract are specified in a SOW and that the SOW is reviewed and approved by an independent reviewer and by site personnel prior to executing the subcontract.

2.7 Inspection

This section establishes the requirement for routine inspections during the maintenance activities at Range A-33. The contractor's site superintendent is responsible for ensuring that confirmation samples are collected. Field inspections include the following:

- Receiving inspections such as visual inspection of or review of supplier quality records for materials used for soil treatment

- Surveying to determine site arrangement and elevations

- Checklists to document critical operations or inspections

- Work inspection such as visual inspection or measurement of an item for compliance with project requirements

- Equipment inspection such as visual inspection of the condition or operating features of equipment used for soil excavation, handling, or treatment.

2.8 Acceptance Testing

This section establishes the requirement for collecting and analyzing confirmation samples collected during the maintenance activities at Range A-33. The RPM or authorized representative is responsible for ensuring that confirmation samples are collected. The required sampling frequency and analyses are summarized in Table C-2.

Table C-2. Acceptance Testing for the Range A-33 Confirmation Samples

Sample Frequency	Analyte/ Method	Accuracy (% recovery)	Precision (%)	Completeness (%)	Detection Limit
One sample each 100 yd^3 (or 130 tons) of soil treated and one duplicate for every tenth sample	Total Pb/EPA SW 846 Method 3051/6010	50-150	50	80	1.0 mg/kg
	TCLP Pb/EPA SW 846 Method 1311	50-150	50	80	0.1 mg/L
	pH/EPA SW 846 Method 9045	0.1 pH unit	0.1 pH unit	50	NA

2.8.1 Representativeness

Representativeness is a measure of how well the sample characteristic matches the population characteristics. The sample collection methods should be selected so that the characteristics of the sample submitted to the laboratory match the characteristics of the batch of material of interest. One sample will be collected from each 100 yd^3 (or 130 tons) of soil treated, and one field duplicate will be collected for every tenth sample. The confirmation samples will be formed as a composite of ten subsamples collected at random locations from the 100-yd^3 unit. The subsamples will be well mixed and then split with a riffler to obtain a 1-L sample for size reduction processing and analysis.

2.8.2 Accuracy and Precision

Accuracy is a quantitative measure of the agreement of a measurement with an accepted reference value and is usually stated as a percent recovery. Precision is a quantitative measure of the agreement of repeated determinations of the same parameter and is usually stated as a relative percent difference or relative standard deviation. Accuracy and precision goals are set at 50% because of the high variation that occurs when analyzing heterogeneous samples. One field duplicate, one laboratory duplicate, and one laboratory duplicate matrix spike will be performed for each ten samples.

2.8.3 Completeness

Completeness is a measure of the amount of valid data collected compared to the data needed to achieve project objectives. The number of valid samples must be sufficient to support decisions based on the data. A high percentage of the analyses for toxicity characteristic leaching procedure (TCLP) leachable lead and total lead must be valid. The TCLP leachable lead is the critical parameter determining the adequacy of immobilization of the lead. The total lead result can assist in interpreting the results, if a sample has a high value in the TCLP test.

2.8.4 Limit of Detection

The limit of detection is a measure of the ability of the test method to determine the presence of element at low concentrations. The limit of detection must be low enough to allow reliable quantitation of the concentration.

3.0 ASSESSMENT

3.1 Management Assessment

This section establishes the requirement for management assessment and maintenance of quality during the maintenance activities at Range A-33.

3.1.1 Enforcement

The contractor or subcontractor will stop work on any item or feature pending satisfactory correction of any failure to conform to project requirements. Work will not continue on any item or feature containing uncorrected work unless the contractor's project manager and the RPM agree that the nonconformance can be corrected without disturbing the completed work.

3.1.2 Corrective Action

This section describes contingency plans for unexpected conditions. Corrective action will be required if a batch of treated soil contains a total lead concentration more than 400 mg/kg or a TCLP leachable lead concentration more than 5.0 mg/L. If any TCLP results are over the required levels, the RPM will assess the results and determine the proper action. If the number and magnitude of treated samples exceeding the limit are small, it may be appropriate to collect additional samples. If many samples exceed the limit or if the lead concentration is much higher than the limit, blending and retreatment of the batch may be required.

3.2 Independent Assessment

The contractor will provide internal review of project documents by an independent expert. The RPM will provide additional independent assessment.

APPENDIX D

STATEMENT OF WORK FOR PERFORMING MAINTENANCE OF THE IMPACT BERM AT RANGE A-33

1.0 SCOPE

This section describes, in general terms, the existing site conditions and work to be performed at Range A-33 under this Statement of Work (SOW). (This SOW is a hypothetical example; the range described does not exist.)

1.1 General

This SOW covers maintenance activities to correct ricochet problems and improve the condition of the berm, particularly by reducing the quantity of lead in the berm. The overall objective of the maintenance activity is to process berm soils to recover bullet metals and reduce the mobility of metals and to resurface the berm to reduce ricochet and improve the condition of the berm. The maintenance activity will involve the following:

- removing the target stands and side barrier walls
- removing a wooden retaining footer at the base of the berm
- excavating soils from the impact berm
- recovering and managing the bullet metals from impact berm soils
- processing excavated soils using acid leaching to reduce the total concentration and mobility of lead
- using the processed soil to rebuild the impact berm
- replacing the wooden retaining footer at the base of the berm and forming a limestone gravel-lined drainage channel
- replacing side barrier walls
- replenish topsoil and reseed damaged areas at the A-33 range caused by project work
- replacing the target stands.

1.2 Background

Range A-33 is a 25-yd pistol range with 15 firing points. The range has been in use for more than 50 years. The berm is 120 ft long, 20 ft high, 50 ft wide at the base, and 10-ft wide at the top. The general arrangement of the range and impact berm is shown in Figure D-1. The results of the sampling

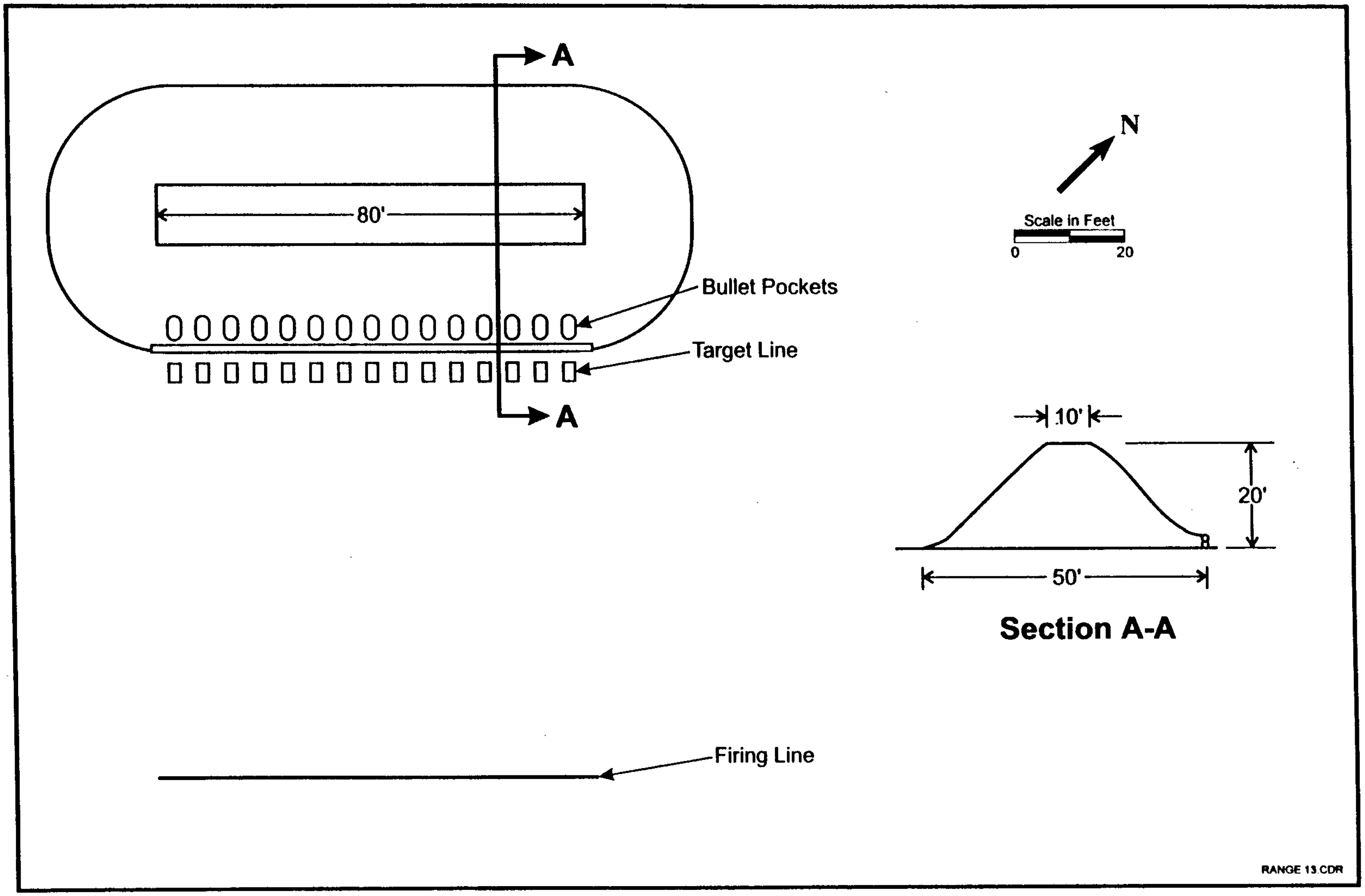

Figure D-1. General Arrangement of the Range A-33 Impact Berm and analysis project, completed in March 1997, indicate that the bullet pockets contain a high concentration of bullet lead fragments and an average concentration of 35% lead. Horizontal borings into the berm at the bullet pocket position located bullet concentrations about 10 ft into the berm indicating that the berm had been resurfaced. Soil on the berm surface surrounding the bullets pockets had lead concentrations averaging 3,770 mg/kg lead with a range of 15.1 to 17,200 mg/kg. The copper content averaged 560 mg/kg with a range of 55.0 to 1,620 mg/kg. Subsurface samples averaged 210 mg/kg with a range of 20 to 545 mg/kg, except for samples from the layer of bullets beneath the resurfacing. Subsurface samples that contained bullets or bullet fragments averaged 5,200 mg/kg lead with a range of 75.2 to 33,400 mg/kg. A site characterization report can be supplied at the contractor's request.

2.0 APPLICABLE DOCUMENTS

This section lists codes, standards, and background documents applicable to the work effort.

a. Department of Defense. 1992. *Military Handbook - Range Facilities and Miscellaneous Training Facilities Other Than Buildings.* MIL-HDBK-1027/3B. Naval Facilities Engineering Command, Southern Division, Charleston, NC.

b. Whiting, R.C. 1989. *The Range Manual - A Guide to Planning and Construction.* National Rifle Association, Fairfax, VA.

3.0 REQUIREMENTS

This section describes the specific requirements for the range activities.

3.1 Scope of Work

a. The contractor shall attend a preconstruction meeting at the site, including a visit to the site, prior to starting work.

b. The contractor shall coordinate with site personnel to arrive on site within one week of notification that the range is available for the start of work.

c. The contractor shall provide materials, equipment, and labor to remove target stands, wooden footer, and side barrier walls, and to excavate and process soil from the impact berm. The total expected quantity of soil to be excavated and processed is 1,970 yd^3 (3,030 tons) in place.

d. The contractor shall provide materials, equipment, and labor to screen the soil to remove lead fragments larger than 0.25 in. and to treat the screened soil. The treated soil shall contain less than 400 mg/kg total lead and pass the toxicity characteristic leaching procedure (TCLP) criteria for lead (5.0 mg/L) and arsenic (0.5 mg/L).

e. Screening is expected to produce 300 tons of oversize material containing about 50% lead and about 5% copper, and 2,730 tons of soil requiring treatment.

f. The contractor shall provide materials, equipment, and labor to pack, label, and ship the recovered lead to a lead processing facility (e.g., The Doe Run Company or ASARCO) identified by the contractor. All shipments shall be in compliance with U.S. Department of Transportation (DOT) regulations. The recovered lead should be acceptable for recycling but will be weathered and mixed with soil and will not have significant scrap value. The proposal should include costs for shipping and processing the recovered lead as a separate line item.

g. The contractor shall provide materials, equipment, and labor to rebuild the berm to the original dimensions using treated soil. Soil placed on the face of the impact berm must be free of rocks or other hard particles larger than ½ inch in diameter. Soil added to the impact berm shall be compacted to 95% of maximum dry density determined by hand compaction. The slope must be as steep as possible and not less than 45 degrees (rise-over-run ratio of 1:1).

h. The front edge at the base of the berm shall be finished with a wooden retaining footer and a drainage channel in front of the footer sloped to the outside edge of the range. The wooden poles removed from the base of the berm should be reused, if possible. The drainage channel should be lined with a 2-in.-thick base of limestone gravel and covered with a 2-in.-thick layer of sand.

i. Barrier walls 1 ft thick and 10 ft high shall be replaced along both sides of the range. The walls shall be constructed of a wooden support structure with an earthen fill.

j. The contractor shall provide materials, equipment, and labor to clean and grade the berm and areas disturbed by soil processing. Hydrospreading, or an equivalent method, shall be used to cover bare areas with grass seed, fertilizer, and wood fiber mulch.

k. The contractor shall provide materials, equipment, and labor to replace target stands.

l. Two weeks prior to the start of work, the contractor shall provide a work plan for review and approval by the RPM. The plan shall define project activities, as follows:

Section 1.0 Introduction

- Site Description and Historical Information
- Previous Investigation
- Planned Program

Section 2.0 Work Activities

- Subcontractor Procurement
- Permitting and Notification
- Site Preparation and Mobilization
- Excavation
- Treatment
- Residuals Management and Transportation
- Sampling and Acceptance
- Site Restoration
- Demobilization

Section 3.0 Environmental Activities

- Water and Biological Resources
- Other Resources
- Impact Pathways Analysis
- Regulatory Drivers

Section 4.0 Project Management Activities

- Project Responsibilities
- Project Cost and Schedule
- Document Control and Data Management
- Meetings and Reports

m. Two weeks prior to the start of work, the contractor shall provide all necessary preconstruction designs, drawings, and specifications for review and approval by the RPM.

n. The contractor shall develop a Health and Safety Plan (HASP) based on Level D conditions for review and approval by the RPM. The HASP may be a stand-alone plan or a site-specific addendum for the contractor's corporate HASP.

o. The contractor shall develop a Quality Assurance (QA) Plan for review and approval by the RPM. The QA plan may be a stand-alone document or a site-specific addendum for the contractor's program or corporate QA Plan.

p. The contractor shall prepare a final report documenting work activities and results for review by the RPM.

3.2 Program Management

a. In the response to this SOW, the contractor shall provide separate pricing for six line items as follows:

   1. Work plan (including HASP and QA plans)
   2. Mobilization to the site
   3. Soil excavation and processing
   4. Shipping and processing recovered lead
   5. Berm reconstruction
   6. Demobilization and site restoration.

b. In the response to this SOW, the contractor shall provide an estimate of operating space and utility requirements for the proposed work.

c. In the response to this SOW, the contractor shall describe the type and processing capacity of screening and treatment equipment to be used for the proposed work.

d. In the response to this SOW, the contractor shall provide a site-specific process flow diagram and preliminary mass balance for the proposed process.

e. In the response to this SOW, the contractor shall designate the person who will manage the site work and briefly describe that person's prior experience and qualifications.

f. In the response to this SOW, the contractor shall provide references for previous similar work.

g. In the response to this SOW, the contractor shall provide the names of any subcontractors to be used for the proposed work.

h. In the response to this SOW, the contractor shall provide an expected project schedule assuming a start date of July 10, 1997. The contractor shall also state the earliest start date the contractor can support.

i. Contractor personnel working at the site shall have successfully completed a 40-hr hazardous waste operations (HAZWOPER) health and safety training course and current 8-hr update in accordance with Occupational Safety and Health Administration (OSHA) 29 CFR 1910.120.

j. The contractor shall maintain a daily field logbook recording site conditions and project activities, including the temperature, weather conditions, and amounts of soil processed, bullet metals recovered, and chemicals consumed.

k. The contractor shall provide monthly progress reports describing completed activities, planned work, budget and hours expended, and major problems and planned resolutions. The monthly progress reports shall be submitted on the 15th day of each month.

l. The contractor shall coordinate with site personnel to obtain clearance for access to the range and any other required permits.

m. The contractor shall provide sampling and analysis for treated soil and provide the results to the RPM for acceptance or rejection of treated batches within 10 calendar days after treatment is completed.

n. The RPM shall provide a representative on site to approve field reports and make on-the-spot decisions should unforeseen situations arrive.

3.3 Quality Assurance

a. In the response to this SOW, the contractor shall submit a copy of the corporate QA plan or a description of the contractor's approach to QA for similar projects.

b. The RPM may perform QA review on site during the range maintenance.

4.0 OTHER CONSIDERATIONS

This section describes special considerations required in planning the small-arms range maintenance activity.

4.1 Program Information

The contractor shall not hold any discussions or release any information pertaining to any efforts under this contract without approval of the RPM at the site. This restriction applies to all releases of information to the public, industry, or government organizations, except as follows:

- Information for actual or potential subcontractors or vendors needed by the contractor to accomplish the contract
- Information to be supplied to site personnel or other duly authorized representatives.

4.2 Government-Furnished Property

The contractor is expected to be self-sufficient in field materials handling, construction, treatment, and metal recycling activities. The RPM shall provide sampling and analysis of treated soil. The government will provide utility and support services, as follows:

- The firing area in front of the impact berm will serve as the work area for soil processing. This is an unpaved area 120 ft by 90 ft.
- The work area has utility supplies available as follows:
  - electricity 400 kva, 3-phase, and 440 volts
  - process water at 50 gpm
  - sewer at 50 gpm (wastewater must contain <10 mg/L lead).

4.3 Security Requirements

This program is expected to be unclassified throughout. The contractor should inform the RPM if any information provided is considered proprietary or business sensitive.

5.0 POINT OF CONTACT

The response to this proposal and all information requests in connection with this proposal should be directed to the following:

Peter Schwartz
Point of Contact
Range A-33
Someplace, OH 43255
614-297-1919

APPENDIX E

EXAMPLE TRANSPORTATION PLAN FOR RECOVERED LEAD

This plan describes the requirements for driver training; loading, handling, and unloading; and vehicle decontamination to support transport of recovered lead from the small-arms range to a lead processing facility.

1.0 DRIVER TRAINING

The trucking company selected to haul the recovered lead shall have experience in transporting hazardous cargo. All truck drivers will be informed about the characteristics of the materials they will be transporting. Training will be provided as a briefing by the site superintendent and an information packet including the following information:

- A map with clear instructions defining the route to follow to the processing facility
- Material Safety Data Sheets for lead, copper, and zinc
- Laboratory results indicating the composition of the material being carried.

2.0 LOADING AND HANDLING AT THE RANGE

Recovered lead will be transferred from a holding pile at the range into the trucks using a front-end loader. The truck beds will be lined and the load will be covered with a tarp or similar durable cover. Any inadvertent accumulation of lead on the outside of the bed during loading will be removed and returned to the pile or placed into the truck bed prior to departure from the site. The driver will ensure that the truck is properly load and placarded with review and inspection by the site superintendent. Trucks will be weighed at a nearby scale and may return to adjust the size of the load to maximize the weight carried within legal limits.

3.0 UNLOADING AND HANDLING AT THE DESTINATION

On arrival at the processing facility, the recovered lead will be offloaded to the storage location designated by facility personnel. The bed liners will remain at the processing facility for their use or disposal.

4.0 DECONTAMINATION OF THE TRUCKS

Use of bed liners will minimize the need for decontamination of the truck beds. If decontamination is required, the beds will be mopped out using a trisodium phosphate detergent solution. The detergent solution will be disposed of by the processing facility.