Texas Custodial Trust

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Review of ASARCO El Paso Smelting Processes

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Contents

Appendices

Acronyms Used in the Report

Sb	antimony
As	arsenic
Bi	bismuth
Cd	cadmium
Cr	chromium
Co	cobalt
Cu	copper
Pb	lead
Mo	molybdenum
Ni	nickel
Se	selenium
Ag	silver
Zn	zinc

1. Introduction

The El Paso smelter processed metals including lead (Pb), copper (Cu), cadmium (Cd), zinc (Zn), and antimony (Sb) during its greater than 110 year history. This summary provides information about the materials that were smelted at the El Paso smelter and details about the "inputs" and "outputs" from the smelting process. The inputs (ore and concentrates) arrived at the smelter from mines in the surrounding area including New Mexico, Arizona, western Texas, and northern Mexico, as well as the recycle material containing hazardous waste that was provided by ENCYCLE/Texas Inc., an ASARCO subsidiary located in Corpus Christi, Texas (ENCYCLE). The outputs included pure metal product and trace metals. The purpose of this document is to provide a technically informed discussion of the history of the material smelted at the El Paso smelter, including the environmental fate of the materials that entered the smelting process.

The smelting process involves separating the target metal (the metal of value) from naturally-occurring impurities. A smelter uses heat and oxygen to accomplish this. For example, the El Paso smelter processed predominantly copper which arrived at the smelter via rail from a variety of mines that prepared the copper in the form of a concentrate for smelting. The concentrate was the result of initial separation and concentration processes, usually performed at the mine. Copper generally occurs with sulfur (S), as a sulfide mineral, and is separated from non-valuable rock materials via a flotation process. The copper sulfide concentrate is delivered to the smelter for further processing into pure copper metal. The concentrate contained trace metals, including Sb, arsenic (As), bismuth (Bi), Cd, cobalt (Co), chromium (Cr), molybdenum (Mo), nickel (Ni), Pb, selenium (Se), silver (Ag), and zinc that were separated from the target metal during the course of smelting. The following sections of this summary provide details regarding the fate of these metals. The following model can be used as a general guide to understand the process:

- **Input**: Copper Concentrate (predominantly chalcopyrite minerals [$CuFeS_2$]) with associated trace elements (Sb, As, Cd, Co, Cr, Mo, Ni, Pb, Ag, Zn) and other iron minerals (pyrite [FeS_2]);
- **Blending**: Application of flux to enhance melting (natural minerals consisting of silicate (quartz [SiO_2]);
- **Smelting**: Application of heat (>1500º C) and oxygen to melt the concentrates;
- **Output**: Copper metal, slag (highly crystalline iron oxide and silicate) with some trace metals incorporated into the crystalline slag matrix, dust (containing trace metals), and flue gas (sulfur dioxide).

A simplified (unbalanced) equation for this process is as follows:

> $CuFeS_2$ (Sb, As, Bi, Cd, Co, Cr, Mo, Ni, Pb, Zn, Fe) + SiO_2 + heat + O_2 → Cu (metal) + Fe_2SiO_4 (crystalline slag, containing trace metals (Sb, As, Bi, Cd, Co, Cr, Mo, Ni, Pb, Se, Ag, Zn)) + dust (containing trace metals) + flue gas (SO_2)

Similarly, for the lead smelting process, a simplified (unbalanced) equation for this process is as follows:

> PbS, FeS_2 (Sb, As, Bi, Cd, Co, Cr, Mo, Ni, Pb, Ag, Se, Zn) + SiO_2 + heat + O_2 → Pb (metal) + Fe_2SiO_4 (slag, containing trace metals (Sb, As, Bi, Cd, Co, Cr, Mo, Ni, Pb, Ag, Se, Zn)) + dust(containing trace metals) + flue gas (SO_2)

This general model was followed throughout the smelting process during the entire history of the smelter. The following provides additional details focused on the pathway to the environment for the trace metals in the ore or concentrates. There have been several soil and groundwater investigations completed at the site. The results of these investigations confirm the pathways that the trace metals and other potential Analytes of Interest (AOIs) took to enter the environment, and additional investigation work is planned to provide information about trace metals and other potential AOIs across the site and to fill in any "data gaps" that may exist in the current data set. All of this work is based upon a comprehensive understanding of the smelter inputs, starting with a brief history of the smelter (Table 1).

Table 1. El Paso Smelter Site History
(metals smelted and major milestones associated with operation)

Year	Milestone
1887	El Paso lead smelter founded by Robert S. Towne, with lead ores coming from Mexico (Chihuahua).
1899	Smelter becomes part of American Smelting and Refining Company (ASARCO).
1910	Copper smelters built in El Paso, Texas.
1930s	Godfrey roaster added for cadmium oxide production.
1948	A zinc plant is installed. Slag fuming facilities were constructed to recover zinc from lead blast furnace slag.
1951	ASARCO builds a 610 foot stack for pollutant control.
1967	ASARCO builds a 828 foot smoke stack.
1972	Acid plant is installed and additional pollution control equipment is added which results in a 80% reduction of lead emissions. Completion of new sulfuric acid plant scrubbing equipment further reduces lead emissions.
1978	A second acid plant installed and ore unloading and handling facility is installed.
1979	A sinter plant installed.
Late 1970s	The antimony plant is completed.
1980	The El Paso smelter no longer processes lead, zinc, antimony or cadmium.
1983	The zinc plant is shut down and demolished.

Year	Milestone
1985	Lead plant operations are closed.
1986	The antimony and cadmium plant closes and is demolished.
1989	ASARCO Mission and Ray mines ramp up production and supply to El Paso.
1992	The cadmium plant is closed.
1993	Modernization of El Paso smelter completed.
1993	Installation of continuous top-feed oxygen process technology (CONTOP). Results in significant reduction in sulfur emissions.
1998	According to EPA documentation, ASARCO accepted 46,486 tons of recycle material from ENCYCLE from 1992-1997.
1999	Smelter placed on care and maintenance status.
2000	Storm water collection and reuse system is built.
2005	ASARCO declares bankruptcy.
2009	ASARCO El Paso smelter is shut down permanently.

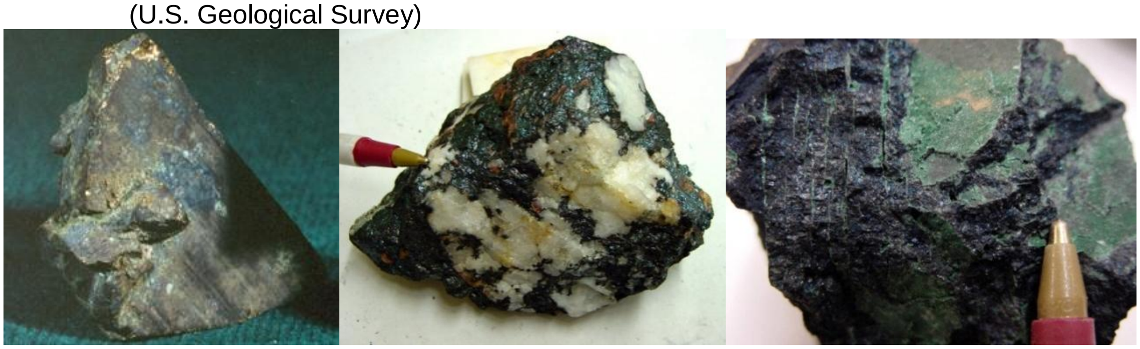
2. Smelting Processes at the El Paso Smelter

Lead, copper, zinc and cadmium were smelted at various times in the El Paso smelter during its operation. Although various metals were smelted, the general smelting processes were similar since pyrometallurgical processes (addition of heat and oxygen) were involved for all metals at the site. A detailed discussion of the copper smelting process at El Paso is presented in this section of the document, with the other metal smelting processed described in Sections 4, 5, 6, and 7. A glossary of smelting terms is provided in Appendix A.

2.1. Copper Concentrate

Chalcopyrite ($CuFeS_2$) was the predominant copper sulfide ore processed to extract copper. Other important copper sulfide ore minerals include bornite (Cu_5FeS_4), chalcocite (Cu_2S), covellite (CuS), and enargite (Cu_3AsS_4). These natural ores (Figure 1) were crushed and separated by flotation at copper mining facilities to produce the copper concentrate used as input to the smelter. Typical impurities in copper concentrate include arsenic, antimony, bismuth, cadmium, lead, selenium, magnesium (Mg), aluminum (Al), cobalt, tin (Sn), nickel, tellurium (Te), silver, gold (Au), and palladium (Pd) (USEPA, 1986). Most of the impurities exist as metal sulfides, such as PbS (galena), sphalerite (ZnFeS), pyrite (FeS_2), millerite (NiS), orpiment (As_2S_3), stibnite (Sb_2S_3), greenockite (CdS), and chromium (although this was present at very low concentrations). Table 2 shows the typical composition of copper concentrate smelter input (feed) and output (slag). Note that elements such as vanadium (V) and beryllium (Be) do not occur at significant levels in the ore materials or feed material, nor do tellurium, tin, gold, or palladium. Strontium (Sr) is present as a naturally occurring element (strontium is similar

Figure 1. Chalcopyrite minerals (left to right: chalcopyrite, bornite, covellite) (U.S. Geological Survey)



to calcium) and is not present as “radiostrontium.” (Radiostrontium is strontium that occurs as a radioactive element produced due to fission [nuclear reaction].)

Table 2. Typical elemental concentration in a typical smelter feed and slag (USEPA, 1978)

Element	Concentration in feed (ppm)	Concentration in slag (ppm)
Copper	>>10,000	>1000
Iron	>>10,000	>>1000
Arsenic	3900	1300
Molybdenum	1600	2400
Cadmium	1200	9
Lead	980	350
Zinc	830	810
Sodium	>600	>640
Barium	320	270
Aluminum	>250	>250
Selenium	200	150
Nickel	190	14
Antimony	120	92
Bismuth	80	5
Fluorine	67	55
Silver	40	1
Strontium	36	130
Manganese	25	260
Cobalt	17	38
Chromium	10	120

2.2. Copper Smelting Flow Diagram

Figure 2 (shown on the following page) provides a process flow diagram for the early copper smelting process (1910-1992); Figure 3 (shown on the following page) provides the details of the process used after 1993. The various steps involved in smelting are described here, along with the environmental fate of the trace metals associated with the inputs to the smelting process.

Figure 2. Existing Copper Circuit Feed Material Flow

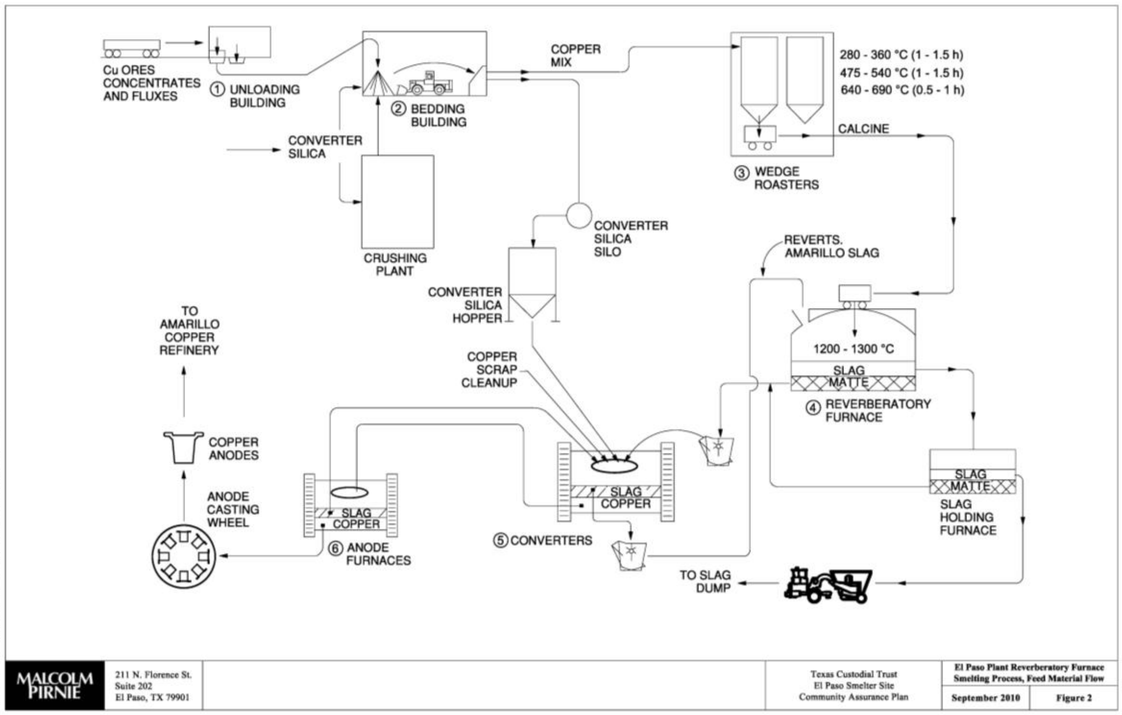
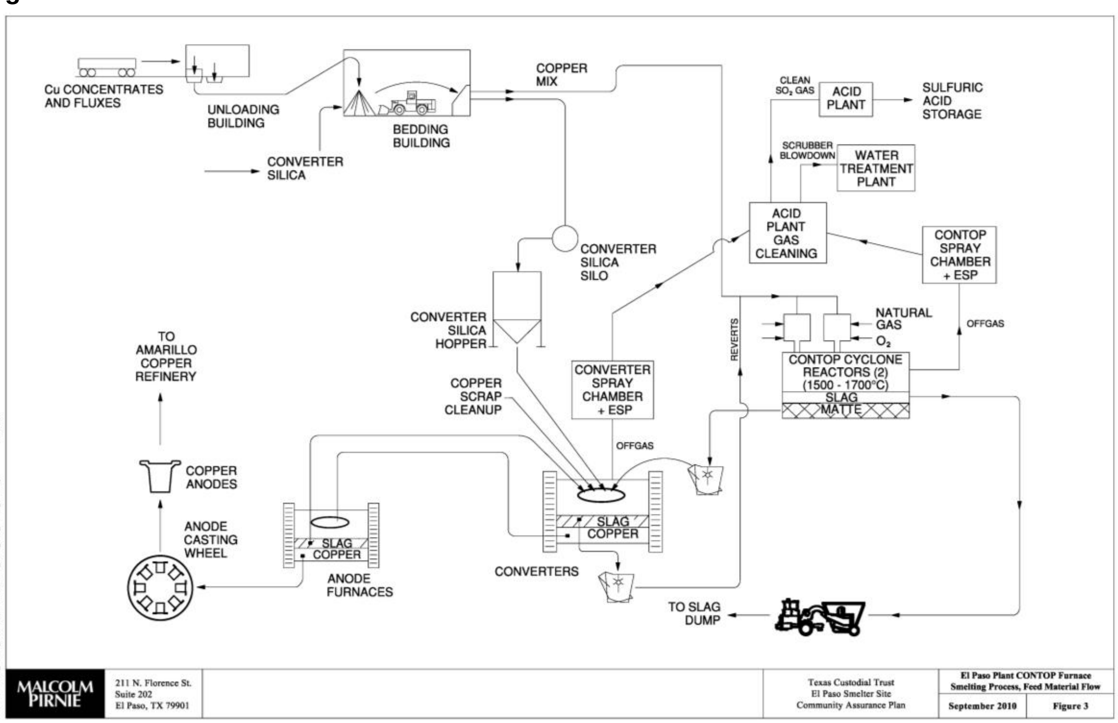


Figure 3. CONTOP Circuit Feed Material Flow



2.3. Unloading and Bedding

Upon arrival at the site, copper concentrate was mixed with silica fluxes and recycled materials in the bedding building. At this step, some trace metals may have been released to the environment through the following processes:

- Dust from copper concentrate, silica sand, copper scrap and other materials;
- Dust from mixing of copper concentrate, recycled materials and silica sand in bedding building;
- Accidental release during transfer from unloading building to bedding building.

2.4. Copper Smelting

Before 1993, reverberatory furnaces were used in copper smelting in El Paso. A reverberatory furnace is a metallurgical furnace that isolates the material being processed from contact with the fuel, but not from contact with combustion gases. The reverberatory furnace smelting operation was a continuous process, with frequent charging and periodic tapping of matte, as well as skimming slag. Heat was supplied by natural gas, with conversion to oil during gas restrictions. Furnace temperatures exceeded 1500°C. Stable copper sulfide (Cu_2S) and stable iron sulfide (FeS) formed the matte with excess sulfur leaving as sulfur dioxide (Habashi, 1997).

The reverberatory furnace was replaced by two continuous top-blowing (CONTOP) process flash furnaces in 1993 as a part of modernization of the plant to improve energy efficiency and reduce emission of pollutants.

Copper concentrate mixes were pneumatically conveyed into the two CONTOP cyclone reactors. These cyclone reactors flash-smelted the concentrates into a "molten rain" of 60 percent copper matte and slag. The molten rain of matte and slag fell into a holding furnace where it separated into two layers. Matte, a copper-rich layer, settled to the bottom and was tapped from holes located on the sides of settling furnace. Slag, containing silica and iron, floated to the top and was skimmed off (ASARCO Phase I Investigation, 1998).

The product from the smelting furnace contained iron, tin, lead, zinc, nickel and sulfur. These elements were removed either by reduction and evaporation or by oxidation. Impurity metals with high vapor pressures (e.g., lead, cadmium, zinc) or with high-vapor-pressure oxides (e.g., SnO, Cs_2O, P_2O_3) volatilized and were collected in the zinc-rich dust (Anigstein et al., 2001). At this step, trace metals may have been released to the environment through the following processes:

- The off-gas from smelting was high in SO_2 (up to 26%). SO_2 gas was captured and diverted to an acid plant where sulfuric acid was produced;
- Dust generated during smelting contained trace metals;
- Smelting temperatures were in the range of 1500 to 1700°C. The high operating temperatures volatilized arsenic, bismuth, lead, selenium, zinc, etc. The majority of volatized metals were captured along with SO_2 in off-gas during production of sulfuric acid. However, some of these metals may have escaped as fugitive gas, aerosols or dust particles;
- The slag was trucked to the slag dump by a specially designed diesel powered "Kress Slag Hauler." Once cooled, the slag was mined by Parker Brothers Company and processed into railroad ballast, sand blasting media, and asphalt aggregate;
- Dust generated from the slag dump may have contained trace metals;
- Slag weathering may have redistributed trace metals to soil;
- Slag leaching contribution to groundwater was minor. The slag is a crystalline heterogeneous material whose main components are iron oxides, calcium/magnesium compounds (hydroxide, oxide, silicates, and carbonate), elemental iron, and quartz. Navarro et al. (2010) show that carbonation reduces the leaching of alkaline earth elements as well as the release of trace elements. Huijgen and Comans (2006) reported that precipitation of calcium carbonates at the surface of slag particles reduces the leaching of alkaline earth elements present in the slag.

Trace metals generated during CONTOP smelting could therefore enter soil through volatile gas phase, as dust particulate matter; with minor contribution from slag dust, slag weathering and leaching during transport and storage.

2.5. Copper Converting

The molten copper matte (60-70% copper as copper sulfide) was converted to blister copper for casting. At this step, trace metals may have been released to the environment through the following processes:

- Copper scrap impurities and residual volatile metals may have been present in off-gas as in the smelting step;
- Fugitive emissions of gas and dust particles may have occurred, resulting in metal deposition onto the land surface.

Similar to the smelter step, trace metals from this step can enter soil through the volatile gas phase or as dust particulates. However, the entire converter building was enclosed and ventilated. Fugitive emissions of gas and dust particles from this step were less likely to be deposited in soil than in the smelter step.

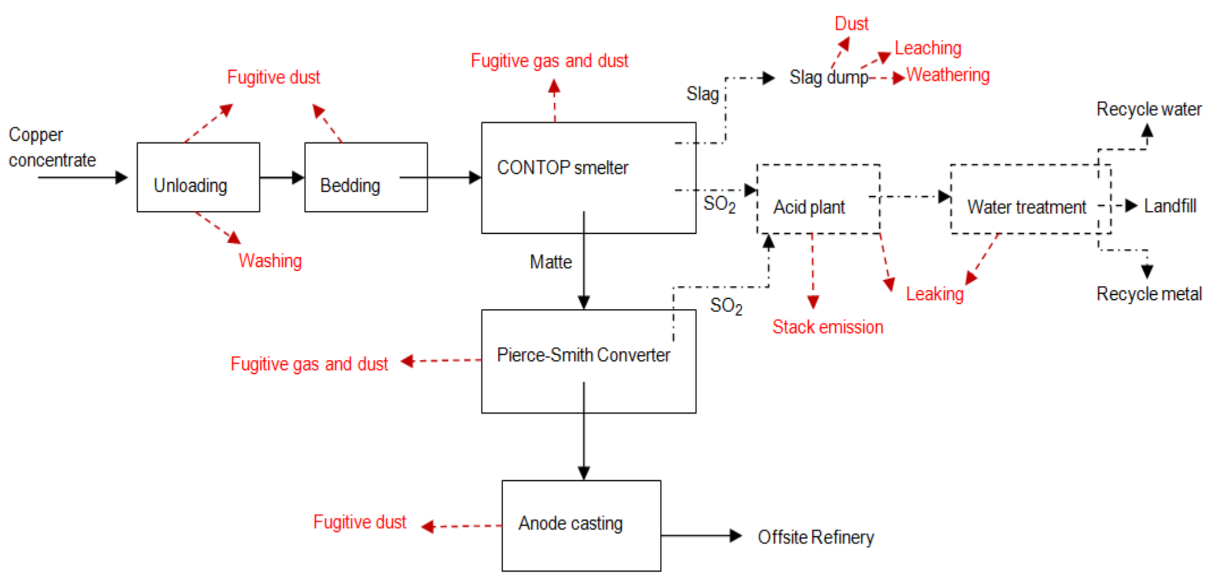
2.6. Anode Casting

The blistered copper was put into an anode furnace for casting, the final step in the copper smelting process at the El Paso plant. At this step, trace metals may have been released to the environment through the following process:

- Fugitive gas and dust emission may be a source of metals deposited in soil.

Figure 4 illustrates major pathways by which trace metals may have entered the environment as a result of operation of the El Paso copper smelter.

Figure 4. Potential pathways for trace metals entering environment during copper smelting. Black solid arrows indicate processes related to copper smelting; Black-dashed arrows indicate waste generation and disposal processes during copper smelting; Red-dashed arrows indicate the processes that may have impacted the environment at the site.



3. Secondary Copper Smelting

Copper scrap has historically been smelted in primary (concentrate) and secondary (scrap) smelters. The major processes involved in secondary copper recovery were scrap metal treatment and smelting. Treatment generally included cleaning and concentrating the scrap materials to prepare the scrap copper for the smelting process. At El Paso, melting of high-Cu scrap and the sludge generated in the on-site water treatment plant was conducted in primary converting furnaces. Table 3 lists the typical elemental composition of converter product blister copper, slag and baghouse dust from smelting of copper scrap.

Table 3. Composition of Converter Products from Smelting of Copper Scrap (%)

Element	Blister Copper	Slag	Baghouse dust
Cu	94-96	30-35	2-3
Ni	0.5-1.0	10-15	0.5-1.0
Sb	0.1-0.3	0.5-1.5	0.5-1.5
Sn	0.1-0.2	2-4	10-20
Fe	0.1-0.3	20-25	0.5-1.0
Zn	0.05-0.1	1.0-1.5	25-35
Pb	0.05-1.0	2.5-4.0	20-25

Source: Anigstein et al., Appendix C, copper recycling, http://www.epa.gov/rpdweb00/docs/source-management/tsd/scrap_tsd_041802_apc2.pdf)

3.1. ENCYCLE Materials

The smelter received recycled materials including hazardous waste from ENCYCLE in the 1992-1997 timeframe (USEPA Response, July 1998). These wastes were fed into the copper smelting process to recycle the metals contained in them. The process of recovering copper and other metals from sources other than ores or concentrates is called secondary copper smelting. There is a public concern that there may have been a release of metals contained in the materials and that dioxins may have been generated when these materials were fed into the El Paso smelter.

The following 17 records, located on the USEPA Region 6 website (http://www.epa.gov/region6/asarco_documents/asarco_documents.html) were subjected to a comprehensive review to summarize the quantity and types of waste shipped to ENCYCLE (1992-1997) from numerous sources. It is worth noting that not all of the material received by ENCYCLE was shipped to the El Paso Smelter.

1. EPA Response to Encycle/ASARCO Settlement Statement, (1998 Confidential Document) July 31, 1998 (73 pages)

2. EPA Inspection Report for Encycle, January 1997, Part 1 (42 pages)
3. EPA Inspection Report for Encycle, January 1997, Part 2 (42 pages)
4. EPA Inspection Report for Encycle, June 1997 (26 pages)
5. EPA Inspection Report for Encycle, June 1997, with attachments (436 pages)
6. Rocky Mountain Arsenal Hazardous Waste Manifest (24 pages)
7. National Enforcement Investigation Center Report for Encycle, 1998 (264 pages)
8. Explanation of Differences for Basin F Liquids (Rocky Mountain Arsenal) (21 pages)
9. Notification from Encycle regarding waste from Molycorp, December 1995 (1 page)
10. DuPont-Sabine River Form R, 1993 (8 pages)
11. DuPont-Sabine River Form R, 1995 (7 pages)
12. Analysis of Waste Sent to Encycle from DuPont-Sabine River (2 pages)
13. Manifests for Wastes from Foreign Sources Sent to Encycle (516 pages)
14. Analysis of Waste Sent to Encycle from NASA (182 pages)
15. Analysis of Waste Sent to Encycle from West Helena (12 pages, NOTE: shipments were actually from ENCYCLE to West Helena)
16. Analysis of Waste Sent to Encycle from Various Generators (197 pages)
17. Rocky Mountain Arsenal Waste Shipment Analyses (323 pages)

Every page of the records found on the USEPA website was reviewed for:

- Source
- Waste/Material Characterization
- Waste/material Quantities

The records indicated that ENCYCLE received wastes from a variety of chemical, manufacturing or waste treatment processes including: metal plating waste water treatment sludge, photo development waste, post-incineration ash, post-waste treatment brines or leachates, broken glass from cathode ray tubes, plating sludge, and filter cake. In addition, ENCYLCE received recycled materials that included untreated hazardous waste that was corrosive, contained metals, or contained pesticides or chemicals related to pesticide manufacturing. The results of the evaluation, that include 300 manifests, are summarized in tabular form in Appendix B.

The USEPA uses a defined list of codes to identify or list hazardous wastes (USEPA, 40 CFR Part 261). The majority of the wastes shipped to ENCYCLE documented in the records included wastes defined under the following codes as presented in Table 4:

Table 4. Waste Codes Shipped to ENCYCLE (Majority)

Code	Description/Contains
D001	Ignitable
D002	Corrosive
D003	Reactive
D005	Barium
D006	Cadmium
D007	Chromium
D008	Lead
D010	Selenium
D011	Sliver
F006	Wastewater treatment sludge, electroplating
F039	Leachate from waste treatment
K002	Wastewater treatment sludge, chromium
K046	Wastewater treatment sludge, lead

The records indicate that ENCYCLE received waste from the Rocky Mountain Arsenal. Most of this waste was brine (leachate from waste treatment, F039) that contained 65% to 75% water, 25% to 35% salt, potentially trace concentrations of dioxins (0.0000000068 milligrams per liter) and furans (0.0000000076 milligrams per liter), and low concentrations of metals (Woodward Clyde, 1990). In addition, the records indicate that ENCYCLE received 91.9 tons of waste, in a single shipment, that included several waste codes as listed in Table 5 (USEPA, 1997).

Table 5. Rocky Mountain Arsenal - Waste Codes Shipped to ENCYCLE

Code	Description/Contains
F001	Spent halogenated solvent
F002	Spent halogenated solvent
F003	Spent non-halogenated solvent
K033	Wastewater and scrub water, chlordane
K097	Vacuum stripper discharge, chlordane
P051	Endrin
P071	Methyl Parathion
U130	Hexachlorocyclopentadiene

In December of 1995 ENCYCLE informed the TNRCC that it had received a lead sulfide waste; containing naturally occurring radioactive material (NORM). This letter stated that the NORM was present at quantities less than the regulated level (ENCYCLE, 1995). The amount of material shipped to ENCYCLE was not documented in the records.

3.2. Other Potential Sources

The Get The Lead Out Coalition website (http://gettheleadout.net/index.sstg) was reviewed; it was determined that this web site did not contain additional records related to the quantity and types of wastes shipped to ENCYCLE.

In October 2010, thirty-seven additional documents were found at the smelter. These documents were related to a process ASARCO developed to accept secondary materials to recover valuable metals. These documents were reviewed in detail; there was one shipping manifest for a copper-bearing material that contained, silver, gold, barium, chromium, nickel, lead, antimony and zinc (similar to the concentrates received at the smelter). The records indicate that 14.9 tons of the material was shipped to the smelter in April 1998. This material would generate the same product and potential emissions as the concentrates discussed in Section 2.

3.3. Dioxin Information

The name "dioxins" is often used for the family of structurally and chemically related polychlorinated dibenzoparadioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). Certain dioxin-like polychlorinated biphenyls (PCBs) with similar toxic properties are also included under the term dioxins. Approximately 419 types of dioxin-related compounds have been identified, about 30 of these are considered to have significant toxicity. The compound 2,3,7,8-tetrachlorodibenzoparadioxin (TCDD), often referred to as dioxin, is the most toxic and the most studied. A ranking approach is used to evaluate potential exposure and risk to PCDDs and PCDFs relative to dioxin. Using the relative toxicity of each of the PCDD and PCDF constituents, a total concentration is derived and reported as toxicity equivalents of dioxin. This concentration then is used to evaluate exposure to the dioxin-like constituents.

Dioxins are mainly by products of industrial processes but can also result from natural processes, such as volcanic eruptions and forest fires. Dioxins are unwanted byproducts of a wide range of processes including but not limited to fuel combustion, smelting, cement production, chlorine bleaching of paper pulp and the manufacturing of some herbicides and pesticides. In terms of dioxin release into the environment, uncontrolled waste burning or incineration (residential waste, solid waste and hospital waste) are the most common, due to incomplete combustion. Although formation of dioxins is local, environmental distribution is global; dioxins are found throughout the world in the environment (World Health Organization, http://www.who.int/mediacentre/factsheets/fs225/en/).

3.4. Typical Primary Copper Smelting and Dioxin Generation

The routine copper smelting process has been evaluated for the production of dioxins. A study was performed in 1995 to evaluate the principal off-gas streams for copper smelters: main stack, plant tail gas stack, and vent fume exhaust (Secor International Inc., 1995a, b) for dioxin production. The two facilities that were tested (Phelps Dodge Mining Co. in Playas, New Mexico, and Cyprus Miami Mining Co. in Claypool, Arizona) were selected as representative of typical copper smelters. Dioxins were not detected in the air emissions from either facility.

In 2001, emission measurements for various persistent and toxic substances, including dioxins, were collected in Canada as a voluntary initiative under the Great Lakes Binational Toxics Strategy (Cianciarelli, 2001). One of the facilities tested was the Falconbridge Kidd Metallurgical plant in Timmins, Ontario, a copper smelting plant. Annual dioxin emission rates were estimated to be 2.0 milligrams per year as measured in toxicity equivalents.

3.5. Typical Secondary Copper Smelting Processes and Dioxin Generation

Typical input to secondary smelters may contain from 30 to 98% copper. The secondary smelting process upgrades the material by reducing the quantity of impurities and alloying materials, thereby increasing the relative concentration of copper. Feed material to a secondary copper smelter is a mixture of copper-bearing scrap such as tubing, valves, motors, windings, insulated wire, radiators, turnings, mill scrap, printed circuit boards, telephone switching gear, and ammunition casings (USEPA, 1994).

Secondary copper smelters charged with these types of materials were recognized by the USEPA (Basu et al., 1985) as a significant source of dioxins to the environment. The presence of carbon-containing materials such as plastics, carbon- and chlorine-containing materials such as polyvinylchloride insulation on wire, and similar non-metal materials provide chemical building blocks for the formation of dioxins.

Dioxin emissions data have been collected from typical secondary copper smelting operations. In one example the USEPA performed a study during 1984 and 1985 and measured 0.72 milligrams of dioxins (as measured in toxicity units) emitted per ton of waste (USEPA 1987) from a smelter that received waste that included copper, iron, plastics, refinery by-products, slag and electronic debris. In a 1992 sampling and analysis effort, emissions measuring 15.08 milligrams toxicity equivalents per ton of waste were detected from a smelter using low-purity, copper-bearing waste as input (AGES 1992).

Stack testing was performed in 1991 at a smelter that processed relatively high-purity copper input; the emissions from that smelter measured 0.0033 milligrams of toxicity equivalents per ton of input (Sverdrup, 1991).

3.6. ASARCO El Paso Secondary Smelting Process and Dioxin Generation

The USEPA reported that 46,486 tons of recycle material was shipped from ENCYCLE to the El Paso Smelter (USEPA Response, July 1998). Table 6 provides a summary of shipments for each year between 1992 and 1997.

Table 6. Shipments from ENCYCLE to ASARCO El Paso

Year	Tons
1992	4,809
1993	7,704
1994	13,598
1995	9,291
1996	6,372
1997	4,712
Total	**46,486**

The amount of copper concentrate smelted during this time period was reported as 415,000 tons per year, or a total of 2.5 million tons of concentrate during the 6 year period. The ENCYCLE material (46,486 tons) therefore constituted 1.86% of the total material that was processed at the smelter over the 6 year period.

As discussed in Section 3.1, most of the waste shipped to ENCYCLE included metal plating waste water treatment sludge, photo development waste, post-incineration ash, post-waste treatment brines or leachates, broken glass from cathode ray tubes, plating sludge, and filter cake. Most of these wastes included metal-bearing materials, similar to the concentrates that were fed to the El Paso Smelter rather than the inputs to typical secondary copper smelters.

The ENCYCLE material was shipped to the smelter by rail and truck. The materials were handled in the same manner as the concentrates and blended into the smelter input. Former employees have stated that, at times, the waste was spilled during transfers and handling. Once blended with the regular input the material would go through the process described in Section 2 of this document. Based on the quantities and types of ENCYCLE wastes that went through the smelting process and the review of dioxin generation from other secondary smelting processes any additional dioxin generation at the El Paso smelter would not be measureable.

4. Primary Lead Smelting

Galena, or lead sulfide (PbS), is by far the most important lead mineral in the lead smelting process. Other common varieties include cerussite ($PbCO_3$), and anglesite ($PbSO_4$). Lead is usually found in ores with zinc, silver and copper. Typical impurities in lead minerals are zinc, copper, arsenic, tin, antimony, silver, gold, and bismuth. These impurities usually exist as sulfide minerals as well (USEPA, 1995). At the El Paso smelter, the ores were drawn from the surrounding territory, comprising New Mexico, Arizona, western Texas, and northern Mexico (Easter, 1915). The capacity of lead production at El Paso smelter was 120,000 ton per year (USEPA 1981). The most common feed for lead production was sulfidic lead concentrate, which contained an average of 50-60% lead. Ore concentration processes normally included crushing, dense-medium separation, grinding, froth flotation, and drying of concentrate. The predominant process for the production of primary lead from a sulfide concentrate is sinter oxidation-blast furnace reduction. The processing of lead concentrate into metallurgical lead involves 4 major steps: sintering, smelting (reduction), drossing and refining (Habashi, 1997), as follows.

Figure 5. Lead minerals (left to right: galena, cerussite, and anglesite (U.S. Geological Survey)

4.1. Sintering

The primary purpose of sintering was the reduction of the sulfur content of the feed material. This feed material typically consisted of the following: lead concentrates, including pyrite concentrates that were high in sulfur content, and concentrates that were high in impurities such as arsenic, antimony, and bismuth, as well as relatively pure high-lead-concentrates; flux materials, lime rock and silica, incorporated in the feed to maintain a desired sulfur content; and undersized sinter recycled from the roast exiting the sinter machine (USEPA, 1995). Other raw materials were added including iron, silica, limestone flux, coke, soda, ash, pyrite, zinc, caustic, and particulates gathered from pollution control devices (flue dusts). Flue dusts from lead sintering plants contained 60-70% lead, about 10% sulfur, and varying amounts of zinc, cadmium, arsenic, antimony, and mercury (Habashi, 1997).

Potential routes for release of metals to the environment included:

- Fugitive emissions from the sinter building, including leaks in the sinter machine and the sinter cake crusher;
- Weak gases from the back end of the sinter machine, which are high in lead dust content but typically pass through cyclones and a baghouse.

4.2. Smelting (Reduction)

The sinter roast was then conveyed to the blast furnace in charge cars along with coke, slags and byproduct dusts from baghouses and various other sources within the facility. Iron scrap was often added to the charge to aid heat distribution and to combine with the arsenic in the charge.

Potential pathways for metals entering environment from this step included:

- Gases exiting the top of the blast furnace, which are typically controlled with a baghouse;
- Fugitive emissions from the blast furnace, including leaks from the furnace covers;
- Lead fumes from the molten lead and slag leaving the blast furnace area;
- Fugitive leaks from the tapping of the kettles and settlers.

4.3. Drossing

The lead pots arriving from the blast furnace were poured into receiving kettles and allowed to cool to the point at which copper dross was skimmed off and transferred to a reverberatory furnace. The remaining lead dross was transferred to a finishing kettle where such materials as wood chips, coke fines, and sulfur were added and mixed to facilitate further separation, and this sulfur dross was also skimmed off and transferred to the reverberatory furnace. The drosses were prepared and heated in the same fashion as the kettles, the dross in the reverberatory furnace separated into 3 layers: lead bullion settles to the bottom and was tapped back to the receiving kettles, and matte (copper sulfide and other metal sulfides), which rises to the top, and speiss (high in arsenic and antimony content) which were both typically forwarded to copper smelters.

Potential pathways of metal emissions included:

- The hauling and dumping of slag, at both the handling and cooling area and the slag storage pile;
- Fugitive emissions from the various pouring, pumping, skimming, cooling, and tapping operations within the drossing building;
- Transporting, breaking, granulating, and storage of speiss and matte.

4.4. Refining

The third and final phase in the processing of lead ore to metallurgical lead, the refining of the bullion in cast iron kettles, occurred in 5 steps: (1) removal of antimony, tin, and arsenic; (2) removal of precious metals by Parke's Process, in which zinc combines with gold and silver to form an insoluble intermetallic at operating temperatures; (3) vacuum removal of zinc; (4) removal of bismuth by the Betterson Process, in which calcium and magnesium are added to form an insoluble compound with the bismuth that is skimmed from the kettle; and (5) removal of remaining traces of metal impurities through the adding of NaOH and $NaNO_3$.

Potential pathways of metal emissions included:

- Fugitive emissions from the unloading, storage, and transfer of byproduct dusts, high grade ores, residues, coke, lime, silica, and any other materials stored in outdoor piles;
- Release of metals to the environment during primary lead smelting.

5. Zinc Slag Fuming Process

Sphalerite (ZnS) is the most heavily mined zinc containing ore; other minerals zinc may be extracted from include smithsonite ($ZnCO_3$), hemimorphite ($ZnSiO_4$), and wurtzite (ZnS) (see Figure 6). Lead and zinc were traditionally mined together because zinc is normally found in association with other metals such as copper, iron and lead in ores, although the concentrates produced from these mixed ores were often processed separately to produce refined lead metal (the lead furnace process) and refined zinc metal (the electrolytic zinc process). However, this was not the case at the El Paso smelter, where only lead concentrate was processed. Zinc was recovered from lead slag through slag fuming process. At the height of production in 1955, the El Paso smelter produced 40,000 tons of zinc oxide (Duval and Kleiner, 2010).

Zinc slag fuming was developed to remove and recover zinc from lead blast furnace slag. Zinc slag fuming was the treatment of molten slag with a reducing agent such as coal or pyrites to reduce dissolved metals to a metallic or sulfidic form to recover zinc. The process was carried out in a rectangular water-jacked furnace on a batch basis. A reducing mixture of a reductant, usually pulverized coal, and air is blown into the batch through sets of tuyeres which are set along the bottom of the long dimension on both side of the furnace. Within the furnace, the reducing mixture reduced the zinc from a dissolved oxide to metallic zinc, a gas at operating temperatures which lie between 1150 and 1325°C. The zinc vapor and tuyere gases pass out of the bath into the freeboard space of the furnace where the zinc is oxidized to a zinc oxide fume which is subsequently captured in a baghouse (Richards, 1985).

Figure 6. Zinc minerals (left to right, sphalerite, smithsonite, and wurtzite. (U.S. Geological Survey)

In addition to lead and zinc, other volatile elements present in the slag were also fumed usually as oxides or sulfides. These include tin, cadmium, and indium. The fume also contains chlorides, fluorides, some lime, silica, iron oxides, and carbon. These metals may enter environment through fugitive emission of dust particles and offgases.

6. Cadmium Recovery in Lead Smelting

Figure 7. Greenockite (CdS) mineral (U.S. Geological Survey)

Greenockite (CdS) is the only known cadmium mineral of importance (Figure 7). It occurs commonly, in minor concentrations, as a secondary mineral in sphalerite deposits. As a consequence, cadmium is produced mainly as a byproduct from mining, smelting, and refining sulfidic ores of zinc, and, to a lesser degree, lead and copper (Feddersen, 1949). The world's cadmium output is obtained through the processing of metallurgical by-products, largely from the treatment of residues from electrolytic zinc, retort zinc and lithopone plants. The sources are supplemented by the processing of fumes from lead and copper smelting operations.

Cadmium is a common impurity in zinc ores, and it is most often isolated during the production of zinc. Some zinc concentrates from sulfidic zinc ores contain up to 1.4% of cadmium. In 1970s, the output of cadmium was 6.5 pounds per ton of zinc. Zinc sulfide ores are roasted in the presence of oxygen, converting the zinc sulfide to the oxide. Zinc metal is produced either by smelting the oxide with carbon or by electrolysis in sulfuric acid. Cadmium is isolated from the zinc metal by vacuum distillation if the zinc is smelted, or cadmium sulfate is precipitated out of the electrolysis solution.

Cadmium is produced primarily as a by-product of zinc production. Cadmium is recovered from the following by-product materials: flue dusts from the sintering of zinc calcines, sludge from the purification of zinc electrolyte solution in the electrolytic production of zinc, recycled zinc metal containing cadmium, and flue dusts from the lead-smelting. Cadmium is produced from these materials by both pyrometallurgic and electrolytic processes (USEPA, 1981).

Cadmium plant processing typically includes preparatory processing (concentration), leaching and purification, sponge precipitation, metal recovery, and refining and casting (Feddersen, 1949), as detailed in following steps.

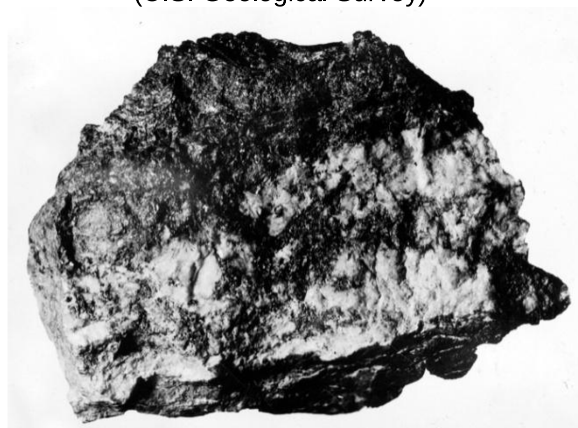
- **Preparatory processing**: The cadmium content of lead handled at the smelter was low, and as a rule, proportional to the zinc content (0.01-0.05 wt % Cd). Blast furnace fume was circulated to increase the cadmium content to 3-6%. It was then removed and incorporated in sinter charges. Blast furnace smelting of the resultant sinter resulted in a fume product containing 15-25% cadmium.

- **Leaching and purification operations**: Concentrated fume was subjected to a direct dilute sulfuric acid leach. The resulting slurry was filtered and washed in a Shriver press, washed cake was returned to the lead smelting circuit.
- **Sponge precipitation operations**: Concentrated solution was drawn from the storage tank to a high-speed agitation tank. The solution was acidified and treated with zinc dust for cadmium sponge precipitation. Initial sponge washing was carried out by decantation and the final dewatering and wash in a Shriver press. Cadmium sponge was briquetted directly with a Stokes machine.
- **Refining and casting operations**: Cadmium briquettes were retorted, and the crude retort metal was melted under a caustic cover residual from previous melt. This cover was then drossed and the bath agitated with ammonium chloride for thallium (Tl) removal. The chloride dross was skimmed and stored. New caustic was then added and melted, followed by a brief period of agitation prior to casting into shape for market.

Trace chromium associated with the cadmium may have been subject to caustic solutions in this phase, and consequently there is the potential for oxidation of trivalent chromium (Cr[III]) to hexavalent chromium (Cr[VI]) at this step. This would have been non-volatile and associated with the smelting and casting workings in the zinc processing area.

7. Antimony

Figure 8: Stibnite (Sb2S3) mineral (U.S. Geological Survey)



Antimony is chalcophile (i.e., has a tendency, due to its chemistry, to associate with sulfur), usually occurring with sulfur and the heavy metals copper, lead, and silver. The most important antimony mineral is stibnite (Sb_2S_3). Antimony rarely occurs in its native metallic form in nature. It easily combines with other elements, usually including sulfur, to form over 100 different minerals. Of these minerals, only stibnite (Sb_2S_3) is mined commercially as a source for metallic antimony. Antimony is found in trace amounts in silver, copper and lead ores (Grund et al., 2006), and it is usually economically possible, as well as environmentally desirable, to extract the antimony from these ores when they are smelted.

Typically, stibnite (Sb_2S_3) was roasted to yield the oxide, which was in turn reduced by salt and scrap iron or carbon. During processing, the antimony ore, which was extremely brittle, was converted into fine dust more rapidly than accompanying rock, leading to high atmospheric concentration of fine dust during operations of reduction and screening. Dust produced during crushing was relatively coarse, and the remaining operations-classification, floatation, filtration are wet processes, were consequently dust free. However, accidental release was a major pathway for Sb entering environmental media.

The El Paso smelter produced 1100 tons/year of antimony from the anode sludge refined from copper between 1978 and 1986 (Yuan, 2007).

8. Summary

Table 7 provides a summary of the smelting processes over the 112 year operational history of the El Paso smelter, as well as a summary of the inputs (ore, concentrates, and trace metals) and outputs from the smelting process. This, in addition to the ENCYCLE materials, represents the entirety of materials handled at the El Paso smelter.

This review of the smelter feed materials, information supplied by former employees, and input from regulatory agencies indicate the following:

- Previous work investigating inorganic constituents of concern (COCs) focused on trace metals (arsenic, cadmium, copper, chromium, iron, lead, selenium and zinc) in soil, water, and smelter structures.
- A list of additional inorganic Analytes of Interest (AOIs) has been developed. In addition to the current COCs, soil and solid samples will be analyzed for the following AOIs: antimony, barium, cobalt, molybdenum, nickel, and silver.
- Hexavalent chromium (Cr[VI]) will be analyzed as an AOI in the locations where historical cadmium and zinc smelting occurred.
- At the request of the Texas Commission on Environmental Quality, mercury has been added as an AOI for soils and solids.
- A list of organic AOIs has been developed. Soil and solid samples from select locations (including those indicated by former employees) will be analyzed for: chlordane, endrin, hexachlorocyclopentadiene, methyl parathion, tetrachloroethylene, trichlorethylene, methylene chloride, 1,1,1-trichloroethane, 1,1,2,trichloroethane, carbon tetrachloride, chlorobenzene, ortho-dichlorobenzene, trichlorofluoromethane, 1,1,2-trichloro-1,2,2-trifluoroethane, dichlorodifluoromethane, xylene, acetone, ethyl acetate, ethyl benzene, ethyl ether, methyl isobutyl ketone, n-butyl alcohol, cyclohexanone, and methanol.
- The remedial action work plan (RAWP) is complete and provides a detailed description of sampling and analysis necessary to address data gaps.

Although the smelter had a long history of operations, with many primary and secondary smelting operations focused on a number of metal ore and concentrate materials, the materials input to the smelter are well understood. The pathways to the environment for trace metals during the various smelting processes are also well understood. This information, supplemented by the upcoming work described in the RAWP, will ensure completeness with respect to the path forward for the remediation and reclamation project at El Paso.

Table 7. Summary of smelting history, process, and trace metal environmental fate of ASARCO El Paso Smelter

Time Period	Ore (Minerals)	Smelter Process	Metal	Environmental Fate
1887-1985	**LEAD** ores and leady copper matte from Mexico (Santa Eulalia and Sierra Mojada mines in Chihuahua) and NM, AZ, and TX	**Godfrey roasting furnace** (major steps include sintering, smelting [reduction], drossing and refining.)	**Pb** (400 tons/day in 1928, source: ASARCO Phase I investigation, 1998. 120,000 ton/year, source: USEPA, 1981)	**Final product**
	Lead ore minerals: • Galena (PbS), • Cerussite ($PbCO_3$), • Anglesite ($PbSO_4$). • Lead usually found in ores with Zn, Ag, and Cu		Flue dust composition	SiO_2 16.8, Fe 17.6, Mn 0.6, CaO 8.1, Zn 4.0, S 9.0, Pb 18.2, Cu 1.4, Ag 23.5, Au 0.30 (%)(Easter, 1915)
			Main Group Metals	
	Orpiment (As_2S_3)		As	Slag, offgas, dust particulate, soil, groundwater
	Aguilarite(Ag_4SeS)		Se	Slag, Offgas, dust particulate, soil, groundwater
	Greenockite (CdS)		Cd	Slag, offgas, dust particulate, soil, groundwater
	Stibnite(Sb_2S_3)		Sb	Slag, offgas, soil
	Bismuthinite(Bi_2S_3)		Bi	Slag, offgas, soil
			Transition Metals	
	Chromite ($FeCr_2O_4$)		Cr	Slag, dust particulate, soil, groundwater
	Alabandite(MnS)		Mn	Slag, dust particulate, soil, groundwater
	Pyrite (FeS_2)		Fe	Slag, dust particulate, soil, groundwater
	Millerite (NiS)		Ni	Slag, dust particulate, soil, groundwater
	Chalcopyrite ($CuFeS_2$), chalcocite (Cu_2S), covellite (CuS)		Cu	Slag, dust particulate, soil
	Sphalerite (ZnFeS)		Zn	Slag, dust particulate, soil, groundwater

Time Period	Ore (Minerals)	Smelter Process	Metal	Environmental Fate
1910-1993	**COPPER** from mines in AZ, NM and northern Mexico, mainly from Chino copper mine (1911-1939), >2000 tons ore daily	**Reverberatory furnace** (major steps including roasting, smelting, converting, anode casting)	**Cu** (150 tons/day in 1928, source: ASARCO Phase I investigation, 1998. 115,000 ton/year, source: USEPA, 1981)	**Final product**
	Major minerals in copper ores: • chalcopyrite($CuFeS_2$), • bornite (Cu_5FeS_4), • Chalcocite(Cu_2S), • covellite (CuS), • enargite (Cu_3AsS_4)		**Main Group Metals**	
	Orpiment (As_2S_3)		As	Slag, dust, soil, groundwater
	Aguilarite(Ag_4SeS)		Se	Slag, dust, soil, groundwater
	Greenockite (CdS)		Cd	Slag, dust, soil, groundwater
	Galena (PbS)		Pb	Slag, dust, soil
	Stibnite(Sb_2S_3)		Sb	Slag, dust, soil
	Molybdenite (MoS_2)		Mo	Slag, dust, soil, groundwater
	Bismuthinite(Bi_2S_3)		Bi	Slag, dust, soil
			Transition Metals	
	Chromite ($FeCr_2O_4$)		Cr	Slag, dust, soil, groundwater
	Alabandite (MnS)		Mn	Slag, dust, soil, groundwater
	Pyrite (FeS_2)		Fe	Slag, dust, soil, groundwater
	Millerite (NiS)		Ni	Slag, dust, soil, groundwater
	Chalcopyrite ($CuFeS_2$), chalcocite (Cu_2S), covellite (CuS)		Cu	Slag, dust, soil
	Sphalerite (ZnFeS)		Zn	Slag, dust, soil, groundwater
1993-1999	**COPPER** 415,000 ton Cu concentrate per year, 18,000 tons Cu scrap per year(ASARCO Phase I investigation, 1998)	**ConTop flash smelting** (major steps including, smelting, converting, anode casting)	**Cu** (140,000 ton/year, source: ASARCO Phase I investigation, 1998)	**Final product**
	46,200 ton of flux/year (estimate based on Goonan, 2004)		252,400 ton/year	Slag generated (estimate based on Goonan, 2004)

Time Period	Ore (Minerals)	Smelter Process	Metal	Environmental Fate
	23,700 ton of limestone/year(estimate based on Goonan, 2004)		290,700 ton/year	Sulfuric acid (estimate based on Goonan, 2004)
			62,100 ton/year	Carbon dioxide(estimate based on Goonan, 2004)
	Major minerals in copper ores: • chalcopyrite($CuFeS_2$) • bornite (Cu_5FeS_4), • Chalcocite(Cu_2S), • covellite (CuS), • enargite (Cu_3AsS_4)		**Main Group Metals**	
	Orpiment (As_2S_3)		As	Slag, dust, soil, groundwater
	Aguilarite(Ag_4SeS)		Se	Slag, dust, soil, groundwater
	Greenockite (CdS)		Cd	Slag, dust, soil, groundwater
	Galena (PbS)		Pb	Slag, dust, soil
	Stibnite(Sb_2S_3)		Sb	Slag, dust, soil
	Bismuthinite(Bi_2S_3)		Bi	Slag, dust, soil
	Molybdenite (MoS_2)		Mo	Slag, dust, soil, groundwater
			Transition Metals	
	Chromite ($FeCr_2O_4$)		Cr	Slag, dust, soil, groundwater
	Alabandite(MnS)		Mn	Slag, dust, soil, groundwater
	Pyrite (FeS_2)		Fe	Slag, dust, soil, groundwater
	Millerite (NiS)		Ni	Slag, dust, soil, groundwater
	Chalcopyrite ($CuFeS_2$), chalcocite (Cu_2S), covellite (CuS)		Cu	Slag, dust, soil
	Sphalerite (ZnFeS)		Zn	Slag, dust, soil, groundwater
1930-1992	**CADMIUM** (processing of zinc byproduct, and fumes from Pb and Cu operations)	**Godfrey Roaster**	**Cd**	**Final product**
	Greenockite (CdS), it is a secondary mineral in sphalerite deposits		**Main Group Metals**	
	Orpiment (As_2S_3)		As	Slag, dust, soil, groundwater

Time Period	Ore (Minerals)	Smelter Process	Metal	Environmental Fate
	Aguilarite(Ag_4SeS)		Se	Slag, dust, soil, groundwater
	Greenockite (CdS)		Cd	Slag, dust, soil, groundwater
	Galena (PbS)		Pb	Slag, dust, soil, groundwater
			Transition Metals	
	Chromite ($FeCr_2O_4$)		Cr	Slag, dust, soil, groundwater
	Alabandite(MnS)		Mn	Slag, dust, soil, groundwater
	Pyrite (FeS_2)		Fe	Slag, dust, soil, groundwater
	Millerite (NiS)		Ni	Slag, dust, soil, groundwater
	Chalcopyrite ($CuFeS_2$), chalcocite (Cu2S), covellite (CuS)		Cu	Slag, dust, soil
	Sphalerite (ZnFeS)		Zn	Slag, dust, soil, groundwater
1948-1983	**ZINC** (Extract Zn from slag produced by lead furnaces)	**Slag fuming** (reduce dissolved Zn in molten slag to metallic Zn, then oxidize to ZnO fume.)	**Zn** (40,000 ton as ZnO in 1955, Source: Duval and Kleiner, 2010)	**Final product**
	Zn normally found associated with Cu, Fe and Pb. Major Zn minerals: Sphalerite(ZnS), smithsonite ($ZnCO_3$), heminorphite ($ZnSiO_4$), wurtzite (ZnS)		**Main Group Metals**	
	Orpiment (As_2S_3)		As	Slag, dust, soil, groundwater
	Aguilarite(Ag_4SeS)		Se	Slag, dust, soil, groundwater
	Greenockite (CdS)		Cd	Slag, dust, soil, groundwater
	Galena (PbS)		Pb	Slag, dust, soil, groundwater
			Transition Metals	
	Chromite ($FeCr_2O_4$)		Cr	Slag, dust, soil, groundwater
	Alabandite(MnS)		Mn	Slag, dust, soil, groundwater
	Pyrite (FeS_2)		Fe	Slag, dust, soil, groundwater

Time Period	Ore (Minerals)	Smelter Process	Metal	Environmental Fate
	Millerite (NiS)		Ni	Slag, dust, soil, groundwater
	Chalcopyrite ($CuFeS_2$), chalcocite (Cu_2S), covellite (CuS)		Cu	Slag, dust, soil
	Sphalerite (ZnFeS)		Zn	Slag, dust, soil, groundwater
1970-1986	**ANTIMONY**	**Antimony plant** (refined from Cu anode sludge, Source: Yuan, 2007)	**Sb** (1100 ton/year, Source: Yuan, 2007)	**Final product**
	Stibnite (Sb_2S_3) is the most dominant Sb minerals, usually associated with Cu and Pb ores		**Main Group Metals**	
	Orpiment (As_2S_3)		As	Slag, dust, soil, groundwater
	Aguilarite(Ag_4SeS)		Se	Slag, dust, soil, groundwater
	Greenockite (CdS)		Cd	Slag, dust, soil, groundwater
	Galena (PbS)		Pb	Slag, dust, soil, groundwater
			Transition Metals	
	Chromite ($FeCr_2O_4$)		Cr	Slag, dust, soil, groundwater
	Alabandite(MnS)		Mn	Slag, dust, soil, groundwater
	Pyrite (FeS_2)		Fe	Slag, dust, soil, groundwater
	Millerite (NiS)		Ni	Slag, dust, soil, groundwater
	Chalcopyrite ($CuFeS_2$), chalcocite (Cu_2S), covellite (CuS)		Cu	Slag, dust, soil
	Sphalerite (ZnFeS)		Zn	Slag, dust, soil, groundwater

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Texas Custodial Trust
Review of ASARCO El Paso Smelting Processes

Appendix A.
Smelting Glossary

6835001

MALCOLM PIRNIE

Appendix A. Smelting Glossary

Blast furnace: A type of furnace where pressurized air is ‘blasted’ from the bottom of the chamber while ores or concentrate is introduced from the top resulting in combustion in the chamber rather than at the top. Gases exit upwards and molten metal settles at the bottom from where it will be tapped (removed).

Blister Copper: Product of matte converting consisting of a crude molten metallic phase (98-99% Cu). Blister copper is then sent to refining.

Briquette: A briquette (or briquet) is a block of flammable matter used as fuel to start and maintain a fire.

Cadmium sponge: All cadmium recovery processes involve the dissolution of cadmium-bearing feed material, followed by various purification and cadmium displacement steps. In electromotive processing, cadmium is displaced from purified solutions by a less noble metal, usually zinc in the form of a metallic sponge. This metallic sponge like material is called cadmium sponge.

Calcination: (also referred to as calcining, roasting) It is a thermal treatment process applied to ores and other solid materials in order to bring about a thermal decomposition, phase transition, or removal of a volatile fraction. The calcination process normally takes place at temperatures below the melting point of the product materials.

Charge: A general term for materials (ore, concentrate and fluxes) that is put into furnace for processing.

Casting: The process of giving a solid shape to a molten metal.

Coke: Hydrocarbon heated to remove volatiles to obtain pure carbon.

Concentrate: A mineral-rich product from a mineral separation process such as flotation. The metals are "concentrated" from ore, and the remainder is discarded as neutralized tailing. The metals contained in the concentrate are recovered from the concentrates either by leaching or by smelting. The concentrate is named after the prevailing metal (copper, nickel, etc.).

Concentration: The process by which ore is separated into metal concentrates and reject material through processes such as crushing, grinding and flotation. Concentrates are shipped to a smelter or leaching facility at which the contained metals are recovered from the concentrates.

CONTOP process: CONTOP stands for CONtinuous smelting and TOP blowing process developed by KHD Hummboldt Wedag in 1979. In the CONTOP process, fine-grained sulfide minerals are smelted in a water-cooled cyclone; molten phases are then treated by top-blowing of fuel-oxygen mixtures. Sulfide particles react quickly, resulting from intense heat and mass transfer, and emitted vapors undergo secondary gas-gas reactions. The high temperature level and rapid phase separation in the cyclone enables it to act as a smelting and extraction reactor simultaneously.

Converting: A pyrometallurgical process in copper smelting to remove iron and sulfur impurities from molten copper matte, the process result in blister copper from this step.

Copper anode: Crude metal (copper, typically >98% pure) obtained from anode smelting and is the fed for electrolytic refining (electrolysis) to further remove impurities. Copper anode is dissolved ($Cu_{(s)} = Cu^{2+}_{(aq)} + 2e-$), while at the cathode $Cu^{2+}_{(aq)} + 2e- = Cu_{(s)}$ in the refining process.

Copper refining: Also see electrolysis. The final stage of copper production is refining to remove remaining impurities to obtain 99.99% copper. In electrorefining, the copper anodes are loaded into electrolytic cells and interspaced with copper starting sheets, or cathodes, in a bath of copper sulfate solution. When a direct current is passed through the cell the copper is dissolved from the anode, transported through the electrolyte and re-deposited on the cathode starting sheets. Solid impurities in the anodes fall to the bottom of the cell as a sludge where they are ultimately collected and processed for the recovery of precious metals such as gold and silver.

Crushing: The process by which ore is broken into small pieces to prepare it for further processing.

Dioxin: Dioxin is a general term that describes a group of hundreds of chemicals that are highly persistent in the environment, and it is a specific name for one compound that is the most toxic chemical in that family. Dioxins are formed by a number of natural (e.g. forest fires) and industrial (e.g. waste combustion, smelting, and pesticide production) processes.

Dross: It is a mass of solid impurities floating on a molten metal. It appears usually on the melting of low-melting-point metals or alloys such as tin, lead, zinc or aluminum, or by oxidation of the metal(s). Dross, as a solid, is distinguished from slag, which is a liquid.

Electrowinning (EW): The recovery of metal from a solution by electrolysis (also see solvent extraction).

Electrolysis: It is a method of using a direct electric current to drive an otherwise non-spontaneous chemical reaction. Electrolysis is commercially highly important as a stage in the separation of elements from naturally occurring sources such as ores using an electrolytic cell.

Filtration: The process of reducing the moisture of the concentrates by moving liquids or gases through porous medium.

Flash Smelter: An autogenous smelter for processing of dry concentrates. The process uses the autogenic principle by using the energy contained in the sulfur and iron for melting the ore. Smelting occurs during the flow of crushed rock and gas oxidizer (air, oxygen) which suspends particles of melted metal. The heat generated by the oxidizing reaction is actively used in the process.

Floatation: A wet chemistry process of concentration by selectively attaching air bubbles to mineral particles, typically metal sulfides, within pulp (a mixture of ore and water). Dry mineral particles attach poorly to the air bubbles and rise through the suspension to the top of the pulp, producing foam. The minerals that moisten well do not attach to the bubbles and remain in the pulp. Thus, the metals are separated.

Differential flotation: The process by which two or more valuable species are recovered in separate concentrates. In the case of a lead-zinc ore, the lead is floated into a lead concentrate by inhibiting the flotation of zinc. After the lead flotation is over, zinc is activated and recovered in a separate concentrate.

Froth Flotation: A method of separating metal-containing minerals from gangue, by adding a chemical to a pulp mixture of water and mineral rendering metal-containing minerals hydrophobic. The hydrophobic particles will cling to air bubbles which pass through the mixture thus separating them from other particles. This selectivity is reached through the addition of chemical reagents to the pulp.

Hearth Furnace: Furnace in which the charge rests on the hearth or kiln wall and is heated by hot gases passing over it.

Flux: An additive, often lime, employed to lower the melting temperature of the slag minerals and to promote smelting at lower temperatures than would be possible otherwise, and help separation of the target metal from impurities.

Gangue: The non-metallic, usually siliceous, component of an ore.

Ladle: Metal ladle used for transporting and pouring molten metal from the furnace to the caster.

Leaching: A hydrometallurgical process in which a soluble metallic compound is extracted from ore by dissolving the metals in a solvent.

Matte: Intermediate product in the form of mixed iron and copper sulfides and non-ferrous metals with varying chemical composition. Matte is the main product in which precious and auxiliary metals are accumulated.

Offgas: Waste gas generated during pyrometallurgical processing of base metals (including roasting, smelting, converting etc.), they typically include SO_2, CO_2 and dust particles from the furnace.

Ore: Mineral bearing rock which can be mined and treated profitably under the current economic conditions, or those conditions which are deemed to be reasonable.

Pregnant solutions: Solutions that have percolated through the ore on a heap leach, containing metallic ions with a high enough concentration to allow efficient extraction.

Primary smelter: A smelter facility where metal concentrate is used as the primary source for a specific type of metal extracted.

Pyrometallurgical process: Metallurgical processes performed at high temperatures. In accordance with the technological characteristics, the following types of pyrometallurgical processes are distinguished: roasting, smelting and conversion.

Reduction: Reduction is the final, high-temperature step in smelting process. The blistered copper is put into an anode furnace (a furnace that uses the blister copper as anode) to get rid of most of the remaining oxygen. This is done by blowing natural gas through the molten copper oxide. The oxygen is burned off. This creates at about 99% pure copper which is fed to the electrorefining process.

Refining: The final stage of the purification of crude metallic products, in which final impurities are removed from molten metal by introducing air and fluxes. The impurities are removed as gases or slag. For instance, the refining of base bullion (silver lead) produces nearly pure lead and silver.

Retort: A retort is an airtight vessel (furnace) in which roasted ores and coke are heated for a chemical reaction producing gaseous products (e.g., zinc vapor) to be collected in a collection vessel or for further processing.

Roasting: A process performed upon heating and keeping various materials (ores, concentrates and etc.) to eliminate light components (carbon or sulfur), leaving an oxide, which can be directly reduced. Roasting is usually carried out in an oxidizing environment.

Reverberatory furnace: A reverberatory furnace is a metallurgical or process furnace that isolates the material being processed from contact with the fuel, but not from contact with combustion gases. A furnace, with a shallow hearth, having a roof that deflects the flame and radiates the heat towards the hearth or the surface of the charge. It is less energy efficient, and release more contaminants to the environment compared to other more modern furnaces.

Secondary smelter: Scrap metal (recycled metal) is used as the primary source for a specific type of metal extracted.

Shriver press: A process use industrial grade heavy-duty machines for slurry filtering and washing.

Slag: The molten, or solidified, waste product of smelting, consisting of used components derived from the ore flux, fuel, and furnace lining. Slags can vary significantly in composition and microstructure, it typically contains iron and silica, and trace metals. .

Slag fuming: a process whereby the residue is melted to form a slag through which powdered coal or coke is blown along with air. The zinc is reduced to the metallic form and is vaporized from the slag during the process.

Slag-tapping: The practice of opening the base of a furnace during operation to drain the accumulated slag and allow the smelt to proceed without blocking the tuyere with slag.

Sintering: A process for making objects from powder, by heating the material in a sintering furnace below its melting point (solid state sintering) until its particles adhere to each other.

Skimming: The process of separation the matte phase from the slag phase.

Smelting: The process of chemically reducing an oxide ore to a range of products including workable metal by the application of heat in a furnace. It is a pyrometallurgical process performed at temperatures enabling the complete melting of the processed metal. Smelting is opposite of roasting which involves an oxidizing reaction.

Speiss: A molten phase consisting primarily of iron arsenide and antimony that is commonly encountered in lead smelting operations.

Tailings: The material rejected from a mill after the valuable minerals have been recovered.

Tap: A quantity of a liquid, as molten metal from a furnace, run out at one time.

Tuyere: A tube through which air or oxygen is blown into a blast furnace.

Texas Custodial Trust
Review of ASARCO El Paso Smelting Processes

Appendix B. ENCYCLE 1992-1997 Manifest Summary

6835001

MALCOLM PIRNIE

Appendix B
ENCYCLE 1992-1997 Manifest Summary

Generator	Manifest /CC #	Waste Codes	Quantity	Unit	Process Date	Processed Materials	Page #/Document Referenced
NASA	3203	D007, D011	4,689	GAL	1/3/1992	Photowaste	130[14]
NASA	3232	D007, D011	4,954	GAL	1/9/1992	Photowaste	128[14]
NASA	3243	D007, D011	4,580	GAL	1/14/1992	Photowaste	126[14]
NASA	3257	D007, D011	4,568	GAL	1/16/1992	Photowaste	124[14]
NASA	3271	D007, D011	4,735	GAL	1/21/1992	Photowaste	120[14]
NASA	3264	D007, D011	4,815	GAL	1/21/1992	Photowaste	122[14]
NASA	3280	D007, D011	4,839	GAL	1/24/1992	Photowaste	118[14]
NASA	3292	D007, D011	4,500	GAL	1/27/1992	Photowaste	117[14]
NASA	3309	D007, D011	4,627	GAL	1/29/1992	Photowaste	115[14]
NASA	3314	D007, D011	4,476	GAL	1/31/1992	Photowaste	111[14]
NASA	3315	D007, D011	4,551	GAL	2/3/1992	Photowaste	113[14]
NASA	3346	D007, D011	4,642		2/6/1992	Photowaste	109[14]
NASA	3380	D007, D011	4,575	GAL	2/12/1992	Photowaste	108[14]
NASA	3404	D007, D011	4,895		2/14/1992	Photowaste	107[14]
NASA	3405	D007, D011	4,641	GAL	2/18/1992	Photowaste	106[14]
Virco Manufacturing Corp/ Virsan S.A.	00263742	F006, D007, D008	29,090	P	2/21/1992	Hazardous Waste Solid N.O.S - waste treatment sludges from a plating line contianing detectable levels of cadmium & lead	230[13]
Virco Manufacturing Corp/ Virsan S.A.	00263741	F006, D007, D008	29,210	P	2/21/1992	Hazardous Waste Solid N.O.S - waste treatment sludges from a plating line contianing detectable levels of cadmium & lead	238[13]
Virco Manufacturing Corp/ Virsan S.A.	00263751	F006, D007, D008	27,520	P	2/21/1992	Hazardous Waste Solid N.O.S - waste treatment sludges from a plating line contianing detectable levels of cadmium & lead	246[13]
NASA	3419	D007, D011	4,634	GAL	2/21/1992	Photowaste	104[14]
NASA	3698	D007, D011	4,726	GAL	2/23/1992	Photowaste	46[14]
NASA	3447	D007, D011	4,576	GAL	2/26/1992	Photowaste	103[14]
NASA	3448	D007, D011	4,630	GAL	2/27/1992	Photowaste	102[14]
NASA	3470	D007, D011	4,704	GAL	3/3/1992	Photowaste	100[14]
NASA	3476	D007, D011	4,615	GAL	3/6/1992	Photowaste	98[14]
NASA	3485	D007, D011	4,929	GAL	3/9/1992	Photowaste	96[14]
NASA	3486	D007, D011	blank		3/10/1992	Photowaste	94[14]
NASA	3496	D007, D011	4,682	GAL	3/12/1992	Photowaste	92[14]
NASA	3507	D007, D011	4,504	GAL	3/13/1992	Photowaste	90[14]
NASA	3508	D007, D011	4,917	GAL	3/16/1992	Photowaste	88[14]
NASA	3514	D007, D011	4,137	GAL	3/17/1992	Photowaste	86[14]
NASA	3515	D007, D011	4,481	GAL	3/18/1992	Photowaste	84[14]
NASA	3528	D007, D011	4,612	GAL	3/19/1992	Photowaste	82[14]
NASA	3540	D007, D011	4,687.80	GAL	3/23/1992	Photowaste	80[14]
NASA	3555	D007, D011	4,715	GAL	3/25/1992	Photowaste	78[14]
NASA	3556	D007, D011	4,678	GAL	3/26/1992	Photowaste	76[14]
NASA	3572	D007, D011	4,763	GAL	3/31/1992	Photowaste	74[14]
NASA	3573	D007, D011	3,669	GAL	4/1/1992	Photowaste	72[14]
Virco Manufacturing Corp/ Virsan S.A.	00120101	F006, D007, D008	37,810	P	4/2/1992	Hazardous Waste Solid N.O.S - waste treatment sludges from a plating line contianing detectable levels of cadmium & lead	203[13]
NASA	3603	D007, D011	4,417	GAL	4/2/1992	Photowaste	70[14]
NASA	3604	D007, D011	4,706	GAL	4/3/1992	Photowaste	68[14]
NASA	3616	D007, D011	4,651	GAL	4/6/1992	Photowaste	66[14]

Appendix B
ENCYCLE 1992-1997 Manifest Summary

Generator	Manifest /CC #	Waste Codes	Quantity	Unit	Process Date	Processed Materials	Page #/Document Referenced
Virco Manufacturing Corp/ Virsan S.A.	00120120	F006, D007, D008	37,320	P	4/8/1992	Hazardous Waste Solid N.O.S - waste treatment sludges from a plating line contianing detectable levels of cadmium & lead	212[13]
NASA	3617	D007, D011	4,707	GAL	4/8/1992	Photowaste	64[14]
Virco Manufacturing Corp/ Virsan S.A.	00120119	F006, D007, D008	38,140	P	4/10/1992	Hazardous Waste Solid N.O.S - waste treatment sludges from a plating line contianing detectable levels of cadmium & lead	208[13]
NASA	3631	D007, D011	4,479	GAL	4/10/1992	Photowaste	62[14]
NASA	3644	D007, D011	blank		4/14/1992	Photowaste	60[14]
Virco Manufacturing Corp/ Virsan S.A.	00120103	F006, D007, D008	36,000	P	4/15/1992	Hazardous Waste Solid N.O.S - waste treatment sludges from a plating line contianing detectable levels of cadmium & lead	219[13]
NASA	3663	D007, D011	4,774	GAL	4/15/1992	Photowaste	58[14]
NASA	3671	D007, D011	4,772	GAL	4/16/1992	Photowaste	56[14]
GE Power Protection	00371704	D008	220	G	4/21/1992	Hazardous Waste Liquid N.O.S. - contains lead	296[13]
NASA	3685	D007, D011	4,634	GAL	4/21/1992	Photowaste	54[14]
NASA	3691	D007, D011	4,598	GAL	4/22/1992	Photowaste	50[14]
NASA	3690	D007, D011	4,821	GAL	4/22/1992	Photowaste	52[14]
NASA	3697	D007, D011	4,771	GAL	4/23/1992	Photowaste	48[14]
NASA	3699	D007, D011	4,791	GAL	4/24/1992	Photowaste	44[14]
NASA	3723	D007, D011	blank		4/29/1992	Photowaste	42[14]
Virco Manufacturing Corp/ Virsan S.A.	00120106	F006, D007, D008	36,560		4/30/1992	Hazardous Waste Solid N.O.S - waste treatment sludges from a plating line contianing detectable levels of cadmium & lead	303[13]
NASA	3743	D007, D011	4,744	GAL	5/1/1992	Photowaste	40[14]
NASA	3747	D007, D011	5,243	GAL	5/4/1992	Photowaste	36[14]
NASA	3746	D007, D011	4,744	GAL	5/4/1992	Photowaste	38[14]
NASA	3758	D007, D011	blank		5/6/1992	Photowaste	34[14]
NASA	3783	D007, D011	4,810	GAL	5/11/1992	Photowaste	30[14]
NASA	3784	D007, D011	3,752	GAL	5/11/1992	Photowaste	32[14]
NASA	3799	D007, D011	4,882	GAL	5/13/1992	Photowaste	28[14]
NASA	3807	D007, D011	4,880	GAL	5/14/1992	Photowaste	26[14]
NASA	3813	D007, D011	4,904	GAL	5/18/1992	Photowaste	22[14]
NASA	3833	D007, D011	4,828	GAL	5/21/1992	Photowaste	20[14]
NASA	3840	D007, D011	4,642	GAL	5/22/1992	Photowaste	18[14]
NASA	3865	D007, D011, D003	4,855	GAL	5/29/1992	Photowaste	16[14]
NASA	3869	D007, D011	4,746	GAL	6/1/1992	Photowaste	14[14]
NASA	3892	D007, D011	4,719	GAL	6/5/1992	Photowaste	12[14]
NASA	3915	D007, D011	4,610	GAL	6/10/1992	Photowaste	8[14]
NASA	3948	D007, D011	4,628	GAL	6/18/1992	Photowaste	6[14]
NASA	3970	D007, D011	4,865	GAL	6/24/1992	Photowaste	4[14]
NASA	3988	D007, D011	4,653	GAL	6/29/1992	Photowaste	2[14]
Virco Manufacturing Corp/ Virsan S.A.	00120107	F006, D007, D008	38,340		7/27/1992	Hazardous Waste Solid N.O.S - waste treatment sludges from a plating line contianing detectable levels of cadmium & lead	280[13]
Virco Manufacturing Corp/ Virsan S.A.	00317595	F006, D007, D008	37,180	P	8/14/1992	Hazardous Waste Solid N.O.S - waste treatment sludges from a plating line contianing detectable levels of cadmium & lead	254[13]
Virco Manufacturing Corp/ Virsan S.A.	00317596	F006, D007, D008	28,940	P	8/18/1992	Hazardous Waste Solid N.O.S - waste treatment sludges from a plating line contianing detectable levels of cadmium & lead	267[13]

Appendix B
ENCYCLE 1992-1997 Manifest Summary

Generator	Manifest /CC #	Waste Codes	Quantity	Unit	Process Date	Processed Materials	Page #/Document Referenced
Virco Manufacturing Corp/ Virsan S.A.	00202316	F006, D007, D008	37,800	P	10/14/1992	Hazardous Waste Solid N.O.S. Waste Treatment Sludges from a Plating Line Containing detectable levels of cadmium & lead	2[13]
Virco Manufacturing Corp/ Virsan S.A.	00202321	F006, D007, D008	35,000	P	12/1/1992	Hazardous Waste Solid N.O.S. Waste Treatment Sludges from a Plating Line Containing detectable levels of cadmium & lead	15[13]
Virco Manufacturing Corp/ Virsan S.A.	00202319	F006, D007, D008	37,740	P	12/7/1992	Hazardous Waste Solid N.O.S. Waste Treatment Sludges from a Plating Line Containing detectable levels of cadmium & lead	28[13]
Crest Products	4947	F006		ROLLOFF	1/11/1993	Sludge - CN	44[16]
Kurfest	5046	F006	20	BAGS	1/15/1993	Metal hydroxide sludge	175[5]
Briggs & Stratton	5021	F006		ROLLOFF	1/15/1993	Plating Sludge	70[16]
Sheldahl	5048	F006	3	BAGS	1/19/1993	Filtercake	10[16]
Virco Manufacturing Corp/ Virsan S.A.	00120118	F006, D007, D008	37,180	P	2/2/1993	Hazardous Waste Solid N.O.S. Waste Treatment Sludges from a Plating Line Containing detectable levels of cadmium & lead	42[13]
Crest Products	5091	F006		ROLLOFF	2/9/1993	Sludge - CN	46[16]
Briggs & Stratton	5118	F006		ROLLOFF	2/9/1993	Plating Sludge	72[16]
Missouri MPP	5200	F006	19	BAGS	2/16/1993	Filter press sludge	173[5]
DK Williams	5205	F006	8	BAGS	2/18/1993	Dried Filter Press	174[5]
Virco Manufacturing Corp/ Virsan S.A.	00120109	F006, D007, D008	34,680	P	2/23/1993	Hazardous Waste Solid N.O.S. Waste Treatment Sludges from a Plating Line Containing detectable levels of cadmium & lead	57[13]
Briggs & Stratton	5237	F006		ROLLOFF	2/26/1993	Plating Sludge	74[16]
Crest Products	5266	F006		ROLLOFF	3/2/1993	Sludge - CN	48[16]
Briggs & Stratton	5387	F006		ROLLOFF	3/24/1993	Plating Sludge	76[16]
Samsonite	5399	F006	6	BAGS	3/26/1993	BLANK	177[5]
Detray Plating Work	5394	F006, D006	1	BAG	3/29/1993	Plating Filtercake (CN)	172[5]
Crest Products	5468	F006		ROLLOFF	4/5/1993	Sludge	50[16]
Briggs & Stratton	5666	F006		ROLLOFF	4/26/1993	Plating Sludge	78[16]
Virco Manufacturing Corp/ Virsan S.A.	00263898	F006, D007, D008	17,078	KG	5/4/1993	Hazardous Waste Solid N.O.S. Waste Treatment Sludges from a Plating Line Containing detectable levels of cadmium & lead	72[13]
Crest Products	5752	F006		ROLLOFF	5/10/1993	Sludge	52[16]
Eagle Picher	5866	D002, D006	22	BAGS	5/26/1993	Zinc Sludge	171[5]
Briggs & Stratton	5933	F006		ROLLOFF	6/4/1993	Plating Sludge	80[16]
Crest Products	5980	F006		ROLLOFF	6/14/1993	Sludge - CN	54[16]
Englehard	6173	D006, D008, K002		ROLLOFF	7/7/1993	WWPT Presscake	12[16]
Crest Products	6212	F006		ROLLOFF	7/19/1993	Sludge - CN	56[16]
Englehard	6284	D006, D008, K002		ROLLOFF	7/21/1993	WWPT Presscake	14[16]
Graves	6252	F006	10	DR (s)	7/23/1993	WTS	176[5]
Briggs & Stratton	6344	F006		ROLLOFF	7/23/1993	Plating Sludge	82[16]
Virco Manufacturing Corp/ Virsan S.A.	00263894	F006	16,266	KG	8/4/1993	Hazardous Waste Solid N.O.S. Waste water treatment sludges from electroplating operations	87[13]
Englehard	6332	D006, D008, K002		ROLLOFF	8/4/1993	WWPT Presscake	17[16]
Englehard	6387	D006, D008, K002		ROLLOFF	8/10/1993	WWPT Presscake	20[16]
Mineral Research	6364	D005, D006		ROLLOFF	8/16/1993	Zinc filtercake	2[16]
Englehard	6490	D006, D007		ROLLOFF	8/20/1993	WWPT Presscake	22[16]
Crest Products	6494	F006		ROLLOFF	8/24/1993	Sludge - CN	58[16]
Briggs & Stratton	6550	F006		ROLLOFF	8/30/1993	Plating Sludge	86[16]

Appendix B
ENCYCLE 1992-1997 Manifest Summary

Generator	Manifest /CC #	Waste Codes	Quantity	Unit	Process Date	Processed Materials	Page #/Document Referenced
Englehard	6531	D006, D007		ROLLOFF	9/1/1993	WWPT Presscake	24[16]
Virco Manufacturing Corp/ Virsan S.A.	00419256	F006	16,238	KG	9/5/1993	Hazardous Waste Solid N.O.S. Waste water treatment sludges from electroplating operations	95[13]
Englehard	6608	D006, D007		ROLLOFF	9/9/1993	WWPT Presscake	26[16]
Crest Products	6675	F006		ROLLOFF	9/20/1993	Sludge - CN	60[16]
Englehard	6686	D006, D007		ROLLOFF	9/22/1993	WWPT Presscake	28[16]
Englehard	6735	D006, D008, K002		ROLLOFF	9/29/1993	WWPT Presscake	30[16]
Zenith Electric/Zenco	00223713	D008 D008	17,723 18,296		10/7/1993	Environmentally Hazardous Substance, Solid N.O.S. Broken CRT Glass	105[13]
Englehard	6776	D006, D007		ROLLOFF	10/7/1993	WWPT Presscake	32[16]
Crest Products	6810	F006		ROLLOFF	10/12/1993	Sludge - CN	62[16]
General Western Chemical/Value Printed Circuits de Mexico	00255976	F006	6,159	P	10/19/1993	Hazardous Waste Solid N.O.S. Filter press sludge	100[13]
Briggs & Stratton	6911	F006		ROLLOFF	10/19/1993	Plating Sludge	88[16]
Englehard	6875	D006, D007		ROLLOFF	10/21/1993	WWPT Presscake	34[16]
Englehard	6876	D006, D007		ROLLOFF	10/28/1993	WWPT Presscake	36[16]
Crest Products	6967	F006		ROLLOFF	11/1/1993	Sludge - CN	64[16]
RMA	6995		19,122	gallons	11/3/1993		3[17]
RMA	6994		19,349	gallons	11/3/1993		13[17]
RMA	6985		18,889	gallons	11/3/1993		22[17]
RMA	6992		18,624	gallons	11/3/1993		161[17]
Englehard	7013	D006, D007		ROLLOFF	11/4/1993	WWPT Presscake	38[16]
RMA	50858	F039	18,842	gallons	11/6/1993	Brine	119[17]
RMA	50859	F039	19,062	gallons	11/6/1993	Brine	126[17]
RMA	50849	F039	18,902	gallons	11/6/1993	Brine	132[17]
RMA	50834	F039	18,707	gallons	11/6/1993	Brine	139[17]
RMA	50817	F039	19,296	gallons	11/6/1993	Brine	147[17]
RMA	50846	F039	18,851	gallons	11/6/1993	Brine	153[17]
Sematech	7070	D002	22	T	11/8/1993	HF	4[16]
RMA	50746	F039	18,878	gallons	11/9/1993	Brine	101[17]
RMA	50748	F039	19,117	gallons	11/9/1993	Brine	114[17]
RMA	50841	F039	19,100	gallons	11/10/1993	Brine	90[17]
RMA	50850	F039	19,320	gallons	11/10/1993	Brine	95[17]
Englehard	7014	D006, D007		ROLLOFF	11/11/1993	WWPT Presscake	40[16]
RMA	50837	F039	19,352	gallons	11/11/1993	Brine	80[17]
RMA	50828	F039	19,384	gallons	11/11/1993	Brine	85[17]
RMA	50855	F039	19,361	gallons	11/12/1993	Brine	70[17]
RMA	50781	F039	18,873	gallons	11/12/1993	Brine	75[17]
RMA	50744	F039	19,324	gallons	11/13/1993	Brine	60[17]
RMA	50826	F039	18,787	gallons	11/13/1993	Brine	65[17]
RMA	50743	F039	18,909	gallons	11/15/1993	Brine	55[17]
RMA	50479	F039	19,184	gallons	11/15/1993	Brine	107[17]
RMA	50811	F039	19,843	gallons	11/16/1993	Brine	43[17]
RMA	50823	F039	18,909	gallons	11/16/1993	Brine	48[17]
RMA	50829	F039	19,302	gallons	11/17/1993	Brine	29[17]
RMA	50799	F039	19,451	gallons	11/17/1993	Brine	36[17]
RMA	50810	F039	19,011	gallons	11/18/1993	Brine	297[17]
RMA	50830	F039	19,427	gallons	11/18/1993	Brine	304[17]

Appendix B
ENCYCLE 1992-1997 Manifest Summary

Generator	Manifest /CC #	Waste Codes	Quantity	Unit	Process Date	Processed Materials	Page #/Document Referenced
RMA	50819	F039	19,031	gallons	11/18/1993	Brine	311[17]
RMA	50865	F039	19,267	gallons	11/18/1993	Brine	318[17]
RMA	50751	F039	18,765	gallons	11/19/1993	Brine	262[17]
RMA	50737	F039	19,641	gallons	11/19/1993	Brine	277[17]
RMA	50838	F039	19,419	gallons	11/19/1993	Brine	283[17]
RMA	50821	F039	19,317	gallons	11/19/1993	Brine	290[17]
Crest Products	7121	F006		ROLLOFF	11/22/1993	Sludge - CN	66[16]
RMA	50822	F039	19,177	gallons	11/23/1993	Brine	238[17]
RMA	50818	F039	19,184	gallons	11/23/1993	Brine	246[17]
RMA	50831	F039	19,269	gallons	11/23/1993	Brine	254[17]
RMA	50829	F039	19,112	gallons	11/23/1993	Brine	269[17]
RMA	50747	F039	19,385	gallons	11/24/1993	Brine	170[17]
RMA	50820	F039	19,535	gallons	11/24/1993	Brine	178[17]
RMA	50740	F039	18,932	gallons	11/24/1993	Brine	186[17]
RMA	50776	F039	19,214	gallons	11/24/1993	Brine	222[17]
RMA	50827	F039	19,784	gallons	11/24/1993	Brine	230[17]
RMA	50866	F039	19,361	gallons	11/29/1993	Brine	194[17]
RMA	50750	F039	19,024	gallons	11/29/1993	Brine	201[17]
RMA	50847	F039	19,436	gallons	11/29/1993	Brine	208[17]
RMA	50788	F039	19,300	gallons	11/29/1993	Brine	215[17]
Briggs & Stratton	7177	F006		ROLLOFF	12/7/1993	Plating Sludge	90[16]
Englehard	7230	D006, D007		ROLLOFF	12/16/1993	WWPT Presscake	42[16]
Zenith Electric Corp/ Partes de Television	00344738	D008	19,758	P	12/17/1993	Environmentally Hazardous Substance, Solid N.O.S. Broken CRT Glass	113[13]
Adflex/Adflex of Mexico	00344784	F006	740		12/19/1993	Hazardous Waste Liquids N.O.S (copper hydroxide & water)	116[13]
Crest Products	7293	F006		ROLLOFF	12/21/1993	Sludge	68[16]
Virco Manufacturing Corp/ Virsan S.A.	00419238	F006	17,287	KG	1/11/1994	Hazardous Waste Solid N.O.S. - waste water treatment sludges from electro plating operations	384[13]
Virco Manufacturing Corp/ Virsan S.A.	00419203	F006	18,008	KG	1/18/1994	Hazardous Waste Solid N.O.S. - waste water treatment sludges from electro plating operations	388[13]
Adflex/Adflex of Mexico	00344783	F006	385	G	1/27/1994	Hazardous Waste Liquid N.O.S (copper hydroxide sludge & water)	335[13]
Briggs & Stratton	7450	F006		ROLLOFF	1/28/1994	Plating Sludge	92[16]
DuPont	7607	D007, D008		ROLLOFF	2/18/1994	Incinerator Ash	110[16]
DuPont	7608	D007, D008		ROLLOFF	2/18/1994	Incinerator Ash	112[16]
Virco Manufacturing Corp/ Virsan S.A.	00419239	F006	19,740	KG	2/22/1994	Hazardous Waste Solid N.O.S. - waste water treatment sludges from electro plating operations	393[13]
DuPont	7678	D007, D008		ROLLOFF	3/4/1994	Incinerator Ash	114[16]
Zenith Electric Corp/ Partes de Television	AR-532744	D008	31,950 10,950 900	P P P	3/15/1994	Waste Environmentally Hazardous sustance Solid N.O.S. Broken CRT Glass	446[13]
Briggs & Stratton	7715	F006		ROLLOFF	3/21/1994	Plating Sludge	94[16]
Zenith Electric Corp/Zenco	00389557	D008	43,803	P	3/30/1994	Waste Environmentally Hazardous sustance Solid N.O.S. Broken CRT Glass	454[13]
DuPont	7879	D007, D008		ROLLOFF	4/8/1994	Incinerator Ash	116[16]

Appendix B
ENCYCLE 1992-1997 Manifest Summary

Generator	Manifest /CC #	Waste Codes	Quantity	Unit	Process Date	Processed Materials	Page #/Document Referenced
DuPont	7878	D007, D008		ROLLOFF	4/8/1994	Incinerator Ash	118[16]
DuPont	7972	D007, D008		ROLLOFF	4/22/1994	Incinerator Ash	120[16]
Briggs & Stratton	7984	F006		ROLLOFF	4/26/1994	Plating Sludge	96[16]
DuPont	7996	D007, D008		ROLLOFF	4/28/1994	Incinerator Ash	122[16]
DuPont	7995	D007, D008		ROLLOFF	4/28/1994	Incinerator Ash	124[16]
DuPont	8045	D007, D008		ROLLOFF	5/6/1994	Incinerator Ash	126[16]
DuPont	8044	D007, D008		ROLLOFF	5/6/1994	Incinerator Ash	128[16]
RMA	653916	M014 F001, F002, F003, K033, K097, P051, P071, U130	183,880	P	5/9/1994	Hazardous waste liquid N.O.S. 7-18% Sodium Chloride, 2-10% Sodium Sulfite/Sulfate, 0.5-4% Sodium Phosphate	5[6]
Virco Manufacturing Corp/ Virsan S.A.	00419204	F006	16,120	KG	5/10/1994	Hazardous Waste Solid N.O.S. - waste water treatment sludges from electro plating operations	379[13]
Adflex/Adflex of Mexico	00344775	F006	385	G	5/17/1994	Hazardous Waste Liquid N.O.S (copper hydroxide sludge & water)	329[13]
DuPont	8109	D007, D008		ROLLOFF	5/19/1994	Incinerator Ash	130[16]
DuPont	8108	D007, D008		ROLLOFF	5/19/1994	Incinerator Ash	132[16]
Adflex/Adflex of Mexico	00344775	F006	7	DRUMS	5/20/1994	All Waste	334[13]
DuPont	8170	D007, D008		ROLLOFF	5/24/1994	Incinerator Ash	134[16]
DuPont	8171	D007, D008		ROLLOFF	5/24/1994	Incinerator Ash	136[16]
DuPont	8210	D007, D008		ROLLOFF	6/3/1994	Incinerator Ash	138[16]
DuPont	8209	D007, D008		ROLLOFF	6/3/1994	Incinerator Ash	140[16]
Briggs & Stratton	8216	F006		ROLLOFF	6/8/1994	Plating Sludge	98[16]
American Nickeloid	BLANK	BLANK	120	Y	6/9/1994	Buff dirt	219[5]
DuPont	8246	D007, D008		ROLLOFF	6/10/1994	Incinerator Ash	142[16]
DuPont	8245	D007, D008		ROLLOFF	6/10/1994	Incinerator Ash	144[16]
DuPont	8299	D007, D008		ROLLOFF	6/17/1994	Incinerator Ash	146[16]
DuPont	8300	D007, D008		ROLLOFF	6/17/1994	Incinerator Ash	148[16]
DuPont	8379	D007, D008		ROLLOFF	6/24/1994	Incinerator Ash	150[16]
Zenith Electric Corp/ Partes de Television	00344742	D008	40,000 2,500	P P	7/1/1994	Waste Environmentally Hazardous sustance Solid N.O.S. Broken CRT Glass	442[13]
DuPont	8411	D007, D008		ROLLOFF	7/1/1994	Incinerator Ash	152[16]
Dupont	8428	D007, D008	1	ROLLOFF	7/7/1994	Incinerator ash	1[12]
DuPont	8435	D007, D008		ROLLOFF	7/8/1994	Incinerator Ash	154[16]
Adflex/Adflex of Mexico	00344776	F006	275	G	7/12/1994	Hazardous Waste Liquid N.O.S (copper hydroxide sludge & water)	323[13]
DuPont	8479	D007, D008		ROLLOFF	7/15/1994	Incinerator Ash	156[16]
DuPont	8478	D007, D008		ROLLOFF	7/15/1994	Incinerator Ash	158[16]
Virco Manufacturing Corp/ Virsan S.A.	00419235	F006	15,767	KG	7/19/1994	Hazardous Waste Solid N.O.S. - waste water treatment sludges from electro plating operations	374[13]
DuPont	8538	D007, D008		ROLLOFF	7/22/1994	Incinerator Ash	160[16]
Briggs & Stratton	8534	F006		ROLLOFF	7/27/1994	Plating Sludge	100[16]
DuPont	8571	D007, D008		ROLLOFF	7/29/1994	Incinerator Ash	162[16]
DuPont	8570	D007, D008		ROLLOFF	7/29/1994	Incinerator Ash	164[16]
Sheldahl	8653	F006, D008	15	(DR) P	8/22/1994	Tin, lead hydroxide	6[16]
DuPont	8763	D007, D008		ROLLOFF	8/31/1994	Incinerator Ash	166[16]
DuPont	8764	D007, D008		ROLLOFF	8/31/1994	Incinerator Ash	168[16]
DuPont	8769	D007, D008		ROLLOFF	9/1/1994	Incinerator Ash	170[16]
Briggs & Stratton	8751	F006, D007		ROLLOFF	9/8/1994	Plating Sludge	102[16]

Appendix B
ENCYCLE 1992-1997 Manifest Summary

Generator	Manifest /CC #	Waste Codes	Quantity	Unit	Process Date	Processed Materials	Page #/Document Referenced
DuPont	8820	D007, D008		ROLLOFF	9/9/1994	Incinerator Ash	172[16]
DuPont	8770	D007, D008		ROLLOFF	9/9/1994	Incinerator Ash "I-18"	174[16]
DuPont	8802	D007, D008		ROLLOFF	9/9/1994	Incinerator Ash "I-18"	176[16]
Adflex/Adflex of Mexico	0034477	F006	550	G	9/13/1994	Hazardous Waste Liquid N.O.S (copper hydroxide sludge & water)	339[13]
DuPont	8848	D007, D008		ROLLOFF	9/16/1994	Incinerator Ash "I-18"	178[16]
Zenith Electric Corp/Zenco	00638030	D008	41,604	P	9/20/1994	Waste Environmentally Hazardous Susbstance N.O.S. Broken CRT Glass	463[13]
DuPont	8917	D007, D008		ROLLOFF	9/23/1994	Incinerator Ash	180[16]
DuPont	8916	D007, D008		ROLLOFF	9/23/1994	Incinerator Ash	182[16]
DuPont	8970	D007, D008		ROLLOFF	9/30/1994	Incinerator Ash	184[16]
Great Western Chemical/ Value Printed	00462471	F006	3,573	P	10/11/1994	Hazardous Waste Solid N.O.S - filter press sludge	318[13]
Virco Manufacturing Corp/ Virsan S.A.	00419212	F006	17,083	KG	10/14/1994	Hazardous Waste Solid N.O.S. - waste water treatment sludges from electro plating operations	398[13]
Zenith Electric Corp/ Partes de Television	00389508	D008	50,450	P	10/24/1994	Waste Environmentally Hazardous Susbstance N.O.S. Broken CRT Glass	467[13]
Briggs & Stratton	9005	F006, D007		ROLLOFF	10/26/1994	Plating Sludge	104[16]
Virco Manufacturing Corp/ Virsan S.A.	00419240	F006	14,960	KG	11/9/1994	Hazardous Waste Solid N.O.S. - waste water treatment sludges from electro plating operations	403[13]
Adflex/Adflex of Mexico	0034478	F006	275	G	11/15/1994	Hazardous Waste Liquid N.O.S (copper hydroxide sludge & water)	345[13]
Zenith Electric Corp/Telson	00389510	D008	30,830	P	11/18/1994	Waste Environmentally Hazardous Susbstance N.O.S. Broken CRT Glass	472[13]
Briggs & Stratton	7012	F006, D007		ROLLOFF	12/6/1994	Plating Sludge	106[16]
Virco Manufacturing Corp/ Virsan S.A.	00307123	F006	17,025	KG	12/7/1994	Hazardous Waste Solid N.O.S. - waste water treatment sludges from electro plating operations	407[13]
Virco Manufacturing Corp/ Virsan S.A.	00419308	F006	19,694	KG	1/26/1995	Hazardous Waste Solid N.O.S. - waste water treatment sludges from electro plating operations	428[13]
Zenith Electric Corp/ Partes de Television	00368798	D008	41,184	P	2/17/1995	Environmentally Hazardous Substances, Solid N.O.S. Glass with lead	477[13]
DuPont	9741	D007, D008		ROLLOFF	2/24/1995	Incinerator Ash	186[16]
Virco Manufacturing Corp/ Virsan S.A.	00419261	F006	18,314	KG	2/28/1995	Hazardous Waste Solid N.O.S. - waste water treatment sludges from electro plating operations	412[13]
Virco Manufacturing Corp/ Virsan S.A.	00419262	F006	15,072	KG	2/28/1995	Hazardous Waste Solid N.O.S. - waste water treatment sludges from electro plating operations	417[13]
Adflex/Adflex of Mexico	0034479	F006	440	G	4/25/1995	Hazardous Waste Liquid N.O.S (copper hydroxide sludge & water)	356[13]
Zenith Electric Corp/ Partes de Television	00368799	D008	41,928	P	5/8/1995	Environmentally Hazardous Susbstances, Solid N.O.S. Glass with lead	459[13]
Virco Manufacturing Corp/ Virsan S.A.	00419285	F006	16,599	KG	5/25/1995	Hazardous Waste Solid N.O.S. - waste water treatment sludges from electro plating operations	434[13]

Appendix B
ENCYCLE 1992-1997 Manifest Summary

Generator	Manifest /CC #	Waste Codes	Quantity	Unit	Process Date	Processed Materials	Page #/Document Referenced
Virco Manufacturing Corp/ Virsan S.A.	00419282	F006	15,009	KG	5/25/1995	Hazardous Waste Solid N.O.S. - waste water treatment sludges from electro plating operations	437[13]
Zenith Electric Corp/Telson	00642923	D008	32,000	P	6/19/1995	Waste Environmentally Hazardous Susbstance N.O.S. CRT Glass	484[13]
Zenith Electric Corp/Zenco	00711736	D008	43,578	P	6/20/1995	Waste Environmentally Hazardous Susbstance Solid, N.O.S. CRT Glass	489[13]
DuPont	10423	D007, D008		ROLLOFF	6/30/1995	Incinerator Ash	188[16]
Zenith Electric Corp/Telson	00642919	D008	32,000	P	7/1/1995	Waste Environmentally Hazardous Susbstance Solid, N.O.S. CRT Glass	505[13]
Adflex/Adflex of Mexico	00344781	F006	440	G	7/11/1995	Hazardous Waste Liquid N.O.S (copper hydroxide sludge & water)	370[13]
DuPont	10507	D007, D008		ROLLOFF	7/20/1995	Incinerator Ash	190[16]
Virco Manufacturing Corp/ Virsan S.A.	00419276	F006	17,488	KG	7/31/1995	Hazardous Waste Solid N.O.S. - waste water treatment sludges from electro plating operations	431[13]
Zenith Electric Corp/Telson	00642920	D008	30,280	P	8/3/1995	Waste Environmentally Hazardous Susbstance Solid, N.O.S. CRT Glass	501[13]
Virco Manufacturing Corp/ Virsan S.A.	00419287	F006	15,273		9/5/1995	Hazardous Waste Solid N.O.S. - waste water treatment sludges from electro plating operations	468[13]
Zenith Electric Corp/Telson	00642921	D008	5,600	P	9/6/1995	Waste Environmentally Hazardous Susbstance Solid, N.O.S. CRT Glass	493[13]
Zenith Electric Corp/Telson	00642922	D008	17,840 7,500		9/12/1995	Waste Environmentally Hazardous Susbstance Solid, N.O.S. CRT Glass	497[13]
BLANKED OUT	10742	D002, D006	1	DRUM	9/13/1995	Copper Sulfate	193[5]
DuPont	10759	D007, D008		ROLLOFF	9/15/1995	Incinerator Ash	192[16]
BLANKED OUT	10774	D002, D006	3	TOTES	9/19/1995	Copper Sulfate	191[5]
Zenith Electric Corp/ Partes de Television	00344743	D008	42,330	P	9/20/1995	Environmentally Hazardous Substances, Solid N.O.S. CRT glass with lead	509[13]
Sheldahl	10750	F006, D008	16	DRUM	9/25/1995	Tin, lead hydroxide sludge	8[16]
Adflex/Adflex of Mexico	00344782	F006	715	G	10/4/1995	Hazardous Waste Liquid N.O.S (copper hydroxide sludge & water)	363[13]
DuPont	10836	D007, D008		ROLLOFF	10/6/1995	Incinerator Ash	194[16]
Zenith Electric Corp/Telson	00961707	D008	3,600	P	10/16/1995	Waste Environmentally Hazardous Susbstance Solid, N.O.S. CRT Glass	513[13]
Zenith Electric Corp/ Partes de Television	00961712	D008	42,503	P	12/14/1995	Environmentally Hazardous Substances, Solid N.O.S. CRT glass	481[13]
Virco Manufacturing Corp/ Virsan S.A.	00419299	F006	15,030	KG	1/11/1996	Hazardous Waste Solid N.O.S. - waste water treatment sludges from electro plating operations	422[13]
Briggs & Stratton	11288	F006		ROLLOFF	1/19/1996	Plating Sludge	108[16]
DuPont	11310	D007, D008		ROLLOFF	1/26/1996	Incinerator Ash	196[16]
Adflex/Adflex of Mexico	01074522	F006	990	G	2/21/1996	Hazardous Waste Liquid N.O.S (copper hydroxide sludge & water)	359[13]

Appendix B
ENCYCLE 1992-1997 Manifest Summary

Generator	Manifest /CC #	Waste Codes	Quantity	Unit	Process Date	Processed Materials	Page #/Document Referenced
Delta Faucet	BLANK	BLANK	100	DRUMS	3/29/1996	Nickel filtercake - 1 pint	227[5]
Inco	12618	BLANK	10	BAGS	9/30/1996	BLANK	253[5]
Ensign Bickford Company	1239142	K046 D007, D008	6,296 4,987 1,541	D D D	3/11/1997	Hazardous Waste Solid N.O.S. Hazardous Waste Solid M.I.S. (lead, chromium) Non-DOT Regulated Material (spent capshells)	215[5]
Parker Hannifin	13872	BLANK	9	DRUMS	4/30/1997	ECM Sludge	242[5]
Delta Faucet	14076	BLANK	1	TOTE	5/22/1997	Green Solid	229[5]
Eaton Corp	14053	BLANK	24	DRUMS	5/30/1997	Kolene Sludge, brown-grey solids	236[5]
Cerro Copper Products	14175	BLANK	32	BAGS	6/3/1997	Nickel Sulfate	270[5]
AGMET	14179	BLANK	BLANK	BLANK	6/12/1997	Precip Ash	276[5]
American Nickeloid	14217	BLANK	10	TOTES	6/16/1997	Buff dirt	217[5]
American Nickeloid	14217	BLANK	10	TOTES	6/16/1997	Buff dirt	277[5]
Raytheon Appliance	14277	BLANK	20	BAGS	6/18/1997	Treated Raw Zinc Sludge	265[5]

[1] EPA Response to Encycle/ASARCO Settlement Statement, (1998 Confidential Document) July 31, 1998 (73 pages)
[2] EPA Inspection Report for Encycle, January 1997, Part 1 (42 pages)
[3] EPA Inspection Report for Encycle, January 1997, Part 2 (42 pages)
[4] EPA Inspection Report for Encycle, June 1997 (26 pages)
[5] EPA Inspection Report for Encycle, June 1997, with attachments (436 pages)
[6] Rocky Mountain Arsenal Hazardous Waste Manifest (24 pages)
[7] National Enforcement Investigation Center Report for Encycle, 1998 (264 pages)
[8] Explanation of Differences for Basin F Liquids (Rocky Mountain Arsenal) (21 pages)
[9] Notification from Encycle regarding waste from Molycorp, December 1995 (1 page)
[10] DuPont-Sabine River Form R, 1993 (8 pages)
[11] DuPont-Sabine River Form R, 1995 (7 pages)
[12] Analysis of Waste Sent to Encycle from DuPont-Sabine River (2 pages)
[13] Manifests for Wastes from Foreign Sources Sent to Encycle (516 pages)
[14] Analysis of Waste Sent to Encycle from NASA (182 pages)
[15] Analysis of Waste Sent to Encycle from West Helena (12 pages)
[16] Analysis of Waste Sent to Encycle from Various Generators (197 pages)
[17] Rocky Mountain Arsenal Waste Shipment Analyses (323 pages)