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Leaching Potential of Metals and Brominated Flame Retardants in Obsolete Notebook Computers

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LEACHING POTENIAL OF METALS AND BROMINATED FLAME RETARDANTS

IN OBSOLETE NOTEBOOK COMPUTERS

By

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Due to the increasing use of electronic components and the accelerated rate in which these components become obsolete, there has been a dramatic increase of discarded electronic waste (E-waste). E-waste includes obsolete electronic products such as computers, scanners, cellular phones, etc. These electronic components are manufactured using a variety of hazardous materials. As these components are discarded, the toxic and hazardous substances may become mobile and could impact human health and the environment. The toxic substances of concern contained in E-waste include heavy metals and brominated flame retardants (BFRs). This study attempts to identify the leaching potential of BFRs and metals.

DEDICATION

I would like to dedicate this thesis to Otho and Dorothy Barnes, Bathsheba Dampeer, Fronce Barnes, Ms. Kenyatta Veals, Dr. Mark Bricka, and my friends. Thank you again for never giving up on me.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

There is a growing concern in the increasing number of discarded electronic devices, due to the increasing use of electronics and the accelerated rate which these components are becoming obsolete. Electronic waste or E-waste includes obsolete and functioning electronic devices The USEPA classifies E-waste as the consumer products that can be grouped in the following categories: (USEPA 2004)

- Televisions
- Computers/computer peripherals
- Audio/stereo equipment
- VCRs
- DVD players,
- Video cameras
- Telephones
- Fax and copying machines
- Cell phones
- Wireless devices
- Video game consoles

E-waste components contain many toxic substances that if mobilized, could impact human health and the environment. The main toxic substances of concern include heavy metals and brominated flame retardants (BFRs). In Europe, research indicates that the rate of E-waste generation is growing three times faster than other solid municipal waste streams (USEPA 2001). Consumer electronic products grew by almost 8.6% from 2005 to 2006, from 2.67 million tons to 2.90 million tons (USEPA 2007). In fact, the National Safety Council reports that computers are generally considered obsolete 3 years after purchase (USEPA 200l). While currently not listed as a hazardous waste, E-waste contains lead, cadmium, beryllium, as well as other toxic metals and often fails the Toxicity Characteristic Leaching Procedure (TCLP) test (Basel Action Network 2004). Thus E-waste has the potential to be classified as hazardous and may require disposal as a hazardous waste.

Studies have shown that televisions and Cathode Ray Tube (CRT) monitors contain large quantities of lead. In addition, brominated flame retardants are commonly added to plastics used in electronics to reduce their flammability. If improperly disposed, these toxins may be released into the environment (USEPA 2001).

Stanford Resources, Inc. conducted a study in 1999 for the National Safety Council. The study suggested that 41 million personal computers would become obsolete in the United States (Basel Action Network 2002). In California, analysts estimated that over 6,000 computers become obsolete daily (Basel Action Network 2002). In a 2006 report, the International Association of Electronic Recyclers projects that the current growth and disposal rate of consumer electronics will be in the neighborhood of 3 billion units during the rest of the decade, or an average of about 400 million units a year (International 2006).

E-waste contains a variety of toxic substances such as cadmium and lead on printed wired boards; mercury in switches and flat screen monitors; and brominated flame retardants in printed wired boards and the plastic casings of electric devices (Basel Action Network 2002). It is estimated that half of all of the heavy metals found in U.S. landfills can be traced to discarded electronics (Agency of Natural Resourc 2004). In the U.S, more than 4.6 million tons of E-waste has been disposed in landfills (United Nations

Environment Programee 2005). Based on these reports, it appears as though the potential for E-waste to negatively impact the environment is substantial.

1.1 Brominated Flame Retardants (BFRs)

Brominated flame retardants (BFRs) are synthetic additives used in electronics and in construction materials. BFRs are added to the plastics to prevent them from igniting during long exposure to high temperatures. Currently, there are 175 different types of flame retardants on the market (McPherson 2004). These flame retardants are used in the high impact plastics used on flat screen televisions, CRT televisions, and computer monitors because of the high temperature exposure. Some BFRs have the properties that are typical of persistent organic pollutants. Other BFRs such as polybrominated diphenyl ether (PBDE) congeners and hexabromocylodencan (HBCD) have been suspected to cause adverse health effects (Morf 2005). The levels of PBDEs in North American women breast milk appear to be doubling every two to five years (McPherson 2004). These BFRs are believed to emanate from E-waste. BFRs are also found in fabrics including upholstery and carpet. It is postulated that BFRs contributes to mammalian BFR tissue and breast milk concentrations.

BFRs exist in most of the plastic used in the manufacture of electronic components including the printed wire boards (PWBs) and the casing of the computers. Once these components have been discarded, they are disposed of in landfills. Research has determined that BFRs can be persistent, bioaccumulative toxins that may leach from landfills (Basel Action Network 2004).

1.1.1 BFR Uses

Humans have always tried to find methods of protecting themselves and their property from fire. Fire has long been a leading cause of death and injures around the world each year. In Canada, 465 deaths and 3,700 injuries were the results of 67,000 fires (de Boer 2004). Various types of BFRs are available based on halogenated organic compounds, phosphorus containing substances, aluminum based compounds, and others.

Fire safety standards for electrical appliances, textiles, upholstery, and other products help to minimize the loss of property and life. To meet fire safety standards, products made of synthetic materials are modified with flame retardants. Flame retardants are chemicals, which are used to inhibit the ignition and spreading of flames. It is important to note that the term flame retardant is not equivalent to fire proof meaning that a flame retardant product is still flammable.

BFRs comprise a large number of substance classes including polybrominated diphenyl ethers and TBBPA. These are used as flame retardants in plastics, textiles, coatings, and electrical components found in many common goods including computers, televisions, and electrical appliances as seen in Figure 1.1, 56% of electrical and electronic appliances use BFRs. BFRs have been added to plastic and polyurethane foam to prevent ignitability. Without additives, plastic, and polyurethane foam would ignite quickly and spread rapidly (Maine Bureau of Health 2005). In addition to flame retardants ignitability and combustibility resistive properties, they also provide valuable time for an occupant to escape from a result of fire.

1.1.2 BFR Regulations

Many steps are being made to control the amount of E-waste that is disposed in landfills. Many states have begun to establish recycling programs to collect E-waste, but this process has been slow to develop. It was reported by the National Safety Council that only 11% of discarded computers were recycled (Lichtensteiger 2003). Computer recycling rate in the state of California ranges from 5% to 15%, compared to a 42% rate for overall solid waste discarded (Kuriyama 2003). Currently, there are no federal mandated regulations addressing BFRs. California passed Assembly Bill 302 to stop the manufacture, processing or distribution of products which contain penta-PBDE or octa-PBDE which became effective in 2008. California has banned CRTs from entering landfills and required manufacturers to collect 50% of their waste products by 2006 and 90% of their waste CRTs by 2010 (Recycling 2003). Hawaii passed a law prohibiting the manufacture, processing or distribution of flame retardant products containing more than 0.1% by mass of penta-BDE or octa-BDE. The ban for these products does not apply to the processing of metallic recyclables containing PBDEs (Maine Bureau of Health 2005). In the U.S, Maine banned all three PBDE flame retardants – penta-, octa-, and deca-BDEs. Penta- and octa-BDEs were to be completely phased out by January 1, 2006 and deca-BDE by January 1, 2008 in the state of Maine (Veleva 2004). In many European countries, regulation has been introduced to prevent electronic waste from being dumped in landfills due to its hazardous content. After European Waste Electrical and Electronic Equipment (WEEE) Directive and the Restrictions on Hazardous Substances Directive (RoHS) were adopted as European law, six toxic chemicals: Lead, Mercury, Cadmium, Hexavalent chromium, Penta-PBDE, and Octa-PBDE, were banned from electronics and electrical equipment (Veleva 2004).

Some industrial companies have also made attempts to phase out certain BFRs from their electronic products. In 2005, Great Lakes Chemical was the only U.S. manufacturer to completely phase out penta- and octa-BDE from their product lines. Companies such as Apple, Ericsson, IBM, Intel, Motorola, Panasonic, Phillips and Sony have begun to use alternatives that are more cost effective and more environmental friendly. Motorola, for example, has begun to use a halogen-free laminate as a flame retardant (Scheifer 2002). Also, IBM once sold more than 3 million computers in the United States and was the first manufacturer to establish a pay-as-you-go system for recycling obsolete computers. IBM charges customers $30 to mail back their discarded computers for recycling (Agency of Natural Resources 2004).

Although the EPA has not provided major funding to state programs to provide the means to fully accept the challenge of removing E-waste from municipal landfills, limited funding has been provided. The Rhode Island Department of Environmental Management won a competitive grant from the EPA's Jobs through Recycling Program in September 1995 to create a self-sustaining disassembling, processing, and recycling center for appliances and electronic equipment. The project organizers are working to provide consulting services to provide the best possible means for dealing with E-waste (Pitts 1996). Actions as those discussed above will help motivate other states to pursue means to provide a cleaner, healthier environment for its residents.

1.1.3 BFRs Health and Environmental Concern

As stated previously, there are more than 175 different flame retardants. These flame retardants can be categorized into classes which consist of brominated, chlorinated, phosphorus, nitrogen, and inorganic flame retardants. Brominated flame retardants are often used for industrial purposes especially in the electronic industry. The most common BFRs and their uses can be seen in the Table 1.1. From the uses that have been stated in Table 1.1, these top five BFRs are present in every aspect of human life.

Although BFRs are used in a variety of household products, much is being done to eliminate these chemicals from our everyday lifestyles. The United States (U.S.) has taken action to voluntarily phase out Penta-BDE and Octa-BDE from manufactured goods. This means however, their release into the environment will continue throughout the products' lifecycles, potentially for several more decades. The European Union (EU), a conglomeration of twenty-seven member states, has decided to completely remove Penta-BDE and Octa-BDE from all products current and future production operations produced. Although the EU has completely eliminated the usage of Penta-BDE and Octa-BDE, it will take some time to completely remove all of the products and components from the environment.

Although Penta-BDE and Octa-BDE are being phased-out, the industrial usage of Deca-BDE is increasing. Deca-BDE is the most widely used of all PBDEs (Birnbaum 2004). Deca-BDE is used as an additive to high-impact polystyrene plastic, which is commonly used in the housings for televisions, computers, and other electronic devices. Deca-BDE is one of the main components of products in all markets and accounts for 80% of all PDBEs manufactured worldwide (Birnbaum 2004). When compared to other

PBDEs, Deca-BDE is the only BFR without major adverse health or environmental effects. A risk assessment was performed on Deca-BDE in May 2004 and it concluded that no major risks were identified that were detrimental to human health or the environment (Morf 2005).

With the increase in production of BFRs, several studies have been performed to investigate the adverse affects that BFRs may have on the environment and humans. BFRs are being found in sediment, beluga whales, seals, bird eggs, human milk, serum and adipose tissue (Darnerud 2001). Other studies have also shown evidence of BFRs are also found in women from other populations around the world such as Sweden, Japan and Canada. There are also significant increases in the amount of BFRs in the animal kingdom. The concentrations of BFRs are lower in invertebrates than those in fish, which are much lower than those in marine mammals (Alaee 2002). The presence of BFRs in seafood has been identified as the method in which BFRs are ingested by humans (Athanaiadou 2007).

Exposure to BFRs has been linked to several adverse health affects. Studies have shown that when animals are exposed to BFRs that these animals exhibit nonhabituating behavior profile similar to when exposed to PCBs (polychlorinated biphenyls). These deficits in learning and memory were observed throughout adulthood and worsened with age, but more research is needed to determine the actual affects to humans and animals (Birnbaum 2004).

Many BFRs are believed to enter the environment in the form of higher brominated congener and breakdown into lower brominated congeners. A study has shown that the lower brominated congeners are the most toxic and are accumulating at the highest rates and levels in wildlife and human tissue samples (Birnbaum 2004). For example, it is believed that since Deca-BDE is one of the most commonly used BFRs, when exposed to the environment it breaks down to small congeners. This is the reason Deca-BDE is believed not to be as prevalent as other small congeners in the environment. PBDEs are persistent in the environment because of their resistance to degradation by lights, acids, bases, and for reducing or oxidizing compounds. The lower brominated congeners are more resistant to degradation, but the higher brominated congeners are not as stable.

A recent laboratory study of sewage sludge in Sweden showed bacteria are able to degrade deca-BDE to octa- and nona-brominated congeners under anaerobic conditions (Danerud 2001). Recent studies also report that concentrations of PBDEs in sewage sludge in the United States are as high as 33 mg/kg. However, DBDE has been identified in sediment with concentrations as high as 5 mg/kg (Birnbaum 2004).

Plastic products containing commercial octa- and deca-BDE may also release these chemicals through decomposition in landfills, especially when exposed to sunlight, which tends to break down plastics more quickly. A recent Norwegian study has suggested that PBDEs escape from discarded products and seep out of landfill sites into the environment (Madsen 2003). Until legislation is developed, the industry will look for the cheapest solution for the disposal of E-waste. Landfills still represent the most cost effective solution in many EU member countries. More than 90% of E-waste are landfilled (Tange 2005).

The penta-BDE product is mainly used as an additive in polyurethane foams made in the United States. The penta-BDE product contains a mixture of molecules with 4, 5, or 6 bromines (tetra, penta, and hexa BDEs). As a result, they can leach from the finished product over time. Some of the components of Penta-BDE product are resistant to biodegradation and persist in the environment. They are also quite insoluble in water and concentrate in the fatty tissues of living organisms (Madsen 2003).

Tetrabromobisphenol-A (TBBPA) is mainly used in printed circuit boards like those in personal computers and other electronic products, as well as in the plastic casing of office equipment. TBBPA is physically attached to the plastic and thus can escape from products (Madsen 2003). Leaching of TBBPA has caused it to be found in the environment and in the food chain. Concern over the ability of TBBPA to form dioxins and disrupt the endocrine system has prompted some electronic manufactures to seek out alternatives.

UV light and bacteria degrade TBBPA. When exposed to UV light, the main breakdown product is 2,4,6-tribromophenol. Researchers have also found a number of other decomposition products, including bromobisphenols, bromobenzenes, and bisphenol-A (DeWit 2002). Depending on the season, photolytic degradation of TBBPA has a half-life of 7-81 days in water. Bacteria degrade TBBPA in soil and sediments under both aerobic and anaerobic conditions with a half-life of approximately 2 months (Birnbaum 2004).

1.2 Metals

In addition to the BFRs in plastics, E-waste also included significant level of metals. Notebook computers are comprised of a wide range of heavy metals. A significant number of the heavy metals, especially Cu, Zn, Sn, and Pb, are present as pure metals or alloys. Examples of components with metal components include the copper in wires, metals such as tin, lead, copper, silver, zinc, and antimony used as solder, circuit on a printed wired board, and lead used in computer chips.

In Table 1.2 the breakdown of the metal composition of a personal computer can be seen. As shown in Table 1.2, 14% of the total weight of a computer is composed of aluminum. It can also been seen that 6% of the total weight of the computers are composed of lead. Presented in the following section is a brief description of the metals found in notebook computer and other electronic waste. The physical properties of the following metals are located in Appendix A.

1.2.1 Metals Regulations

About 70% of the heavy metals found in landfills come from discarded electronic equipment (Nexus 2006). These heavy metals and other hazardous substances found in electronics can contaminate groundwater and pose other environmental and public risks (USEPA 2001). Although E-waste is not regulated, some of the metals used in electronic devices are regulated. The materials are characterized as hazardous or non-hazardous by the TCLP test according to the leaching levels of these metals. The metals regulated by the TCLP test include barium, cadmium, chromium, lead, mercury, selenium, and silver.

1.3 Objectives

The objective of this study was to investigate the leaching potentials of metals and BFRs from selected notebook computers. The contaminants of concern (COCs) investigated in this study included the following:

Brominated Flame Retardants

- Tetrabromobisphenol A (TBBPA)
- 2,2',4,4',5- pentabrominated diphenyl ether
- 2,2',4,4',6'-pentabrominated diphenyl ether
- decabrominated diphenyl ether
- 2,4,4-tribromintated diphenyl ether
- 2,2',4,4'-tetrabrominated diphenyl ether
- 2,2',4,4',5,5'-hexabrominated diphenyl ether
- 2,2',4,4',5,6-hexabrominated diphenyl ether
- 2,2',3,4,4',5',6-heptabrominated diphenyl ether

Heavy Metals

- Antimony (Sb)
- Aluminum (Al)
- Barium (Ba)
- Beryllium (Be)
- Cadmium (Cd)
- Chromium (Cr)
- Copper (Cu)
- Gold (Au)
- Iron (Fe)
- Lead (Pb)
- Nickel (Ni)
- Tin (Sn)
- Zinc (Zn)

These COCs were selected based on the fact that these contaminants are commonly occurring in desktop computers based on a previous study, as shown in Table 1.1 and Table 1.2. Although desktop computers are much larger than notebook computers, it was assumed that the desktop computers could be used as a reference. While the overall objective is to investigate the mobility of the contaminants, the specific sub objectives include:

- To determine if the BFRs are mobile from notebook computer PWB, casing, and LCD screens.

- To determine if metals are mobile from notebook computer PWB, casing, and LCD screens.

- To determine if notebook computers can be characterized as a hazardous waste, if disposed as characterized by the USEPA.

- To determine how different notebook computers will behave when exposed to different conditions in the environment.

- To determine which notebook computer component contains the most mobile metals.

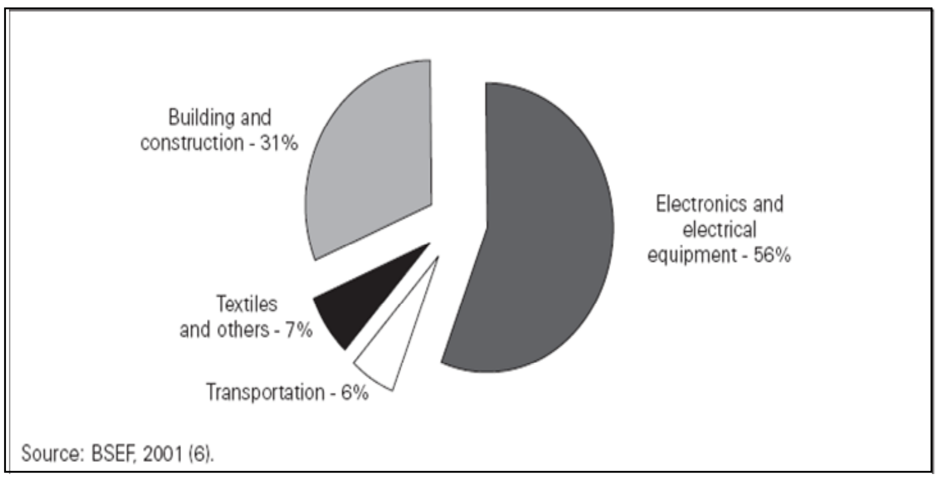


Figure 1.1 Breakdown of Brominated Flame Retardant Use in Industry

Table 1.1 Brominated Flame Retardants and Uses

Brominated Flame Retardant	Use
Tetrabromobisphenol A (TBBPA)	Epoxy resin (printed circuit boards and printed wire boards of computer and other electronic products), and acrylonitrile butadiene styrene (ABS) (housing of computers, PC monitors, televisions and other electronic products)
Decabromodiphenyl Oxide (Deca-BDE)	High impact polystyrene(HIPS) (electronic equipment), polyethylenes (wire and cables of electronic), upholstery textiles, building and construction applications.
Octabromodiphenyl Oxide (Octa-BDE)	ABS plastics (PC monitors, housing for televisions, mobile phones, and copy machine parts).
Pentabromodiphenyl Oxide (Penta-BDE)	Polyurethane foam, mattresses, seat cushions, upholstered furniture, carpet underlay, and bedding.
Hexabromocyclododecane (HBCD)	Polystyrene foam (building materials, i.e. insulation) and textiles (upholstered textiles).

(Bromine Science and Environmental Forum Website: www.bsef.com)

Table 1.2 Composition of a Desktop Personal Computer

Name	Content (% of total weight)	Weight of material in computer (lbs.)	Recycling Efficiency (current recyclability)	Use/Location
Silica	24.88	15	0%	glass, solid state devices/CRT,PWB
Plastics	22.99	13.8	20%	includes organics, oxides other than silica
Iron	20.47	12.3	80%	structural, magnetivity/(steel) housing, CRT, PWB
Aluminum	14.17	8.5	80%	structural, conductivity/housing, CRT, PWB, connectors
Copper	6.929	4.2	90%	Conductivity/CRT, PWB, connectors
Lead	6.299	3.8	5%	metal joining, radiation shield/CRT, PWB
Zinc	2.205	1.32	60%	battery, phosphor emitter/PWB, CRT
Tin	1.0078	0.6	70%	metal joining/PWB, CRT
Nickel	0.8503	0.51	80%	structural, magnetivity/(steel) housing, CRT, PWB
Barium	0.0315	< 0.1	0%	in vacuum tube/CRT
Manganese	0.0315	< 0.1	0%	structural, magnetivity/(steel) housing, CRT, PWB
Silver	0.0189	< 0.1	98%	Conductivity/PWB, connectors
Tantalum	0.0157	< 0.1	0%	Capacitors/PWB, power supply
Beryllium	0.0157	< 0.1	0%	thermal conductivity/PWB, connectors
Titanium	0.0157	< 0.1	0%	pigment, alloying agent/(aluminum) housing
Cobalt	0.0157	< 0.1	85%	structural, magnetivity/(steel) housing, CRT, PWB
Antinomy	0.0094	< 0.1	0%	diodes/housing, PWB, CRT
Cadmium	0.0094	< 0.1	0%	battery, glu-green phosphor emitter/housing, PWB, CRT
Bismuth	0.0063	< 0.1	0%	wetting agent in thick film/PWB
Chromium	0.0063	< 0.1	0%	Decorative, hardener/(steel) housing

Table 1.2 (Continued)

Mercury	0.0022	< 0.1	0%	batteries, switches/housing, PWB
Germanium	0.0016	< 0.1	0%	Semiconductor/PWB
Indium	0.0016	< 0.1	60%	transistor, rectifiers/PWB
Gold	0.0016	< 0.1	99%	Connectivity, conductivity/PWB, connectors
Ruthenium	0.0016	< 0.1	80%	resistive circuit/PWB
Selenium	0.0016	0.00096	70%	rectifiers/PWB
Gallium	0.0013	< 0.1	0%	Semiconductor/PWB
Arsenic	0.0013	< 0.1	0%	doping agents in transistors/PWB
Palladium	0.0003	< 0.1	95%	Connectivity, conductivity/PWB, connectors
Vanadium	0.0002	< 0.1	0%	red phosphor emitter/CRT
Europium	0.0002	< 0.1	0%	phosphor activator/PWB
Niobium	0.0002	< 0.1	0%	welding allow/housing
Yttrium	0.0002	< 0.1	0%	red phosphor emitter/CRT
Terbium	0	0	0%	green phosphor activator, dopant/CRT, PWB
Rhodium	0		50%	thick film conductor/PWB
Platinum	0		95%	thick film conductor/PWB

Based on a typical desktop computer including a CRT, weighing ~ 60lbs.Table presented in: Microelectronics and Computer Technology Corporation (MCC) (Just 2004)

CHAPTER 2

METHODS AND MATERIALS

1.1 Overview of Study

This study focuses on using a number of extraction methods to determine the quantity of metals and (BFRs) that are mobile under the influences of different leachability scenarios, which can be seen in Figure 2.1. The details of each of these experimental scenarios are shown in the treatability study approach flowcharts which are shown in Figures 2.2 and 2.3. The combined results of each of the experimental scenarios were gathered to determine the quantity of BFRs and metals that are leached from the various components.

As shown in Figure 2.1, this study consisted of several phases that are discussed in the following section:

- Phase I – Notebook Computer Selection – A group of computers were donated by the Mississippi Department of Environmental Quality (MDEQ) Computer Recycling program at Jackson State University. These computers were selected based on brand and model of duplicate notebook computers.

- Phase II – Disassembly of Notebook Computer – Each of the notebook computers selected were dissembled to prepare the individual components for use in this study.

- Phase III – Sample Preparation – Each notebook component was ground or cut per specification by each extraction method.

- Phase IV – Leach Test and Extraction – This consisted of the leach test and extraction method used for each notebook component. The leaching methods that were used are as followed:
    - Toxicity Characteristic Leaching Procedure (TCLP)
    - Synthetic Precipitation Leaching Procedure (SPLP)
    - Dynamic Leaching Test (DLT)
    - Total Extraction of Metals
    - Soxhlet Extraction of Total BFRs

With the exception of the DLT, each of these tests is an EPA approved extraction method for determining the mobility of organics and inorganics in liquid and solid materials.

- Phase V – Data Analysis – The data from each extraction method was gathered and compiled to determine which BFRs or metals leached from each notebook component.

- Phase VI – Report Preparation – The results of each test was compiled and a final report of the findings was generated.

Figure 2.1 and Figure 2.2 presents an overview schematic of the different phases used in this study. The details of each phase of this study are presented in the following section.

2.1 Phase I - Treatability Study and Sample Collection

The treatability study for this project focused on the components of notebook computers. Studies have shown that notebook computers have concentrated amounts of toxic chemicals housed in the various components of the computer. For this study we focused on the printed wired board (PWB), liquid crystal display (LCD), and outer plastic casing. Each of these components was chosen for the study because these components are believed to have the highest concentration of heavy metals and BFRs based on previous studies as shown in Table 1.1 and Table 1.2. Notebook computers are closely related to desktop computers. However, they are very different in size and more BFRs are used in the manufacturing of notebook computers.

The notebook computers selected for this study consist of a variety of manufactures and models. Two identical computers of each model were collected. The types and detailed descriptions of the computers are given in Table 2.1.

2.2 Phase II - Disassembly of Notebook Computer

The first step in preparing the duplicate notebook computers for analysis was to disassemble the computers. Before each of these units was disassembled, the model, manufacture, and the type of central processing unit (CPU) were recorded in Table 2.1. Once this information was recorded, the components from each of these computers were separated as seen in Figure 2.4. The components of the casing included the entire plastic casing of the computer, the casing of the LCD screen, and the outer battery covering. The keyboard was not included. The motherboard was the only component of the PWB that was used. The LCD screen components that were separated from the computer consisted of the plastic outer cover of the screen and the actual screen. The actual LCD screen was the only component used in this analysis.

As described above, these components were kept separately by computer and component type. As the components were separated into the proper categories as seen in Figure 2.5, the weight of each component was measured using Denver Instrument Company TL-81020 Digital Balance and placed in a plastic sealable container. After each component was weighed, the components were stored until required for testing.

When dismantling each notebook, special care was taken to remove components of the Liquid Crystal Display (LCD) screen. The LCD screen not only consisted of the screen itself, but a mercury filled lamp. The lamp was separated from the LCD screen and stored in a Rubbermaid container to prevent potential contamination of the lab and other components. The plastic casing and the PWB of the notebook computer are believed to contain the majority of the BFRs. BFRs are required for notebook computers due to the intense heat that is generated because of the compact size of the computer.

After each of the components were completely separated and grouped, the computer chips and other components were removed form the PWB. The components removed were weighed and placed in Zip-lock bags and stored until Phase III-Sample Preparation. The reason for weighing these components separately was to determine the percentage by weight of BFRs and metals in each of the analyzed components. The amount of BFRs and metals was not provided by the individual computer manufacturers and this method was determined to give the best estimate of the actual amount of these compounds.

2.3 Phase III - Sample Preparation

The first step in preparing the samples for analysis was to determine the experimental method recommended by EPA SW846 for analyzing the metals and brominated flame retardants. The method used to determine if the sample should be placed in a sanitary landfill is the USEPA Method 1311 Toxicity Characteristic Leaching Procedure (TCLP) (USEPA 1992). The TCLP test is used to simulate sanitary landfill contaminants leaching in waste samples. The test determines if the contaminants are hazardous or non-hazardous waste. The USEPA Method 1312 Synthetic Precipitation Leaching Procedure (SPLP) was also used to evaluate the affects of contaminants to groundwater (USEPA 1994). This test provides a realistic testing assessment on the mobility of metals and organics due to the affects of rain, snow and other weather elements in these landfills.

The USEPA Method 3540C Soxhlet Extraction Procedure was used as a procedure to extract all of the known BFRs that are present in each of the notebook computer components (USEPA 1996). Soxhlet extraction is a method in which there is intimate contact with the extraction fluid and the component. The contact time allows total separation of the organic material from the computer component.

Samples of the disassembled notebook computer components are prepared as required for each of the different tests defined in Table 2.2. For the TCLP and SPLP test methods, the samples are prepared so that they can pass through a 9.5 mm mesh sieve manufactured by Gibson Company, Inc. Initially, a pair of tin snips was used to cut the different components into the desired size to pass through the 9.5 mesh sieve. Later, this procedure was modified by using a band saw to cut the component pieces into the proper size to increase productivity. The different components were cut into squares so that they could pass through the 9.5 sieve as seen in Figure 2.6. When the entire sample had passed through the sieve, it was then stored in a plastic sealable bag for later testing.

When the disassembled notebook computer components were prepared as samples for the Modified TCLP and Soxhlet extraction, the LCD screen, casing, and PWB were ground so that the different components were passable through a Gibson Company, Inc.1-mm sieve. The 1-mm sieve was used to provide the greater surface area possible to insure intimate contact between the extraction fluid and the sample. Initially, the grinding process consisted of using a pair of pliers and a large Delta-Flat Bast file. Particle size reduction of the different notebook components was achieved by using pliers to hold the 1 inch squares and rubbing the square aggressively against the file. The grounded sample increased the surface area of the component to provide maximum exposure to the leaching medium. This process generated a fine powder. The pliers and file method proved to be inefficient. To speed the process, a Delta Rockwell Drill with a Roto Zip ¼" Dura Cut Bit was used to grind the squares. The use of the drill and special bit proved to be more effective for grinding the different computer components as seen in Figure 2.7. This resulted in a finely ground powder which was then stored in a plastic sealable plastic container as seen in Figure 2.8. Prior to testing each of the samples, the sealed containers were shaken to insure that the sample was completely mixed. A composite of the samples generated for each extraction method is shown in Figure 2.9.

2.4 Phase IV-Leaching Test and Extraction

A variety of test methods from EPA SW 846 were used to determine if the metals and BFRs leached from the computers' components. The following test methods were used: TCLP, SPLP, Dynamic Leach Test, Soxhlet Extraction and a Total Digestions. Each of these extraction procedures are described below.

2.4.1 TCLP

For this study, the USEPA TCLP method 1311 (USEPA 1998) was followed with only one modification. As written, this method specifies using a 100 gram sample. This quantity of sample requires large quantities of computer components as well as a large volume of extract. Typically, the liquid to solid ratio used for the TCLP is a 10:1 ratio. To insure that this reduction in sample size did not alter the test results, a liquid to solid ratio of 20:1 was maintained for this study. Due to the limited amount of sample available for the study, it was decided to scale down from the 100 gram sample required by the to a 5 gram sample to reduce the amount of computer components required for the test and to reduce the extract generated.

As required by USEPA Method 1311 and explained previously, the samples were passed through a Gilson Company Inc. 9.5 mm sieve. As written in Method 1311, a pretest is required to verify the buffering capacity of the sample to determine which extraction fluid is needed to perform the experiment. Two extraction fluids are specified, TCLP Extraction fluid #1 and TCLP Extraction fluid #2. TCLP Extraction fluid #1 was prepared by adding 5.7 mL glacial acetic acid and 64.3 mL 1N NaOH to18.2 MΩ water in a 1000mL Kimax Volumetric Flask. Extraction fluid #2 was prepared by diluting 5.7 mL glacial acetic acid with 1L 18.2 MΩ water in a 1000 mL Kimax Volumetric Flask. Extraction fluid # 1 had a pH of 4.94 and the pH of Extraction Fluid #2 was 3.05. The pH of these fluids was verified using a Fisher Scientific Accument Portable AP62 pH/mV meter electrode. Based on the pretest, all samples in this study used extraction fluid #1.

After the pretest, samples were homogenized by shaking the Zip-Lock bag, in which the samples were stored. This material was sub-sampled by weighing 5.0 + 0.05 grams of sample using a Denver Instrument Company TL-81020 Digital Balance. The sample was placed in a 100 mL HDPE sample container. One hundred mL of extraction fluid #1 was added to the sample and the sample was tumbled end-over-end for 18 hours using the apparatus shown in Figure 2.10. At the completion of this tumbling period, the 100 mL samples were vacuum filtered through a Whatman Glass Fiber Filter (GF/F) 0.70 μm filter using the filtration setup shown in Figure 2.11. After filtration, the samples were preserved by the addition of 1.0 mL ACS grade concentrated nitric acid. Each component was sampled in triplicate for the TCLP analysis by collecting three sub samples from each of the HDPE containers used to store the generated samples. Each extract was analyzed for the compounds of concern as described in Table 2.2.

To measure the amount of BFRs in the TCLP extract, a concentration step was used. The concentration procedure required the usage of a 500 mL Kimax separatory funnel filled with 300 mL of the filtered TCLP fluid and 30 mL of ACS Reagent Grade Methylene Chloride as seen in Figure 2.12. The mixture was shaken vigorously for 10 minutes. While shaking the funnel, gas pressure built up. Therefore, periodically, the gas was released from the funnel by inverting the funnel and opening the stopcock. After approximately 10 minutes of shaking, the funnel was placed in a ring stand and remained undisturbed for 2 minutes. This allowed the mixture to separate into two-phases as shown in Figure 2.12. After the two phases separated, the organics of the solution were collected in a 500 mL Pyrex beaker. The extractant from the first sub-sample was kept in the funnel while the second sub-sample was added to it. This entire procedure was performed two additional times to ensure all BFRs were extracted into the methylene chloride. When all three of the sub-samples had been added to the funnel, it was assumed that 90 mL of methylene chloride contained all the BFRs from the TCLP extraction. The methylene chloride solution in the 500 mL beaker was placed in a storage container and disposed of by the Mississippi State University Hazardous Lab. This procedure was preformed under a fume hood, because of the hazardous vapors that were produced from the methylene chloride solution.

After the TCLP extraction, the 90 mL of methylene chloride containing the BFRs was placed in a 200 mL round bottom flask and attached to the BUCHI Rota Vapor R-205 as seen in Figure 2.13. The rota vapor was then lowered into a 40oC water bath as seen in Figure 2.14. The boiling point of methylene chloride is 40ºC. Therefore, the methylene chloride quickly evaporated. The evaporation was allowed until about 1 mL of the sample remained in the flask. The sample was then removed from the flask and added to a Target DP Vial, which was filled to insure no headspace existed. These concentrated samples were stored at 4º C until required for analysis.

2.4.2 Modified TCLP

The Modified TCLP follows the USEPA Method 1311 TCLP procedure as described in the previous section with one exception. For this test, the samples were prepared by grinding the samples into a fine powder using a Delta Rockwell Drill with a Roto Zip ¼" Dura Cut Bit and then passed through a 1 mm sieve as seen in Figure 2.7 and 2.8. Thus, the Modified TCLP samples are much smaller than the 9.5 mm samples specified for the TCLP. The samples were analyzed as described in Table 2.2. The concentration procedure was also followed for the BFRs as described above in the TCLP method.

2.4.3 SPLP

The SPLP is designed to evaluate the leaching potential of metals and other sample constituents under acid rain conditions. EPA SPLP method 1312 (USEPA 1998) was followed with one exception. As discussed with the TCLP method, 5.0+ 0.05 grams of sample was extracted rather than the full 100 grams of sample as described in method 1312.

For the SPLP, one of two possible extraction fluids can be used depending on where the waste originates. If the waste originated east of the Mississippi River, then the pH of the extraction fluid should be 4.5. If the waste originated west of the Mississippi River, then the pH should be 5.0. Extraction fluid #1 (east of the Mississippi River) consisted of a 60/40 wt% sulfuric/nitric acid mixture diluted with 18.2 MΩ water to a final pH of 4.20 + 0.05. Extraction fluid #2 (west of the Mississippi River) consisted of a 60/40 wt% mixture of sulfuric/nitric acid diluted with 18.2 MΩ water to a final pH of 5.00 + 0.05. For this study, it was decided to use the more aggressive extractant. At a pH of 4.20, SPLP Extraction fluid # 1 was used for all tests.

As described previously, notebook computer components (printed wire board, casing, and LCD screen) were prepared for the SPLP extraction by initially passing the components through a 9.5 mm sieve. The sample was placed in a 100 mL HPDE container and 100 mL of extraction fluid #1 was added to the container. The sample was then tumbled for 18 + 2 hours as seen in Figure 2.9. After tumbling, the samples were filtered using a Whatman GF/F 0.70 µm filter as seen in Figure 2.11. The samples were analyzed as described in Table 2.2 for metals and BFRs. The samples were preserved by the addition 5.0 mL of concentrated nitric acid. The concentration procedure was followed as described above in the TCLP method for the BFR components. Upon completion of the experiment, the samples were extracted and stored in a 4oC refrigerator for no longer than 24 hours for analysis.

2.4.4 Total Extraction

For this study it was desired to measure the total BFRs and metals contained in the computer components. EPA method 3540C, a Soxhlet extraction procedure, was selected for the extraction of BFRs. A photo of the Soxhlet extraction setup can be seen in Figure 2.15. A summary of the method used is as follows.

There are four different solvent systems specified in method 3540C that can be used for the extraction: Methylene Chloride, Acetone/Hexane, Methylene Chloride/Acetone, and Toluene/Methanol A.C.S. Grade. Reagent grade methylene chloride was chosen as the extraction solvent because it was considered to be the most aggressive solvent and capable of removing all the BFRs from the sample matrix.

To initiate the total extraction procedure, first the computer components (PWB, casing, and LCD screen) were prepared by grinding the samples as previously described until passable through a 1 mm sieve. See Figures 2.7 and 2.8. After the sample was completely ground, 10 grams of the sample was weighed and added to a Whatman 26mm x 60mm cellulose extraction thimble. Next, 300 mL of methylene chloride was measured using a graduated cylinder, and then added to a round bottom flask. The filled flask was connected to the soxhlet extraction apparatus, and one/two boiling chips were added to the flask. The Whatman extraction thimble was then inserted into mouth of the soxhlet extraction apparatus. The condenser was attached and the apparatus was refluxed for 24 hours. Upon completion of the 24 hour run, the soxhlet extraction apparatus was disassembled. Three samples were taken from the flask and stored at 4°C until further analysis. The data measured in the soxhlet extraction is provided in Table 2.2

2.4.5 Total Digestion

To measure the total amounts of metals contained in the computer components, USEPA Method 3051 for a Microwave Assistance Acid Digestion was followed. The test was performed by first weighing 0.5 g of sample into a microwave digestion vessel. 10 mL of concentrated nitric acid was added to the sample. The vessel was then placed in a microwave and heated to 185 °C for 15 minutes. The samples were cooled and vacuum filtered using Millipore HA 0.45µm filters. The filtrate was analyzed for the metals as seen in Table 2.2 using USEPA Method 6010B.

2.4.6 Dynamic Leach Test

The Dynamic Leach Test (DLT) is a benchtop testing procedure that simulates typical landfill conditions that computers would be exposed to after disposal. The Dynamic Leach Test is less aggressive than the TCLP or SPLP test. This test was developed to overcome the shortcomings of the TCLP method when applied to E-Waste. The DLT was preformed at the civil engineering laboratory at Jackson State University by Dr. Yadong Li as part of a research project entitled "Study of E-waste Environmental Hazards and Treatment" funded by the National Science Foundation. The data from this study was incorporated into our analysis.

Two motherboard, MB-21 (IBM with 286 CPU) and MB-22 (Hewlett Packard with a Pentium II), from two desktop computers, IBM with 286 CPU and Hewlett Packard with a Pentium II, were used in the DLT test. These two computers were donated with a group of computers to Jackson State University. These computers were believed to have a high concentration of heavy metals on the Printed Wire Board (PWB) that would leach in large amounts when exposed to the environment.

The motherboards were rinsed with deionized water to free any dirt that was on its surface, and then placed on top of supports built inside of the DLT container. These supports allowed the extraction fluid to flow freely and the PWB to be complete submerged. The container, which can be seen in Figures 2.16 and 2.17, was constructed of high-density polyethylene (HDPE). It was filled with TCLP extraction fluid # 1 at a liquid-to-solid ratio of 10:1. The PWB was submerged and allowed to leach inside of the container for 3 to 10 days. After each leaching cycle, the leachate was replaced with fresh extraction fluid. Samples of the DLT extraction fluid were collected at the end of each cycle and analyzed for BFRs and Metals according to the methods presented in Table 2.2.

2.5 Phase V-Analytical Methodology

2.5.1 ICP-OES

A Perkins Elmer ICP-OES (Inductive Coupled Plasma-Optical Emission Spectrometer) DL 4300 was used in the analysis of the metals in this study. This analysis followed USEPA Method 6010B, as seen in Table 2.2. The ICP-OES was used to measure the metal concentrations in the aqueous samples produced from the following tests:

- TCLP
- SPLP
- Total Digestions
- Dynamic Leaching Test

In preparing the aqueous samples for analysis, a pipette was used to remove 2.5 mL of the sample, and it was placed into an ICP Vial as seen in Figure 2.18. The aqueous samples used for this method had previously been filtered to make sure that no solids were present. After the sample had been added to the ICP Vial, 1 mL of Yttrium was added to it. The Yttrium was used as the internal standard because of its limited availability in the environment and to help establish a baseline for the QA/QC because of its known quantity added to the vial. A 5% HNO3 solution was also added to the solution to complete the sample preparation. It was added to the 10 mL mark on the ICP vial.

After the ICP was allowed to initialize as shown in Figure 2.19, the operating parameters of USEPA Method 6010B were loaded and the system was calibrated. The machine was calibrated to insure that the standard used fit the calibration coefficient of 0.9995. The multi-element calibration solution ranged from 10 ppm to 0.5 ppm. The concentrations of the standards used for the analysis of these elements can be seen in Table 2.3. This provided more accurate data and also allowed the calibration to use the correct wavelength for each of the elements analyzed as seen in Table 2.4. The lines of the ICP were flushed to free any waste in the lines. The torches, fittings, and nebulizer chamber were also cleaned and checked before the analysis began.

2.5.2 GC/ECD

A method developed by Andreas Sjodin was intended for the analysis of brominated flame retardants (Sjodin 1999). Sjodin's method specified the use of a Gas Chromatograph with Electron Capture Detector (GC/ECD). Sjodin developed the method for the analysis of polybrominated diphenyl ethers in blood from Swedish workers. The three groups of Swedish workers evaluated during this study were individuals employed at an electronic dismantling plant, clerks working full-time at computer screens and hospital cleaners. The hospital cleaners were the control group. The method was used to measure the amount of PBDEs present in the blood of the clerks working full-time at computers screens and personnel at an electronic-dismantling plant.

A Gas Chromatograph with Electron Capture Detector (GC/ECD) was not available for use in our study. Therefore, it was decided to use the Hewlett Packard 5890

Series II/ Hewlett Packard 5972 with EI source Gas Chromatography with Mass Spectrometry (GC/MS) for the analysis of the BFRs. After an initial run, this method was not used because there was too much background noise that caused interference with the results.

Although the method developed by Sjodin was not used, it was instrumental in developing the method for analyzing the BFRs in the notebook components. The method used to measure the BFRs in the notebook computers was based on Sjodin's method for analyzing the PBDEs in the Swedish workers blood with some modifications. The modifications made to the method were as followed:

- Mass Spectrometry used instead of the Electron Capture Detector.
- The carrier gas used was Helium
- The injector
- Oven temperature

The details of these modifications are listed in Table 2.6. The other operating conditions were used as stated in the method used by Anderas Sjodin as seen in Table 2.5.

The Agilent 6890 Gas Chromatograph equipped with a 7673 autosampler and an Agilent 5973 Mass Spectrometry was used for the analysis of BFRs. This aspect of the research was carried out at Jackson State University's Civil Engineering Department by Dr. Yadong Li and Ms. Hongbin Yang, a fellow from Xiamen Environmental Monitoring Center, Xiamen P.R. China.

The samples used in the analysis were prepared at Mississippi State University following the sample preparation methodology as discussed in Section 2.6.4 and stored at 4ºC until readied for analysis. The samples were then transported to Jackson State

University bi-weekly to be analyzed. However, once the data was quantified, it was determined that the results produced were below the detection limit of the GC-MS. The GC-MS used had a detection limit of 15 ppt.

2.5.3 QA/QC

The QA/QC performed for the analysis of metals and BFRs included duplicates, matrix blanks, and method spikes. Since Yttrium does not naturally occur in the environment, it was used as the internal standard to help establish a baseline, and it was used as the matrix blanks in the analysis for metals. The same QA/QC procedure was used when analyzing for the organic material housed in the notebook computer components, as well as when measuring the metals in the LCD screen, casing and the printed wired board.

To further the QA/QC for these samples, a matrix blank and method blank was analyzed every ten samples. Duplicates and Spikes were used as a means of checks in the ICP analysis. These checks were used every five samples to verify that there was no contamination and that the samples were being analyzed properly.

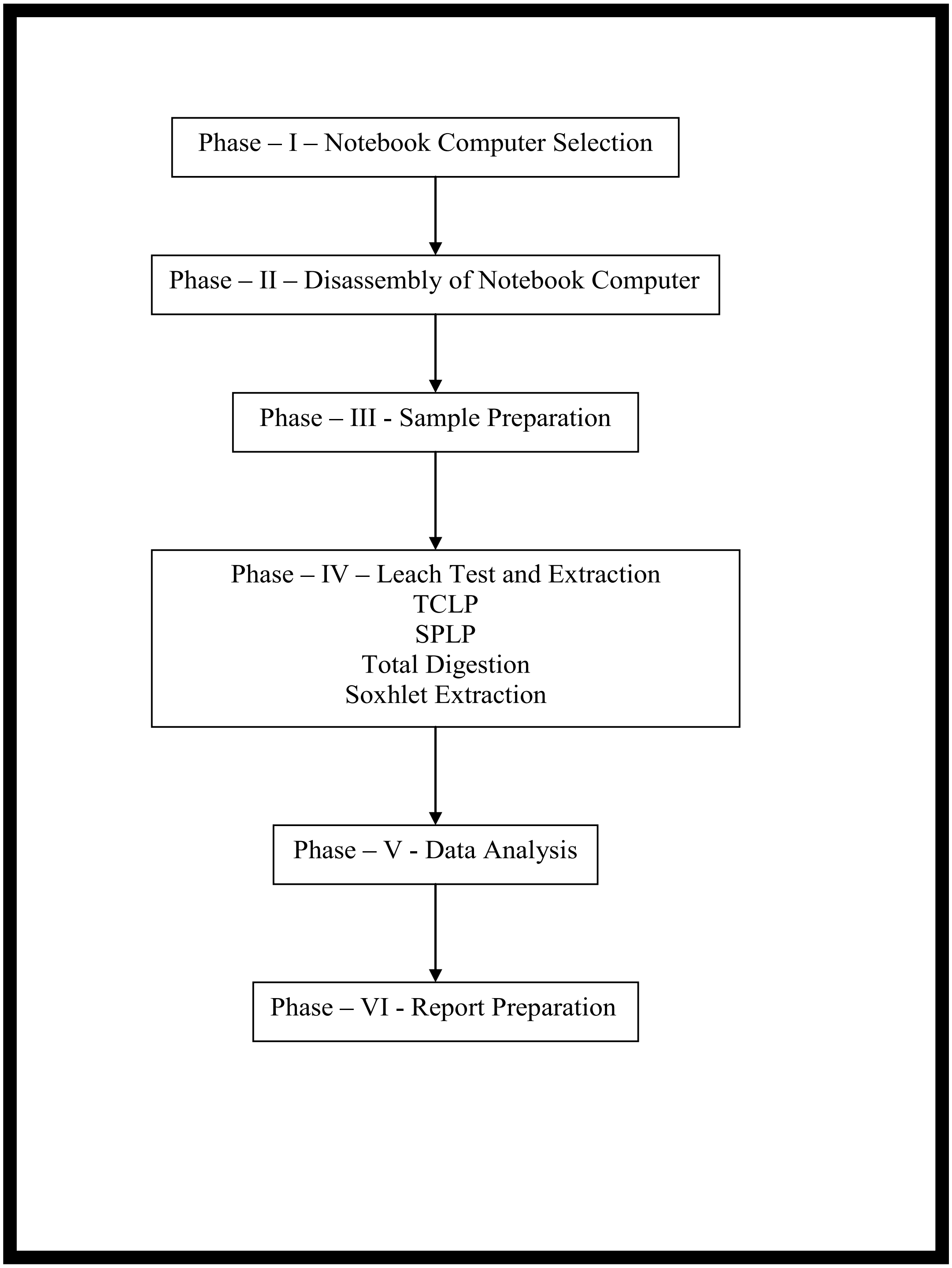


Figure 2.1 The Overall Treatablity Study Approach Flowchart

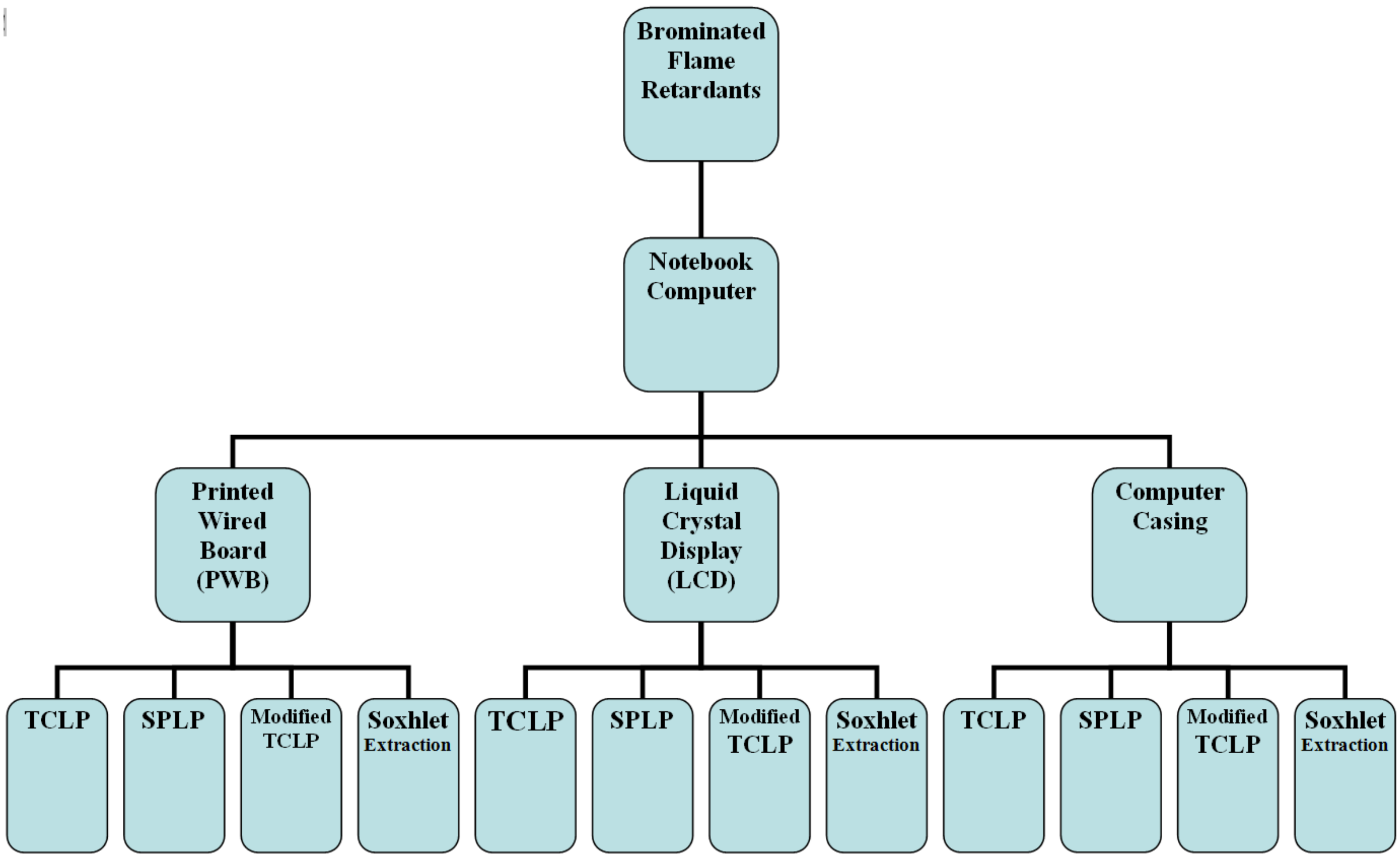


Figure 2.2 Treatablity Study of BFRs Flowchart

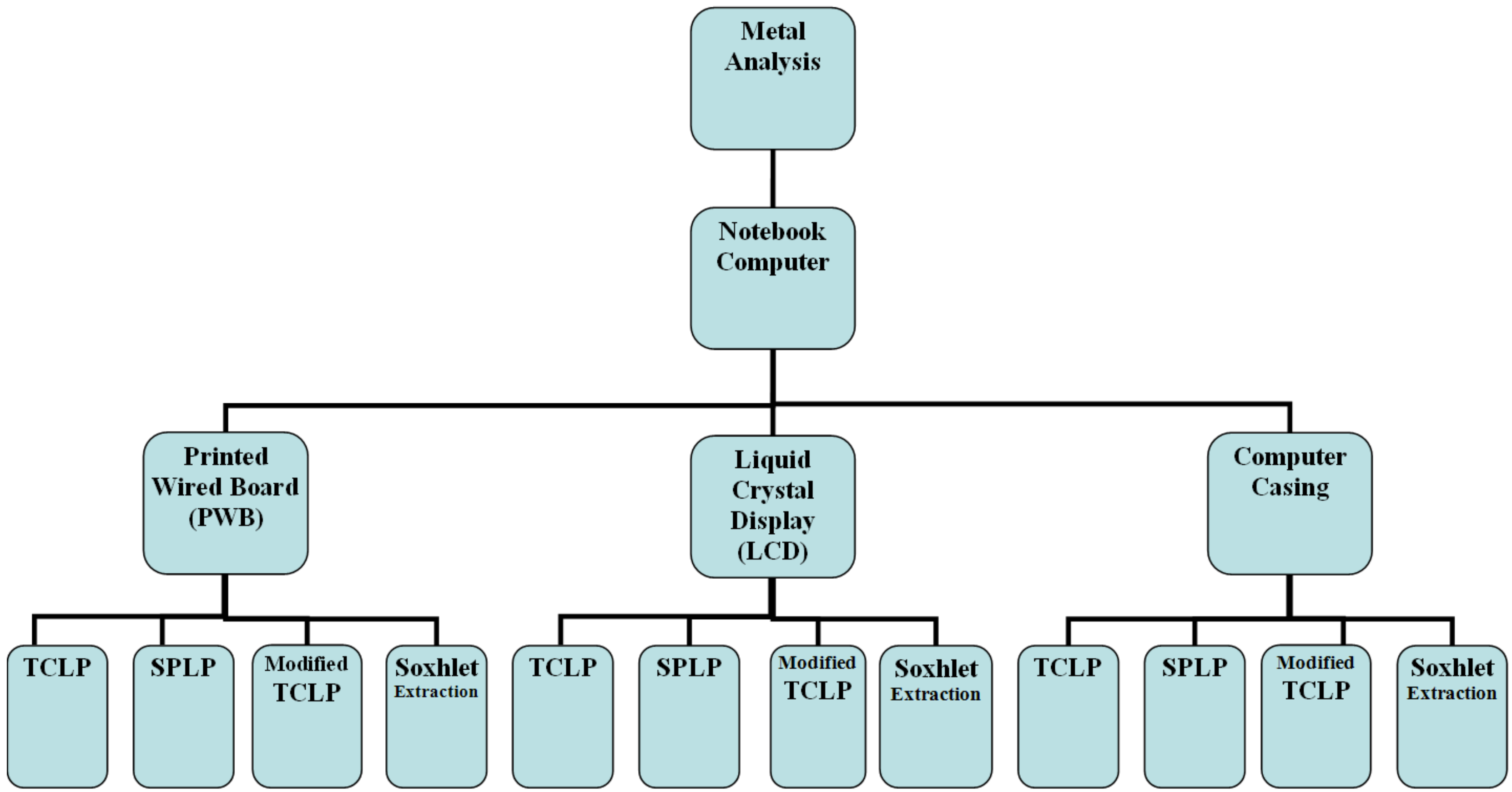


Figure 2.3 Treatablity Study of Metals Flowchart

Figure 2.4 Grouping of Various Notebook Computer Components

Figure 2.5 Disassembly of Notebook Computer

Figure 2.6 Pieces of Cut Samples

Figure 2.7 Grind Procedure of Casing Component

Figure 2.8 Grinding Procedure Used for Samples

Figure 2.9 Composite of PWB, LCD screen and Casing Samples Used In Experiments

Figure 2.10 TCLP Tumbler

Figure 2.11 TCLP Vacuum Filtration System

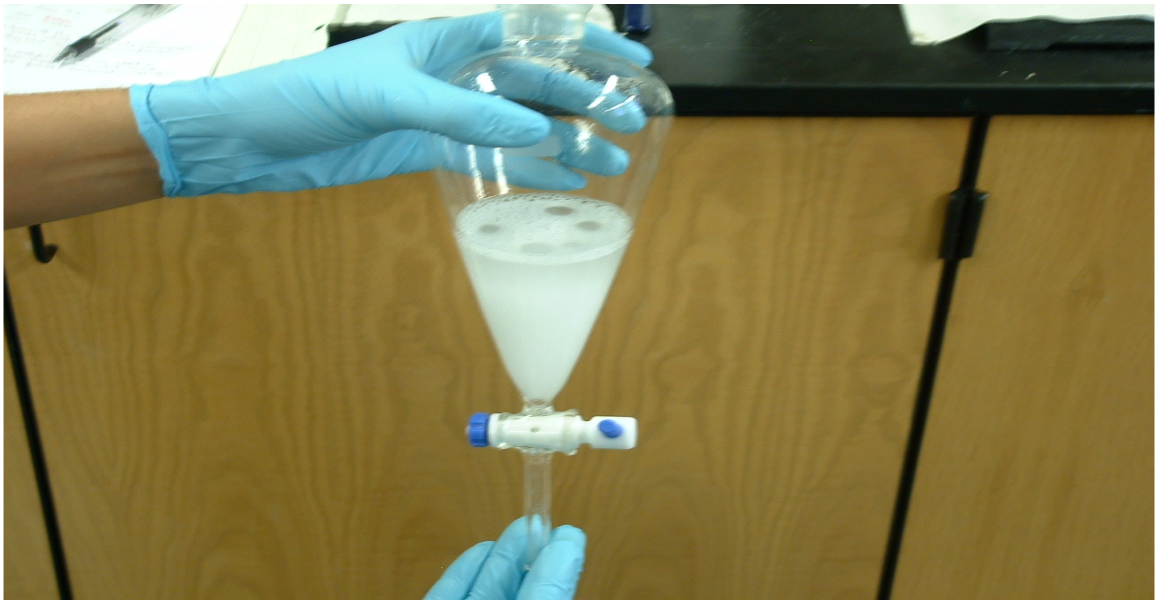


Figure 2.12 Concentration of TCLP, SPLP and DLT Samples for BFR Analysis

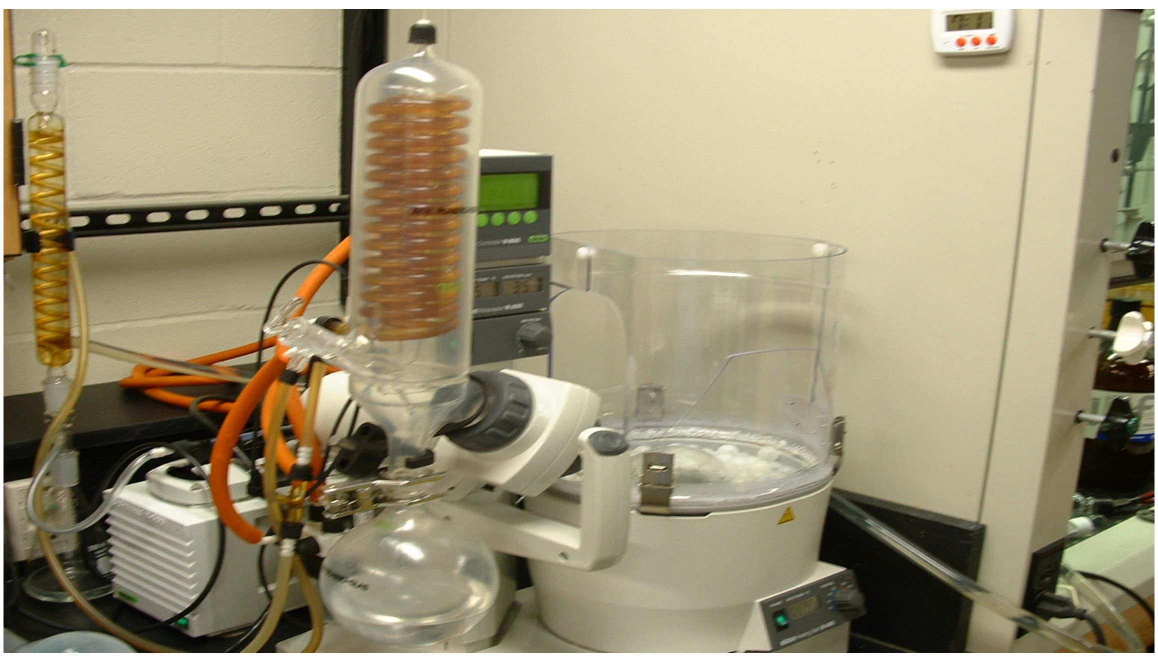


Figure 2.13 BUCHI Rota Vapor R-205 Used for the BFR Sample Preparation

Figure 2.14 BUCHI Rota Vapor R-205 Water Bath

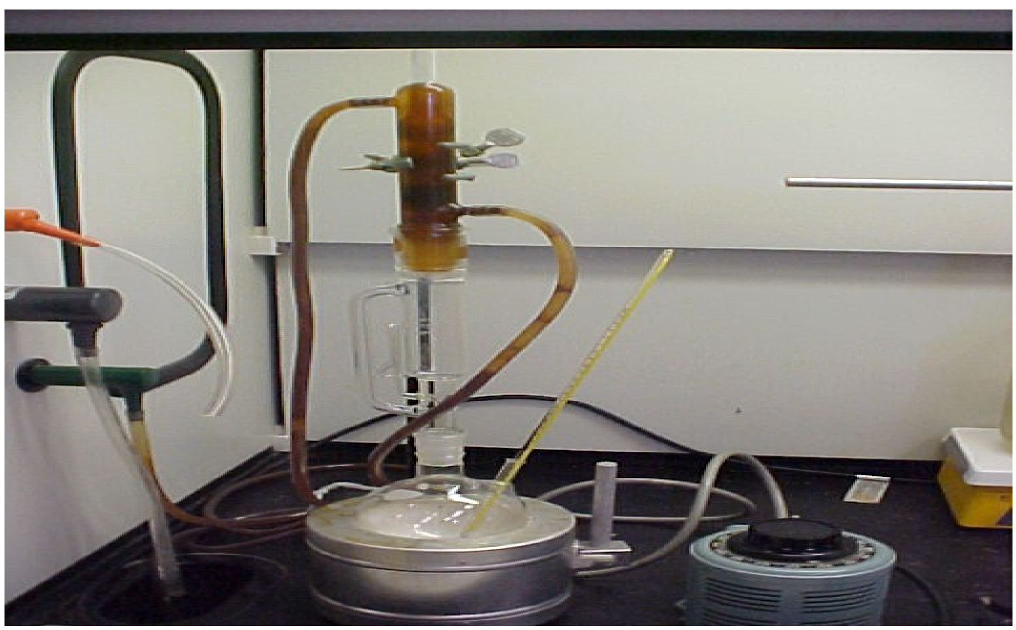


Figure 2.15 Soxhlet Extraction Apparatus

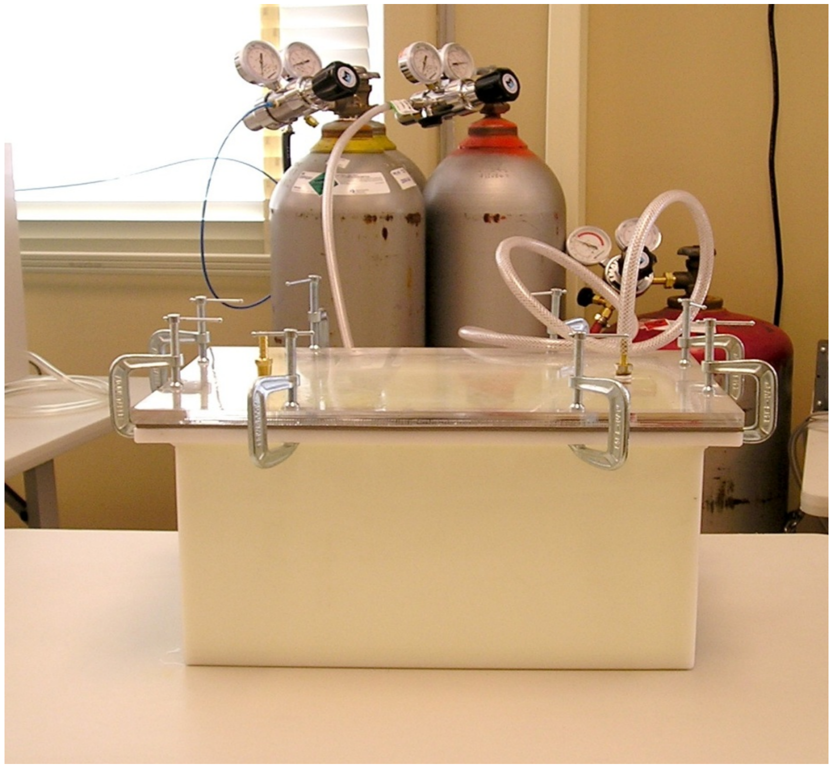


Figure 2.16 Dynamic Leach Test Apparatus

Figure 2.17 Top View of Dynamic Leach Apparatus with a PWB

Figure 2.18 ICP Sample Preparations

Figure 2.19 Initializing

Table 2.1 Details and Description of Notebook Computers Used in This Study

Study Identification Number	Manufacturer	Model	CPU
LP-6	IBM	ThinkPad 365X	486 DX4
LP-7	Gateway	Gateway 2000 Solo	Intel
LP-8	Compaq	Contura 4125	Intel
LP-9	Macintosh	PowerBook Duo 230	Power PC Chip
LP-10	IBM	ThinkPad 390E	Intel

Table 2.2 Extraction Methods and Analytical Procedures for Each Test

Extraction Method	**Sample Preparation**	**Analytical Test**	**Analytes**	**Analytical Techniques**
TCLP	EPA 1311 (USEPA 1992)	Metal	Sb, Al, Ba, Be, Cd, Cr, Cu, Au, Fe, Pb, Ni, Sn, Zn BFR*	EPA Method 6010 (USEPA 2007)
		BFR		GC/MS (Sjodin 1999)
Modified TCLP	EPA 1311 (USEPA 1992)	Metal	Sb, Al, Ba, Be, Cd, Cr, Cu, Au, Fe, Pb, Ni, Sn, Zn BFR*	EPA Method 6010 (USEPA 2007)
		BFR		GC/MS (Sjodin 1999)
SPLP	EPA 1312 (USEPA 1994)	Metal	Sb, Al, Ba, Be, Cd, Cr, Cu, Au, Fe, Pb, Ni, Sn, Zn BFR*	EPA Method 6010 (USEPA 2007)
		BFR		GC/MS (Sjodin 1999)
Soxhlet Extraction	EPA 3540C (USEPA 1996)	BFR	TBBPA, 2,2', 4',4'5 penta BDE, 2,2'4',4',6' penta-BDE; deca-BDE	GC/MS (Sjodin 1999)
DLT	-------	Metal	Sb, Al, Ba, Be, Cd, Cr, Cu, Au, Fe, Pb, Ni, Sn, Zn	EPA Method 6010 (USEPA 2007)
		BFR		GC/MS (Sjodin 1999)
Total Digestion	EPA 3051A (USEPA 2007)	Metal	Sb, Al, Ba, Be, Cd, Cr, Cu, Au, Fe, Pb, Ni, Sn, Zn	EPA Method 6010 (USEPA 2007)

BFR* -TBBPA, 2, 2', 4', 4', 5-penta BDE, 2, 2', 4', 4', 6-penta, deca-BDE, 2,4,4-triBDE, 2,2',4,4'-tetraBDE, 2,2'4,4',5,5'-hexaBDE, 2,2'4,4'5,6'-hexaBDE, 2,2'3,4,4',5'6-heptaBDE

NOTE: A composite photo of the different types of samples used in each analysis can be seen Figure 2.9

Table 2.3 Concentrations of Standards

Element	Concentrations of Standards (ppm)		
Sn	10	1	0.1
Au, Ba	1	0.5	0.1
Be	1	0.5	0.1
Cu, Sb	1	0.5	0.1
Zn	5	1	0.1
Ni, Pb, Fe	10	1	0.1
Al	10	5	1

Table 2.4 ICP Measured Wavelengths

ICP Measured Wavelength	
Element	**Wavelength**
Au	267.60
Ba	493.41
Be	313.11
Cu	327.39
Fe	238.20
Ni	231.60
Sb	206.84
Sn	189.93
Y	371.03
Zn	206.20

Table 2.5 Gas Chromatography Experimental Conditions

GC Condition	
GC:	Agilent 6890 Gas Chromatograph with 7673 autosampler
Column:	DB-5MS 30m×0.25mm×0.1μm
Carrier Gas:	Helium at 1.2 mL/min
Oven:	310ºC; 100 ºC for 1 min 20 ºC /min to 310 ºC hold for 13min
Injector:	Cool-on-column, over-track mode
Detector:	Agilent 5973 MS

Table 2.6 Sjodion Gas Chromatography Experimental Conditions

GC Condition	
GC:	Varian 3400 Gas Chromatograph
Column:	DB-5 30m×0.25mm×0.25μm
Carrier Gas:	Hydrogen at 38 cm/sec at 100 ºC
Make Up Gas:	Nitrogen
Oven:	80ºC for 2 min; 10ºC/min to 300 ºC for 6 min
Injector:	Splitless mode
Detector:	Electron Capture Detector

(Sjodion 1999)

CHAPTER 3

RESULTS AND DISCUSSION

The purpose of this study was to determine the leachability of metals and BFRs from the components of selected notebook computers. This will aid in the understanding of what measures should be taken to reduce the leaching of toxic contaminants into the environment as a result of computer disposal. The results generated in Phase IV (Leaching Test and Extraction) and Phase V (Data Analysis) of this study are divided and discussed by metals and BFRs in the following sections.

3.1 Totals Metals

As discussed previously, each computer was separated by three groups by components, which include PWB, casing, and LCD screen and subjected to total metal analysis. These samples were produced using USEPA Method 3051 for digestion. The purpose of this portion of the data analysis was to determine the total metals contained in the PWB, LCD screen, and casing of the notebook computers tested. The following sections will provide the results of the total analysis for each notebook component. Table 3.1 is a summation of all the metals extracted from each computer component, totaled for all the computers tested. Thus, Table 3.1 shows that Ba, Cu, Ni, Pb, and Zn were present in large quantities in the computer components used in this study. However, there were several metals present in the notebook computer components in minute concentrations. The detection limits for these metals can be seen in Table 3.2. These metals were present in such small amounts that it is suspected that the environmental impact from these metals will be limited, and thus these metals are not discussed further in this report.

While several metals were present in the notebook components, only six were selected as focus metals for this study: Ba, Cu, Ni, Pb, Sn, and Zn. These metals were selected for discussion because they are the contaminants of concerns (COCs) most commonly used in the makeup of notebook computers. While Fe and Al are present in all computers at high levels these two metals are not typically considered toxic. Thus, the discussion of Fe and Al is limited.

3.1.1 Total Metals in PWBs

Figure 3.1 presents the six COCs contained in the PWB of each notebook computer tested. Unlike Table 3.1, Figure 3.1 presents the total metals in each computer separately. Please note that the data presented in Figure 3.1 are the average of three replicate samples. The raw data for each individual sample is presented in Appendix B.

As shown in Figure 3.1, of the COCs tested, Cu and Pb were present in the PWB at the highest concentrations; however, there were also considerable amounts of Ba, Ni and Zn. Cu was extracted at concentrations ranging from approximately 200,000 to 155,000 mg/kg throughout the entire range of notebook computers evaluated. This can be attributed to the fact that Cu is a major metal component in the manufacturing of a PWB due to its highly conductive properties. It should be noted that LP-8 (Compaq Contura 4125) has the least amount of Cu when compared to the other notebook computer studied. This suggests that manufacturers of Compaq computers use less copper than the other computer manufacturers studied. Figure 3.2 was prepared using the same data used to generate Figure 3.1 for the PWBs, however, this figure was generated to show the overall composition of each metal in the PWB. As shown in Figure 3.2, Cu represented 82% of the overall metal composition present in the PWB. The metal with the second largest contribution to the PWB is Pb, which is 12% of the total metal present in the PWB. This raises concern because Pb is very toxic in the environment. Fe and Al also contribute a considerable portion of the total metals but are not included as part of Figure 3.2. Fe and Al were not discussed further due to the negligible concentration of each metal present in the TCLP leachate, as discussed later in a later section. It should be noted that the combined percentage of Cu and Pb account for 94% of the total metals presented in this figure. It can be suggested that the manufacturers of the notebook computers evaluated in this study used large amounts of Cu and Pb in the manufacturing of the PWB.

Figure 3.3 presents the same data as presented in Figure 3.1, without Cu plotted. This allows the vertical axis to be adjusted to better illustrate the concentrations of other the metals present in the PWB. Figure 3.3 clearly shows that there are considerable amounts of Ba, Ni, Pb, and Zn contained in the PWB. This figure illustrates that while Pb is in all PWBs, the notebook computer type is a major factor contributing to the Pb concentration. Three notebook computers (LP-6, LP-8, and LP-10) have over 25,000 mg/kg of Pb, and two notebooks computers (LP-7 and LP-9) have less than 16,000 mg/kg of Pb. The combined concentrations of Ba, Ni, Pb and Zn accounted for 24% of the total metals present in the PWB (Figure 3.2). Of all the computers studied, LP-9 (Macintosh Power Book Duo 230) has the least amount of Pb present when directly compared to of the other notebook computers analyzed in the study (Figure 3.3). It is suggested that LP-

9 will have lower TCLP and SPLP concentrations (later discussed in detail) in the leachate of these tests due to the almost 30% lower amount of Pb in the PWB when compared to the other notebook computer tested.

Figure 3.3 presents the total concentration of metals present in the PWBs of all the notebook computers tested. This figure indicates that the PWB of LP-6 (IBM ThinkPad 365X) has the highest concentration of Zn when compared to the entire group of notebook computers tested. LP-6 also has considerable amounts of Pb present in the PWBs, however, LP-10 has more Pb present in the PWB when compared to LP-6 according to Figure 3.3. As previously discussed, LP-6 has the largest amount of Cu present in the PWB when compared to the other notebook computers tested. Based on this information, it is postulated that LP-6 has the highest concentration of metals of the computers studied.

According to the State of California Code of Regulations Title 22 §66261.24 regarding hazardous waste, if a waste has a concentration that exceeds or equals to Total Threshold Limit Concentration (TTLC) it falls in the category of hazardous waste. This limit is also used along with the federal regulated USEPA TCLP test to be classified a waste as hazardous by the state of California. The metals and the TTLCs of California are Pb (1,000 mg/kg), Ni (2,000 mg/kg), and Zn (5,000 mg/kg) (Code 2004). When compared to the total metals present in the PWBs, all of the PWB tested would be classified as hazardous waste because each exceeded the total amount of Cu (> 170,000 mg/kg) and Pb (>14,000 mg/kg) allowed by the TTLC for waste. Ni also exceeded, in total amount, the California TTLC for all of the PWBs with the exception of LP-8 (>1500 mg/kg). Zn, on the other hand, exceeded the TTLC for only one of the PWBs tested, LP-

6 (>23,688 mg/kg). Each of the PWB tested would be considered hazardous because of the total amounts of Cu, Pb, Ni, and Zn present.

3.1.2 Total Metals in LCD Screen

Total metal analyses were also conducted for the LCD screens of the computers. Figure 3.4 summarizes the total amount of metals present in the LCD screens of the notebook computers tested for this study. As presented in Figure 3.1 and 3.3, Figure 3.4 is the average across three replicate samples. The raw data for each sample is presented in Appendix C. Figure 3.4 shows that there are considerable amounts of Pb in LCD of LP-8, Ni in LCD of LP-9, and Ba in LCDs of both LP-7 (Gateway Solo 2000) and LP-10 (IBM Thinkpad 390E). Sn and Zn are equally abundant in the LCD screens of the entire group of notebook computers tested. A study performed by the California Department of Toxic Substances Control, trace amounts of metals were found in LCD screens (California 2004). However, from the data generated from this study, significant amounts of metals were found. When compared to the PWB, the metal concentrations are much lower, generally by at least one order of magnitude. The metals concentrations of the LCD screens would be considered hazardous when compared to California TTLC limits for hazardous waste. It appears that the majority of toxic metals contained in the notebook computer can be attributed to the PWB components.

Figure 3.5 is similar to Figure 3.2 for the PWB, where the metal concentrations in the LCD screens are summed for all the computers tested. While the concentration of metals was low in the LCD screens when compared to the PWB, when the LCD screens are compared as a group, Cu accounts for the majority of metals found in the screens. Cu accounts for 45% of the total amount of metals present. The average amount of Sn and

Zn, combined with Cu accounts for over 90% of all the metals contained in the LCD screen. Figure 3.4 shows that LP-6 and LP-8 have the highest level of Cu in the LCD screens compared to the other computers. This suggests that the manufacturers of LP-6 (IBM Think Pad 365X) and LP-8 (Compaq Contura 4125) use large amounts of Cu in the production of LCD screens.

Figure 3.4 also shows that LP-8 (the Compaq Contura 4125) has the highest amount of Pb (380 mg/kg) and Sn (50 mg/kg) compared to the other computer screens. LP-8 has more than 95 times the amount of Pb than the other notebook computers, which average 4 mg/kg of Pb in the LCD screen per notebook computer.

In general, the low concentration of metals in the LCD screens should not present a significant environmental concern. However, the amount of Pb present in LP-8 does draw concern and further evaluation is needed. The ranking of the notebook computers tested that have the largest amount of metals present in the LCD Screen is as follows: LP-8 > LP-6 > LP-9 > LP-7 > LP-10.

3.1.3 Totals Metals in Casing

Figure 3.6 is used to summarize the total amount of metals present in the casing of the notebook computers tested in this study. The raw data for each individual sample is presented in Appendix D. As observed in Table 3.1, the concentration of the metals found in the casing, while higher than those in the LCD screens, are much lower than those found in the PWBs. As seen in Figure 3.6, there were very low amounts of Pb present in the computer casings. However, a large quantity of Ni was found in the casings of LP-6, LP-7, and LP-9. As illustrated in Figure 3.6, LP-6, LP-7, and LP-9 each contain more than 1300 mg/kg of Ni. When compared to Figure 3.7, which provides the total percentage of metals present in the casings of all of the tested notebook computers, Ni accounts for 67% of the total metals present. It can be concluded from the Figure 3.6, that the manufacturer of LP-6, LP-7 andLP-9 uses high concentrations of Ni in the production of their casings. It should be noted that the amount of Ni in LP-9 (4,250 mg/kg) exceeded the TTLC for the state of California. This would make the casing of LP-9 hazardous waste.

As illustrated in Figure 3.6, a large amount of Ba was also present in the casing of LP-6 (580 mg/kg), but it was found at much lower concentrations in the other notebook computers tested. As shown in Figure 3.6, LP-6 contains a large portion of the total Ba (580 mg/kg) and Ni (1,370 mg/kg) present in the casing of notebook computer tested. It can be suggested that the manufacture of the IBM ThinkPad 365X uses large amount of Ba and Ni in the production of the casing of their notebook computers.

3.1.4 Summary

In summary, when comparing the overall metal composition present in the notebook computer components, the ranking of the components are PWB > Casing > LCD screen. As indicated in Table 3.1, the PWB contains more than 550 times more metals than the Casing and LCD screen. The casing and the LCD screen only account for 1% of the total amount of metals in the tested notebook computers.

For clarification, Figure 3.8 presents the total percentage of metals in each of the notebook components analyzed. This figure is based on the data in Table 3.1 which summarizes the total amount of metals found in the notebook computers tested. Figure 3.8 shows that Cu makes up 82% of the total amount of metals present in the PWB. However, when compared to the other tested components, Cu makes up 13% of the total metals present in the LCD screen and 3% in the notebook computer casing. This figure also indicates that Pb has the second highest presence in the tested computer components. Pb in the PWB accounts for 11% of total metals present, 21% in the LCD screens and 1% in the casing.

Table 3.3 shows the total weight of the notebook computers and the tested components. As previously discussed, Figures 3.1 and Figure 3.3 presents the actual amount of Pb in the PWB of each notebook computer. Comparing these figures and Table 3.2, it can be determined that the actual amount of Pb present in the PWB for each computer is as followed: LP-6 (6 g, 3.0% of the total weight of the PWB), LP-7 (4 g, 2.0% of the total weight of the PWB), LP-8 (5 g, 3.0% of the total weight of the PWB), LP-9 (3 g, 2.0% of the total weight of the PWB), and LP-10 (7 g, 3.0% of the total weight of the PWB). Each of these weights was calculated using the actual weight of the PWB for each notebook computer (Table 3.2) and the total amount of Pb in each PWB (Figure 3.1 and Figure 3.3). This data will provide a better understanding of how much of the metals was leached during the TCLP, SPLP, and DLT tests. As discussed earlier, the all of the tested PWBs would be classified as a hazardous material based on the State of California TTLC regulatory limits. The total amount of Cu, Pb, Ni and Zn present exceeded the concentration allowed in the environment. It should also be noted that the casing of LP-9 would be also classified as a hazardous waste because the concentration of Ni exceeded 2000 mg/kg. As explained in the previous section, the PWB is expected to leach the highest concentration of metals.

3.2 Leaching of Metals in TCLP Test

For this study, the TCLP was also used to determine the concentration of metals that leached from each of the notebook components. As explained in the Materials and Methods section of this report, the TCLP test is a regulated method for hazardous waste classifications. As observed for the total COC metals in notebook component, the LCD screen and casing concentrations are at much lower levels than the PWB. Processing of the LCD screen and casing was difficult and the quantities of these materials were limited. As a result of a large portion of each being used for the analysis of the BFRs in an early phase of this study, the TCLP tests were limited to the PWBs.

3.2.1 Leaching of Pb

Figure 3.9 shows the total concentration of metals that leached from the PWB during the TCLP test. It can be determined that Pb leached from each notebook computer at higher concentrations than any of the other metals tested. All of the notebook PWBs tested leached Pb at concentrations greater than 43 mg/L, which exceeded the concentration limit of Pb classifying it as hazardous. The concentration of Pb classifying it as hazardous by EPA is 5.0 mg/L. A line was drawn in Figure 3.9 to indicate the Pb concentration limit of 5.0 mg/L set by EPA. The concentration of Pb that leached from the PWB was more than 8 times the minimum amount set by EPA.

It should also be noted that Ba is the only other TCLP metal that leached at elevated levels from the PWB. The minimum concentration of Ba set by EPA to classify a waste as a hazardous waste is 100 ppm (100 mg/L). However as shown in Figure 3.9, the actual concentration that leached from the PWB was less than 4.0 mg/L, which does not exceed the hazardous waste classification limit. As a result, this discussion will focus on Pb due to the hazardous concentrations of Pb that leached from the PWBs of each notebook computer.

As discussed in section 3.1.1., the state of California has regulatory limits to determine if a material should be classified as hazardous based on the total amount of metals present. The regulations also have limits if the concentration exceeds the allowable soluble threshold limits concentrations (STLC) when the Waste Extraction test (WET) is preformed. It should be noted that these limits are similar to the TCLP conditions. However, the STLC covers other metal concentrations that are not regulated for TCLP. For the metals tested, California regulates the STLC for Ba (100 mg/L), Cu (25 mg/L), Pb (5.0 mg/L), Ni (20 mg/L), and Zn (250 mg/L). Pb was the only metal that leached in concentrations that exceeded the STLC. It exceeded the allowed concentrations by 8 times the STLC limit. In conjunction with the TCLP test, Pb would be classified as a hazardous waste.

Figure 3.10 is used to illustrate the actual percentage of Pb present in the PWB that leached during the TCLP test when compared to the total amount of Pb present in the PWB. According to Figure 3.10, LP-9 leached a maximum of 3.4% (478 mg/kg) of the total amount of Pb in the notebook computer PWB. In comparison, LP-10 (IBM ThinkPad 390E), which had the highest concentration of Pb present in the PWB (Figure 3.1), only leached 1.6% (515 mg/kg) of the total amount of Pb; the lowest amount of Pb leached. It can be suggested that although LP-9 (IBM ThinkPad 365X) has the least amount of Pb present, it would be more likely to release Pb into the environment than the rest of the notebook computers studied evaluated by the TCLP test. Based on the leachability of the metals from each notebook computer's PWB, the notebook computers would be ranked as followed: LP-9 > LP-7 > LP-8 > LP-10 > LP-6.

Figure 3.11 was generated to illustrate the total amount of Pb that leached from each notebook computer during the TCLP test. This figure was generated by using the total weight of the PWB as shown in Table 3.3 and the concentration of Pb that leached from the PWB during the TCLP test as presented in Figure 3.10. As shown in Figure 3.11, LP-9 leached the highest concentration of Pb. However, when the actual amount of Pb that leached from each notebook computer is compared to the actual weight of each PWB, LP-7 and LP-10 leached more than 100 mg of the total weight of the PWB. However, for LP-9, when compared to the actual weight of the PWB, the actual amount of Pb that leached is lower. This suggests that although the overall percentage that leached from each notebook computer is small, the actual amount of Pb that leached has the potential to harm the environment.

It should be noted that each of the notebook computers tested exceeded the concentration of 5.0 mg/L. This amount of Pb would classify all of the tested PWBs as hazardous waste. It is suggested that special attention should be taken in the removal of Pb containing components from the PWB before disposal because of toxic characteristics.

3.2.2 Leaching of Other Metals in TCLP Test

Figure 3.12 presents the same data as Figure 3.9 with the scale adjusted, and is used to better illustrate the presence of Ba, Cu, Ni, Sn and Zn in the PWBs. As previously discussed in the Total Analysis, Cu made up 83% of the total metals present in the PWB. Although there were large quantities of Cu present, less than 1.0 mg/L leached from the PWB. It can be suggested from the data in Figure 3.12, Cu would not be mobile once the computer is disposed. Thus, Cu would also be less likely to cause any major environmental concerns although a large amount of Cu is contained in the computer.

As previously discussed, Ba, Ni, and Zn were present in large amounts in the PWB. However, as seen in Figure 3.12, Ni and Zn leached less than 2.0 mg/L of the total amount of metal present in the PWB. When compared to the amount of Ba that leached, Ni and Zn leached 3.5 times less than Ba. Nevertheless, each of the metals leached in small concentrations when compared to the amount of Pb that leached from each of the PWBs. From Figure 3.12, Ba, Ni, and Zn would not be considered very mobile in the environment. Although each of these metals was present in elevated concentrations in the PWB, the total concentration that leached during the TCLP test was not of high concern. As discussed previously, the Ba, Cu, Ni, and Zn did not exceed the STLC limits set by the State of California WET test and were not considered hazardous. It should be noted that Fe and Al were present in negligible amounts in the TCLP leachate and were not discussed further. The raw data for the all of the metals present is presented in Appendix E.

3.3 Leaching of Metals in SPLP Test

As previously discussed in the Materials and Methods section, the SPLP test was used to determine the leachability of the metals in the PWBs of notebook computers when exposed to acid rain conditions. The SPLP test is a less aggressive leaching test when compared to the TCLP test. Thus, the SPLP is anticipated to have much lower concentration of the COCs in SPLP leachate. The results from the SPLP test were compared to the actual concentrations of Pb that leached from the PWBs during the

TCLP test. As previously stated, Pb leached at the highest concentration from the PWBs when compared to the other COCs (Ba, Cu, Ni, Zn).

3.3.1 Leaching of Pb in SPLP Test

Figure 3.13 was generated to illustrate the total amount of metals that leached from the PWBs of each notebook computer during the SPLP test. It can be determined from Figure 3.13 that the Pb content of LP-9 and LP-10 exceeded the concentration limit of 5.0 mg/L by more than 3.0 mg/L. However, these concentrations are not considered to be hazardous by the SPLP test because there is not a set standard for this test. These concentrations indicate that LP-9 and LP-10 would leach significant amounts of Pb if exposed to acid rain conditions. It is unclear if these concentrations would be harmful to the environment or for humans.

3.3.2 Leaching of other Metals in SPLP Test

Also shown in Figure 3.13, other COCs (Ba, Cu, Ni, and Zn) were present in the leachate of the PWB during the SPLP test. Although the other COCs were present, the concentrations of these metals did not exceed 2.0 mg/L. These concentrations would be considerd less harmful to the environment or for humans when compared to the concentration of Pb that leached from each notebook computer. The raw data for these metals are provided in Appendix F.

3.3.3 Comparison of SPLP to TCLP

Figure 3.14 is used to illustrate the percentage of Pb that leached from the average of three triplicate samples of each PWB during the SPLP test. The data in Figure 3.14 was generated by comparing the TCLP test results to SPLP test results to determine how much Pb leached from each PWB tested. As indicated in Figure 3.14, LP-6, LP-8, LP-9, and LP-10 leached on average ≥7% of the total amount of metals when compared to the TCLP test. However, LP-7 leached only 1% of the total amount present in the PWB when compared to the TCLP results. These results are expected because of the less aggressive nature of the SPLP test. It is believed that the concentration of Pb that leached from the PWBs during the SPLP test were so small amounts that the likelihood of affecting the environment is low.

Figure 3.15 is used to graphically illustrate the correlation between the results of the SPLP test and TCLP test. A trend line was added to the figure to determine if there was a trend associated with the data. From Figure 3.15, the R-squared value generated from the data is 0.86. The R-Squared value suggests that there is a direct correlation between the TCLP and SPLP results. This was expected due to the similarities of each test.

Figure 3.15 also illustrates that as the concentration of Pb increases for the TCLP test, the concentration of Pb also increases during the SPLP test. It can be concluded that the higher concentrations of Pb leached during the TCLP test when compared to the SPLP test is due to the less aggressive nature of the SPLP. The raw data for the SPLP vs. TCLP comparison is presented in Appendix G.

3.4 Results of Dynamic Leach Test of PWB

As discussed in the Materials and Methods section, the dynamic leach test was used to determine the mobility of the COCs in the desktop computers components tested. However, it should be noted that the dynamic leach test was not performed on any of the notebook computer components tested during this study. The notebook components were not tested because of the limited availability of each component after the initial phase of the BFR analysis. It was assumed that the PWB of notebook computers would be comparable to the PWB of desktop computers. The major differences between the PWB of the notebook and desktop computers are size and composition. In general, it would be assumed that the PWB of the desktop computer would have a greater mass. It was assumed that each desktop computer PWB used would be 2 times the size of a notebook computer.

The PWB samples were motherboards taken from two desktop computers MB-21, IBM with 286 CPU and MB-28, Hewlett Packard Vectra VE with a Pentium II. It should be noted that MB-21 used TCLP Fluid #1 for its extraction fluid and MB-28 used SPLP Fluid #1 for its extraction fluid. The different extraction fluids were used to compare how the PWBs of desktop computers would leach in different extraction conditions. The data generated from this evaluation is presented for Cu, Pb, Ni, and Zn in Figures 3.16 thru 3.19. It should be noted that Figures 3.16 thru 3.19 are based on a logarithmic scale because of the large range of the concentration data. Although Cu, Ni, and Zn were studied during this test, Pb will be the focus of much of the discussion to compare the results to the results of the TCLP and SPLP tests as discussed in the previous section. The raw data used to generate Figures 3.16 thru 3.19 are supplied in Appendix H and I.

3.4.1 MB-21

Figure 3.16 was generated to show the average concentrations of the COCs (Cu, Ni, Pb and Zn) that leached from MB-21 during the 1.5 year testing period for the Dynamic Leach test in TCLP extraction fluid. As illustrated in Figure 3.16, Pb leached in the highest concentrations during the first month and half of the study. Pb leached at concentrations as high as 20 mg/L during the first month and half of the study, but reached a steady state concentration of less than 3.0 mg/L thereafter. It can be suggested from this data that during the first month and half Pb is the most mobile from the PWB of the desktop computer. It could be assumed from the data generated from the desktop computer that during the first month and a half, the highest concentration of Pb leaches from the PWB (assuming the PWBs of the notebook and desktop computers are similar). However, Pb leached continually from the PWB during the entire time of the test, just at much lower concentrations.

Although Pb leaches in high concentrations, it should be noted that Zn is also highly present. As shown in Figure 3.16, Zn also leached at a high concentration during the first month and half of the study. Initially, Zn leached at concentrations as high as 50 mg/L in the first two months of the test. After the first two months of the DLT test, the total amount of metals that leached reached a steady state and decreased to a concentration of 0.6 mg/L per month. Thus, it can be suggested that Zn is the most mobile metal when compared to Cu, Ni, and Pb during the first month and half of this study. Although Pb and Zn leached in high concentration, the other metals present leached in such minute amounts thus, are not discuss further.

Figure 3.17 was generated to illustrate the actual amount of each metal present in the leachate over the year and half test time. As shown in Figure 3.17, a dotted line was used to mark the month and half time period at which Pb and Zn had leached out at their highest concentrations. However, both Pb and Zn metals continued to leach from the PWB, but at much lower concentrations during the leaching test. In combination with Figure 3.16, it can be seen during the first month and half time period, more than 500 mg of Pb leached from MB-21. On the other hand, Zn leached more than 900 mg of the total amount of metal present in the PWB. This amount of Zn was nearly double the amount of Pb that leached during the first month and half time period of the study. The presence of Zn at elevated concentrations in the leachate can be attributed to the amount present on the galvanized steel of the PWB. This would explain why the Zn concentration is so high during the initial leaching stage. This further supports the data in Figure 3.16 that Zn is the most mobile metal.

3.4.2 MB-28

Like Figure 3.16, Figure 3.18 was generated to illustrate the average concentration of Cu, Ni, Pb, and Zn that leached from MB-28 in SPLP extraction fluid over a year and half test period. As previously discussed, MB-28 was analyzed using SPLP extraction fluid, which is used to simulate acid rain conditions. From Figure 3.18, it can be concluded that Zn, Pb, and Cu leached from MB-28 more readily than Ni. When MB-28 is exposed to the SPLP fluid, Zn, Pb, and Cu would be the most mobile metals. This is indicted by the amounts of each metal that leached using this less aggressive leaching method.

Figure 3.19, like Figure 3.17, was generated to illustrate the total amount of metals that leached from MB-28 of the desktop computer. In the Figure 3.19, a dotted line was used to mark the month and a half time frame when the highest concentration of the metals had leached. However, each of the metals continued to leach at a lesser concentration throughout the duration of the test. Pb leached more than 65 mg of metal before it reached steady state, as defined by the dotted line. When compared to the amount of the other COCs (Zn, Cu, and Ni) that leached, Pb leached 13 times more than the other metals present in the first month and a half of the test. It could be suggested from the data that Pb would leach more metal into the environment when compared to Zn, Cu, and Ni.

3.5 Summary

In summary, it can be determined from the data generated during the Total Analysis, TCLP, and SPLP tests that Pb would leach from the PWB of each notebook computer at a high concentration. When comparing the Total Analysis results to the TTLC limits for Pb, it can be determined that the metal content of Pb is 14 times higher than the limit set by the TTLC limits for all the computer tested. The Pb content in the PWB would be considered hazardous when compared to the TTLC limits. During the TCLP test, more than 40.0 mg/L of Pb leached from each PWB. It should be noted that each notebook computer tested exceeded the concentration set by the EPA (5.0 mg/L). The PWBs of each of the notebook computer tested would be considered hazardous waste by the EPA. These results were also supported by data generated from the DLT test performed on the motherboard of a desktop computer, which also exceeded the concentration set by EPA. To prevent significant environmental impacts, it is suggested that the PWBs be removed from each notebook computer prior to disposal. This will reduce the amount of mobile metals that can be potentially leached in the long term.

3.6 Results for BFRs

As discussed previously in the Materials and Methods section, the amount of BFRs were measured in three components of the notebook computer: PWB, LCD screen, and Casing. The samples were generated in triplicate sets for each notebook component and an average of the triplicates samples was taken. The average of the triplicate samples were used to determine the total amount of BFRs that leached from each notebook component. Also discussed in the Materials and Methods section, the samples generated for the BFRs analysis were produced from the Total BFR Analysis and the TCLP leachate. The amount of BFRs present in each notebook computer component is presented in the following sections.

3.6.1 Total BFR Analysis

As previously discussed in the Materials and Methods section, the total analysis was performed to determine the quantity of BFRs in each of the individual notebook computer components. A Soxhlet extraction was used for this analysis. As discussed earlier, triplicate sample sets were analyzed for each notebook component. As explained in the Materials and Method section, two samples sets were produced for BFR analysis. The two samples sets were produced at different times because of the length of time took to generate a set of samples. The samples were delivered to Jackson State University at different times for BFR analysis. The first samples generated from the analysis produced some results. However, the second set of samples that was produced did not provide any results. It is suggested that the data generated from the first set of samples is more plausible than the second set generated. The analysis of total BFRs in plastic samples proved to be difficult because of the aggressive nature of the Soxhlet extraction. The samples contained a large amount of dissolved organics making the samples too thick for analysis of the BFRs. The data generated from each sample set can be seen in Appendix J.

3.6.2 BFR Analysis on TCLP and SPLP Leachates

As previously discussed in the Materials and Methods section, BFRs were analyzed in the leachate from TCLP and SPLP tests performed on the notebook computer components. For this analysis, a modification was made in the way the sample was prepared for the TCLP test. The samples for this test are generally cut into pieces so that it can pass through a 9.5 mm sieve. However for the BFR analysis, the notebook components (PWB, LCD screen, and Casing) were ground to a fine powder. This was done to increase the surface area of each sample and to provide maximum exposure to the extraction fluid. As discussed previously, each sample was separated into triplicate sample sets. After each sample was separated into triplicate sets, the samples were concentrated to provide a greater possibility to recover BFRs from the leachate of the TCLP and SPLP test. The TCLP and SPLP samples were analyzed using the GC/MS. The GC/MS was unable to detect any of the targeted BFRs (2,4,4-triBDE; 2,2',4,4'-tetraBDE; 2,2,4,4',5-pentaBDE; 2,2,4,4',6-pentaBDE; 2,2',4,4',5,5'-hexaBDE; 2,2',4,4'5,6'-hexaBDE and 2,2'3,4,4'5,5',6,6'-heptaBDE). As indicated from the results that these BFRs either did not exists in the E-waste components tested or hard to leach out under the under TCLP and SPLP conditions. This is a good indication that these BFRs will not leach into the environment under the conditions produced from the TCLP and SPLP test. These results coincided with the BFR results produced by Lincoln for his study of cellular phones (Lincoln 2007). It was also determine that the lab did not have the capabilities of analyzing for deceBDE because it decomposed in the GC column during the analysis. The results of this analysis are provided in Appendix K thru M.

3.6.3 Summary

The triplicate samples produced from the total BFR analysis proved to be difficult to analyze. The results of BFRs in the TCLP and SPLP leachates suggest that there is no detectable leaching of the seven BFRs from the notebook components tested. Other types of BFRs may present, but this study could not prove because of the limitation of capability of the analytical instrument.

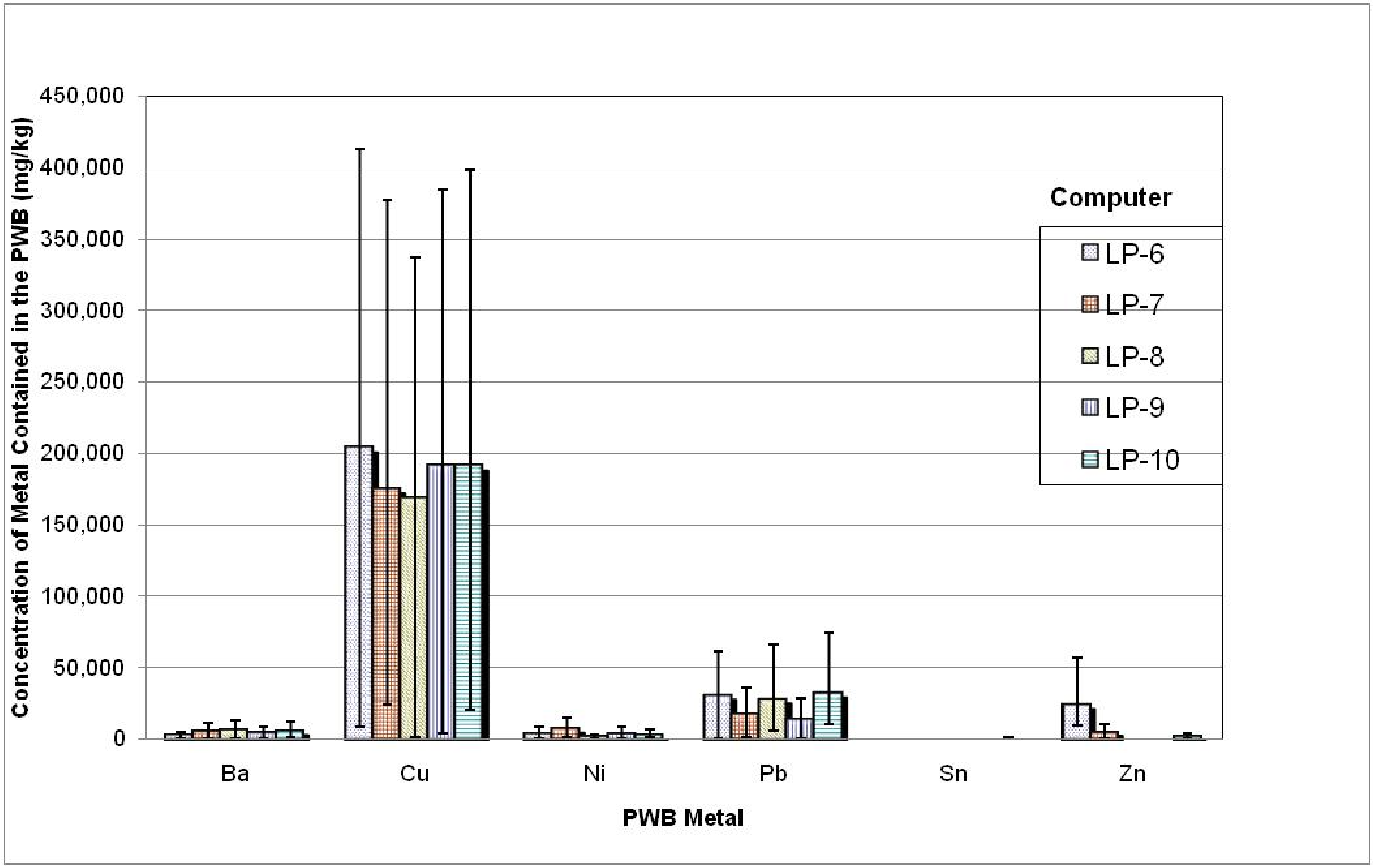


Figure 3.1 Average Over 3 Replicate Samples of Metals Contained in the PWB for All Laptops

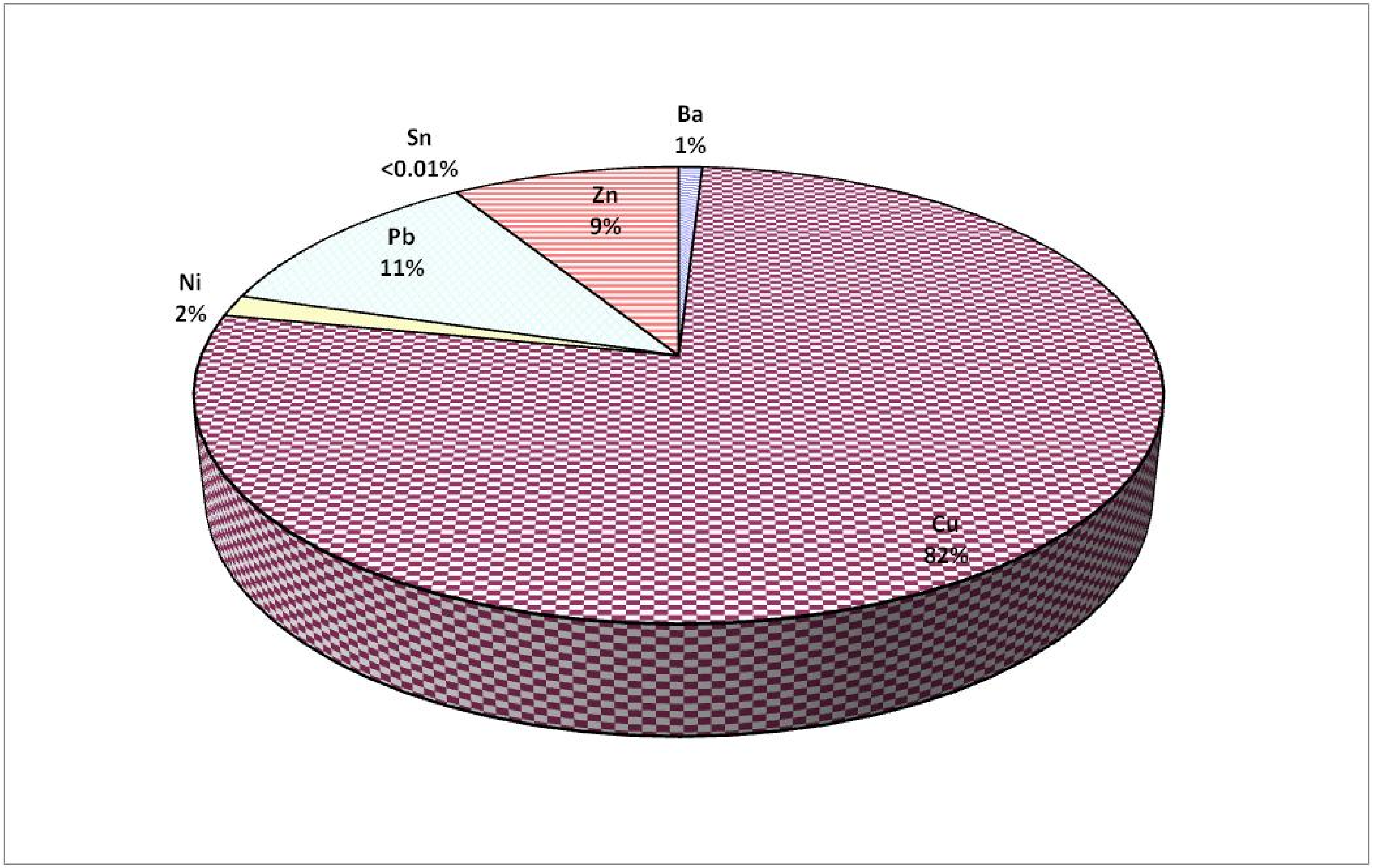


Figure 3.2 Average Metal Composition of the PWB for All Computers Studied

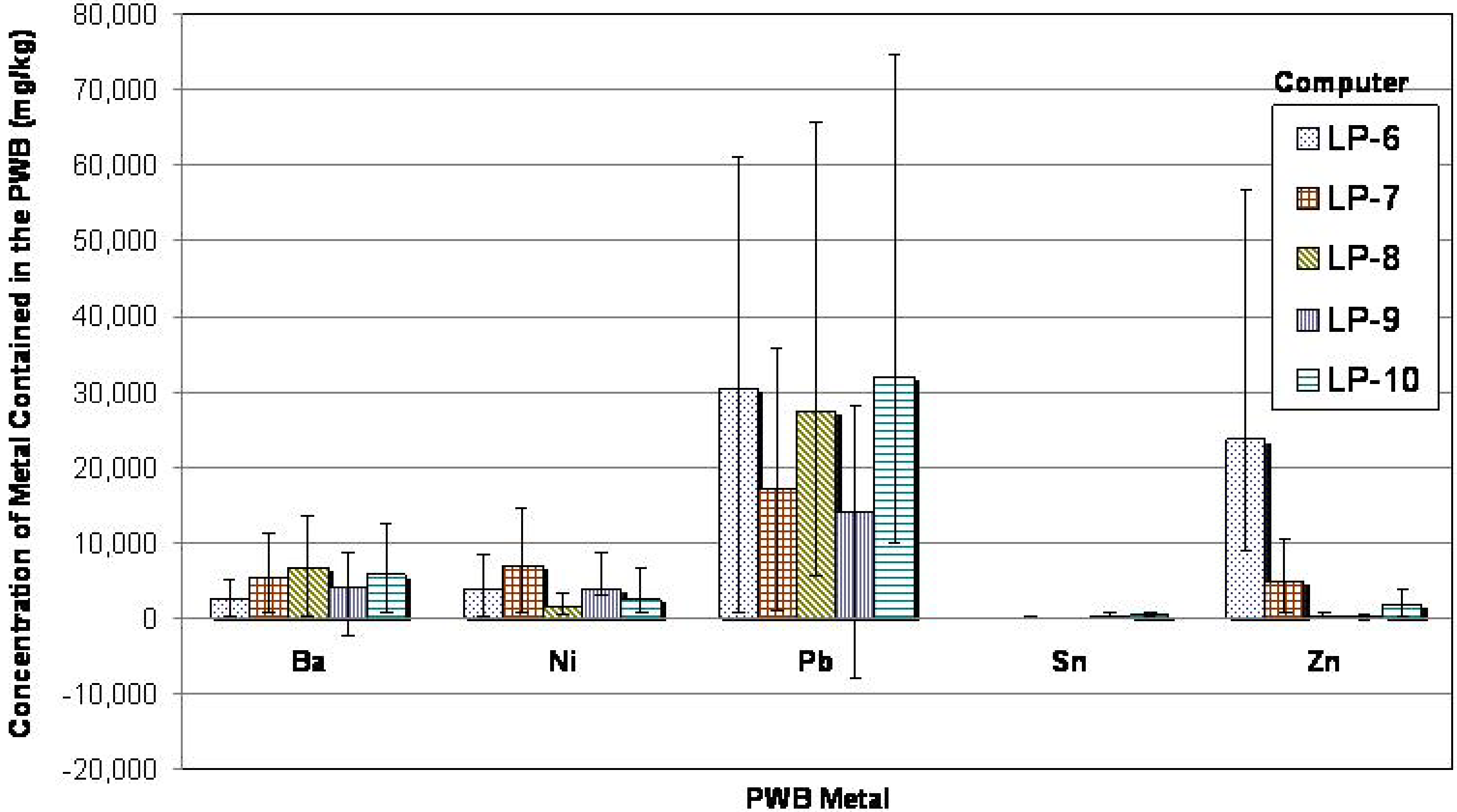


Figure 3.3 Average Over 3 Replicate Samples of Metals Contained in the PWB for All Laptops Without Cu

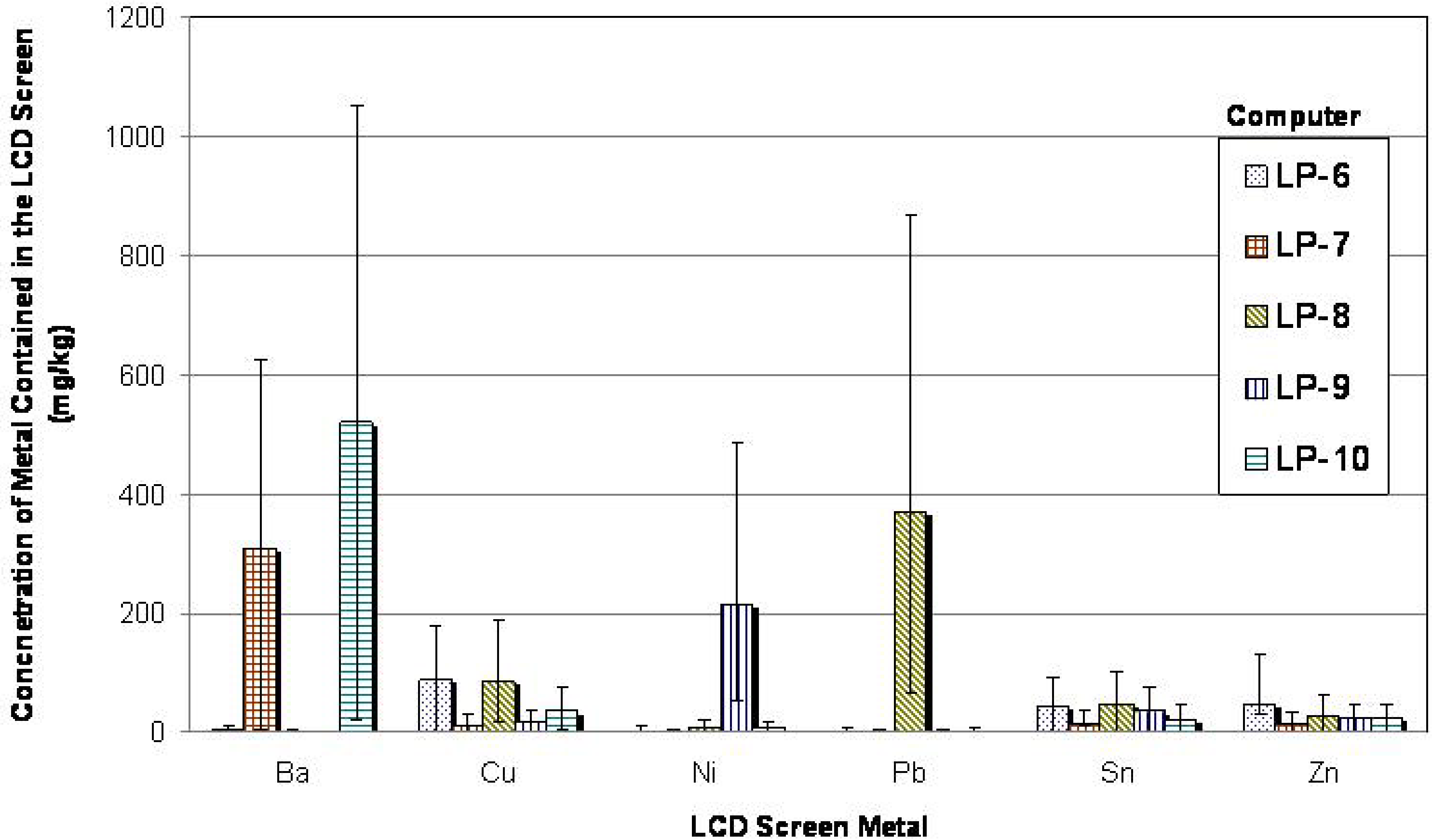


Figure 3.4 Average Over 3 Replicate Samples of Metals Contained in the LCD Screen for All Laptops

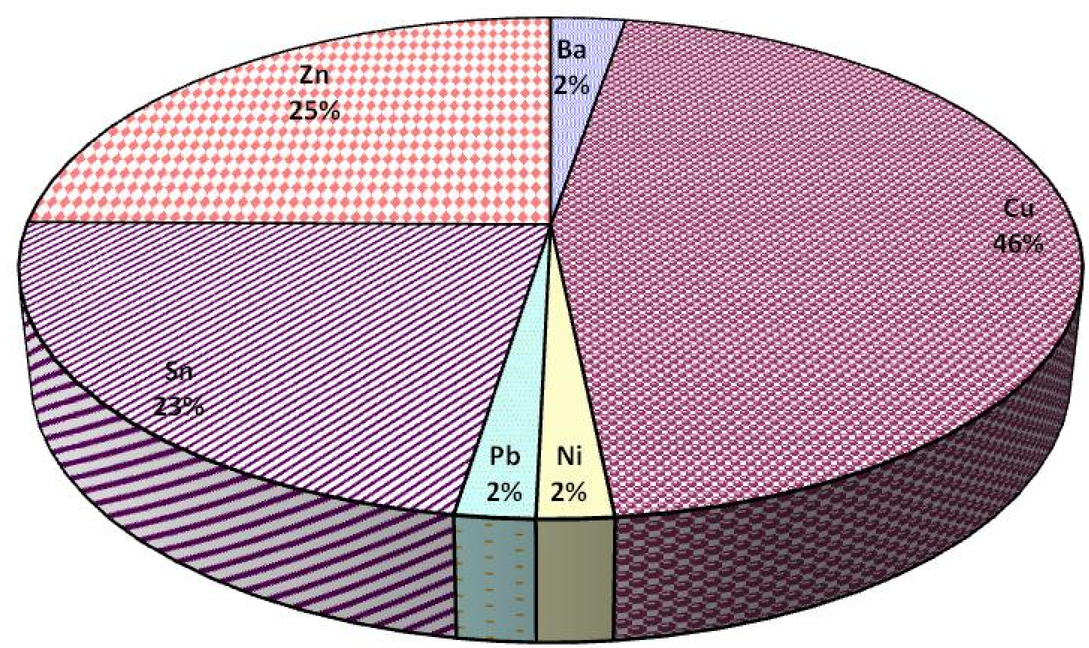


Figure 3.5 Average Composition of Metals in LCD Screen for All Computers Studied

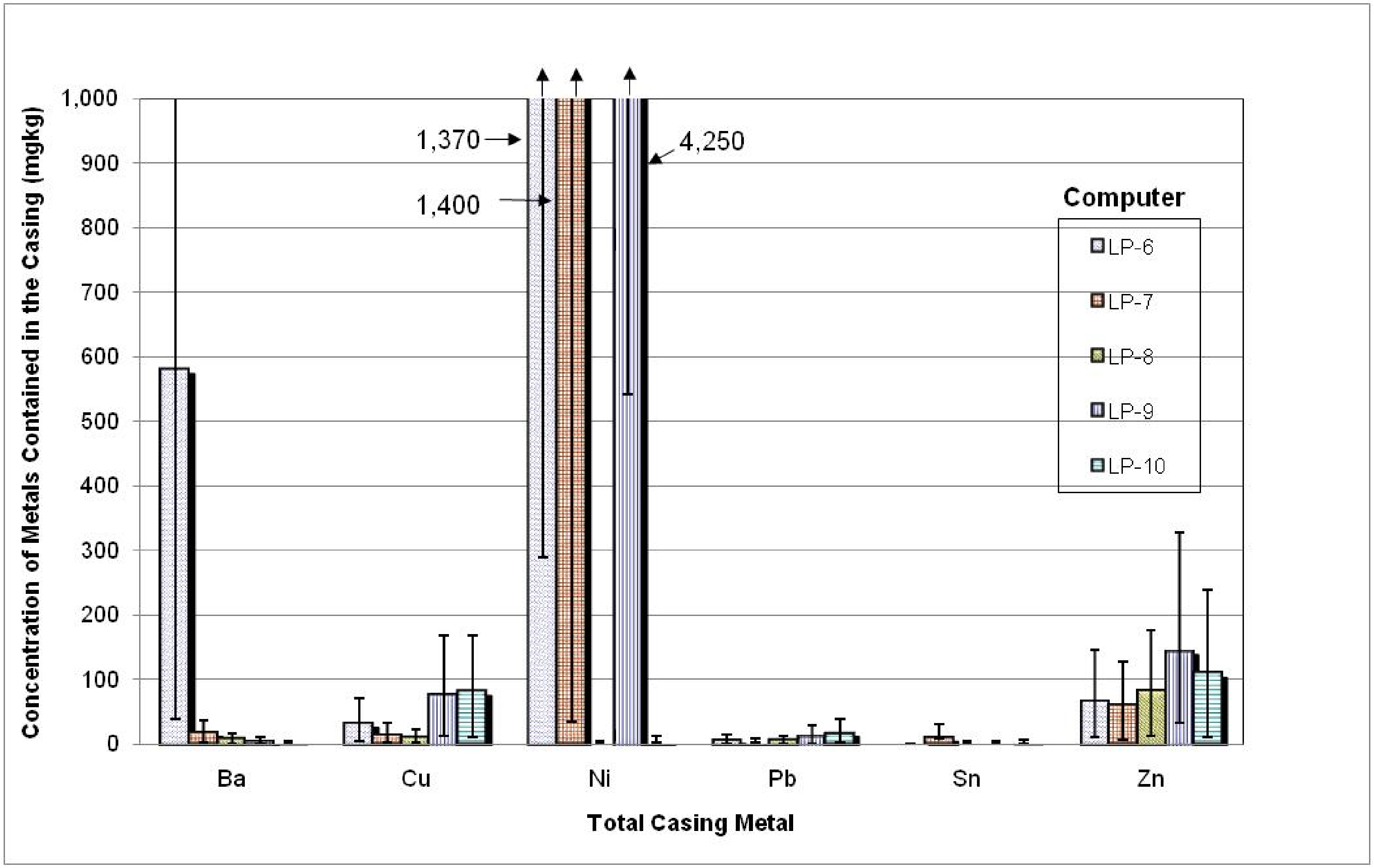


Figure 3.6 Average Over 3 Replicate Samples of Metals Contained in the Casing for All Laptops

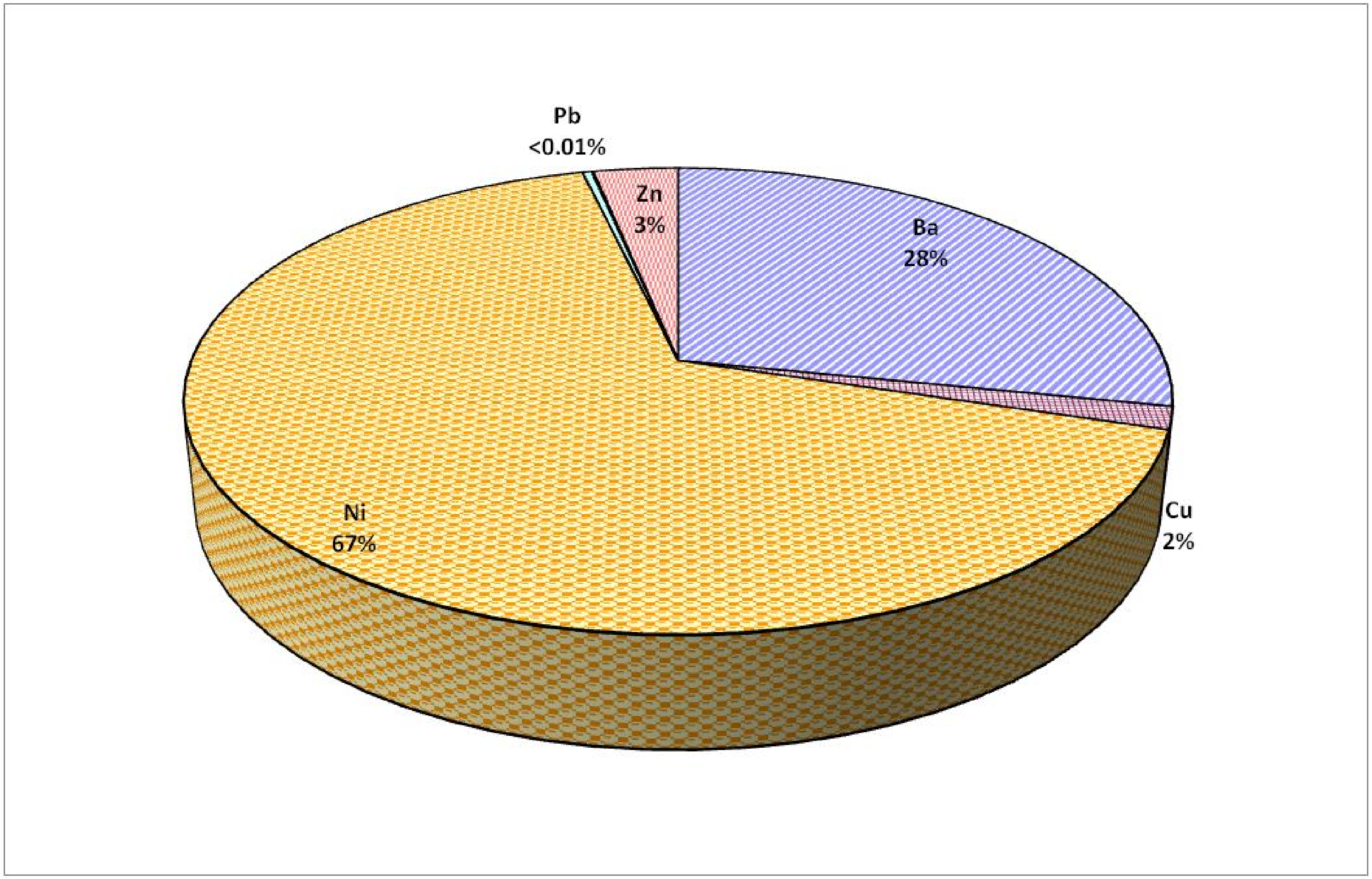
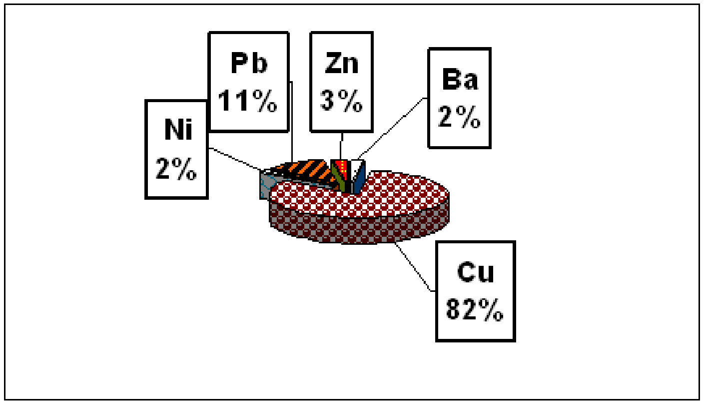
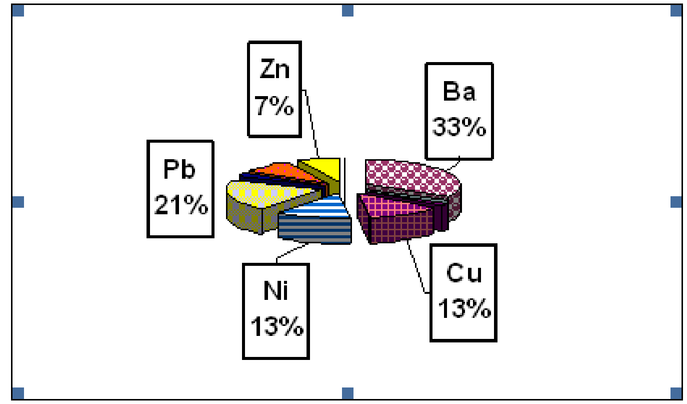


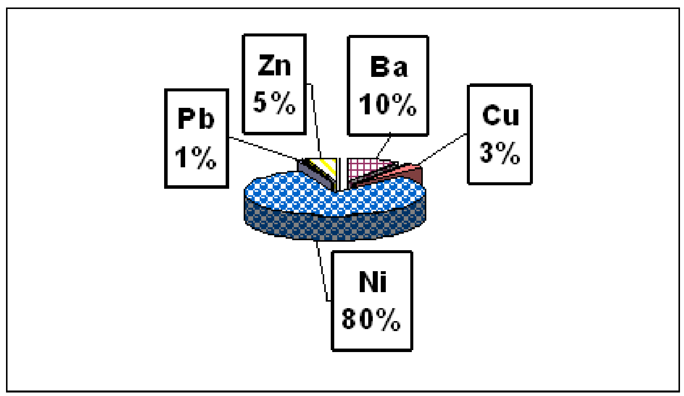
Figure 3.7 Average Composition of Metals in Casing of All Computers Studied



PWB



LCD Screen



Casing

Figure 3.8 Total Percentages of Metals in Each Notebook Computer Components

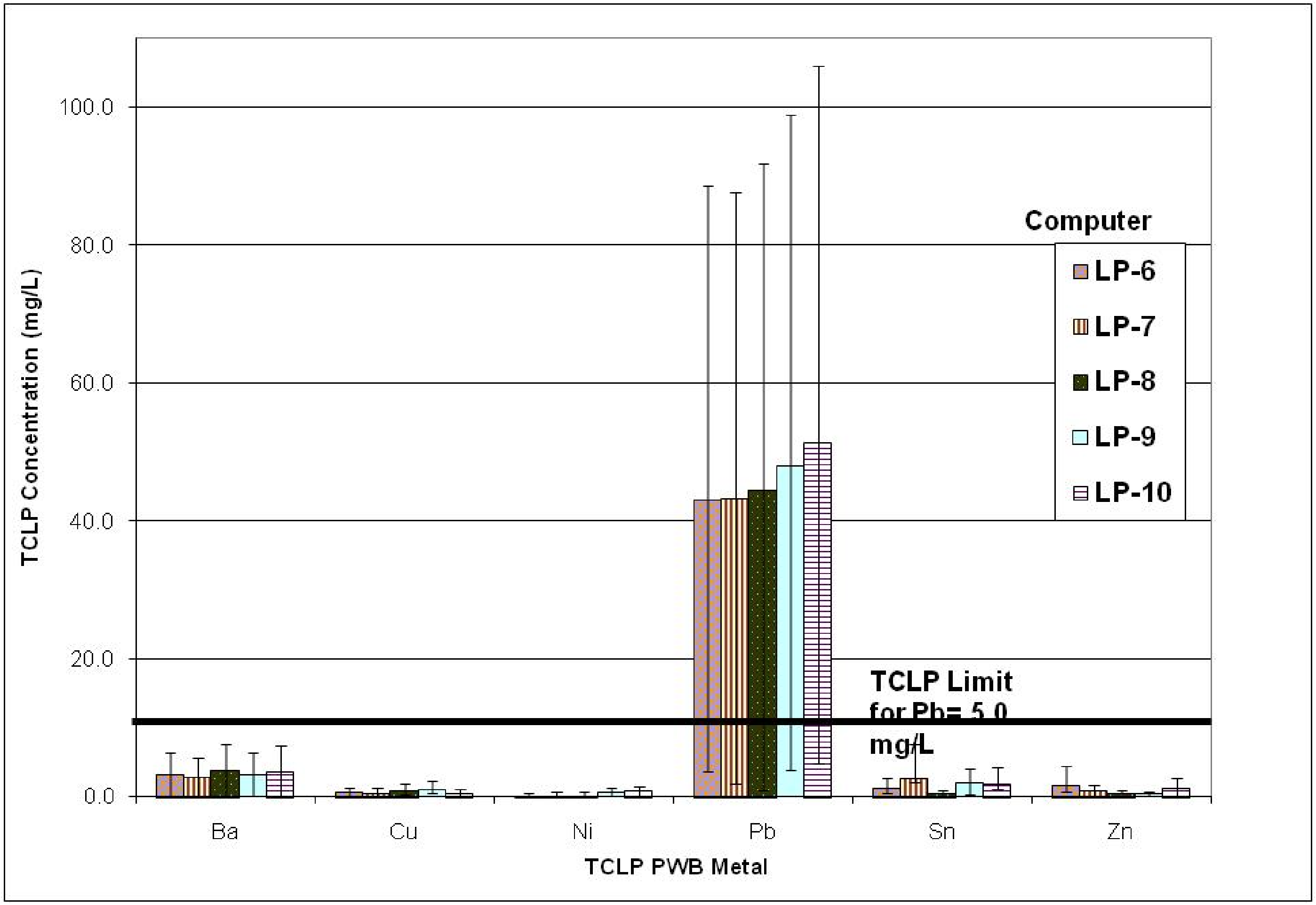


Figure 3.9 Average Over 3 Replicate Samples of TCLP PWB Metal Concentration

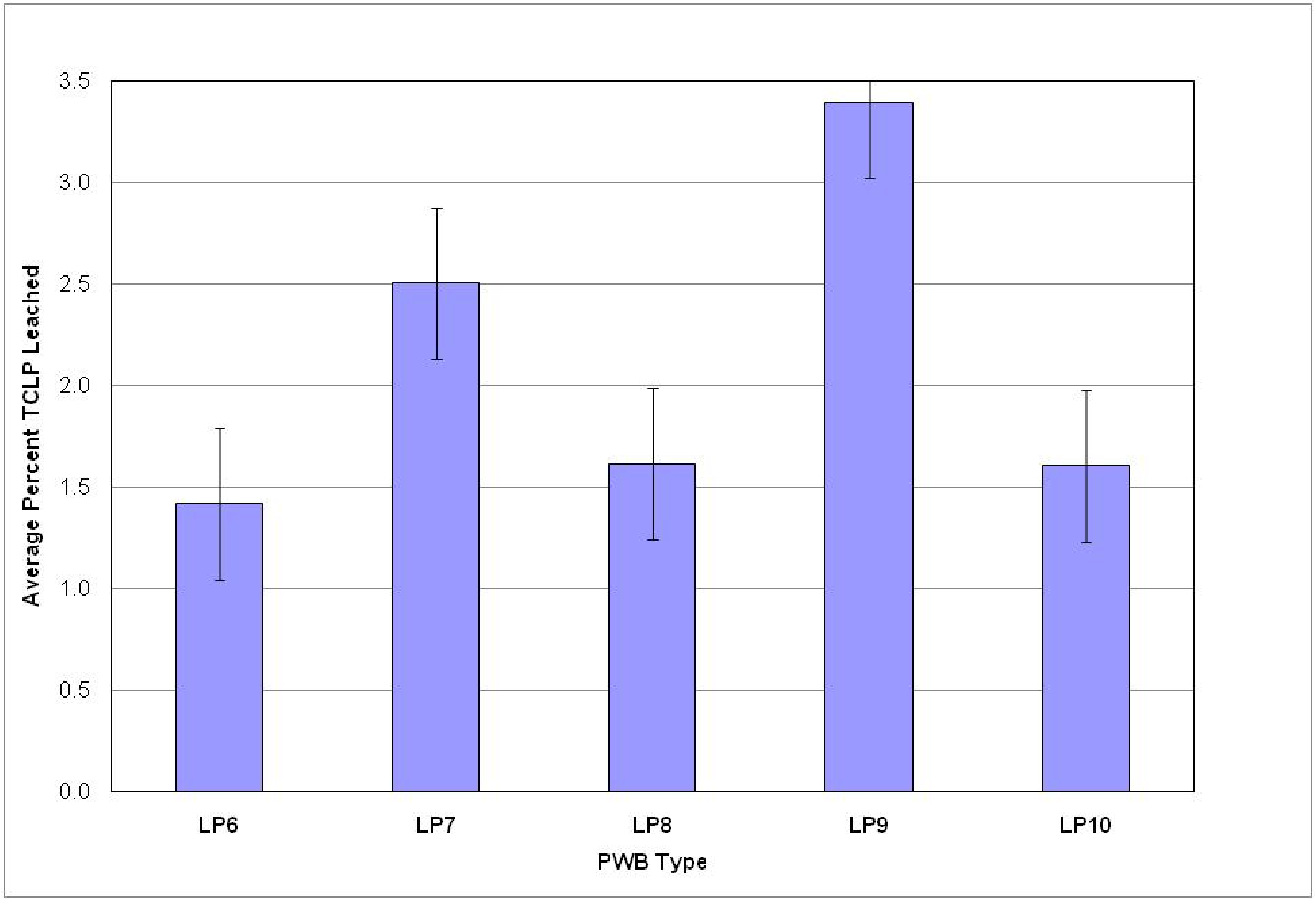


Figure 3.10 Average Percent of Pb Leached from the PWB in the TCLP Test

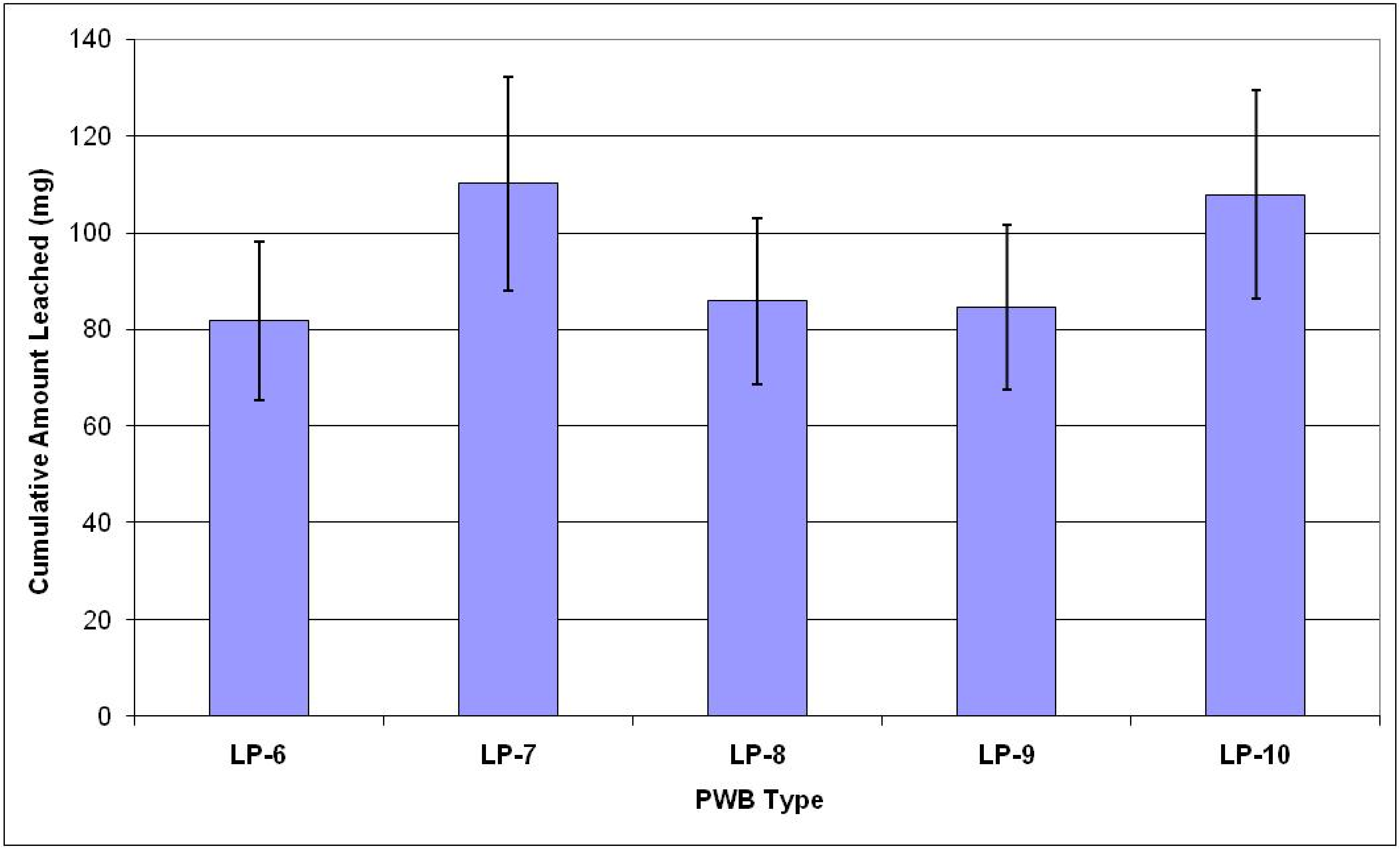


Figure 3.11 Cumulative Amount of Pb That Leached from the PWBs

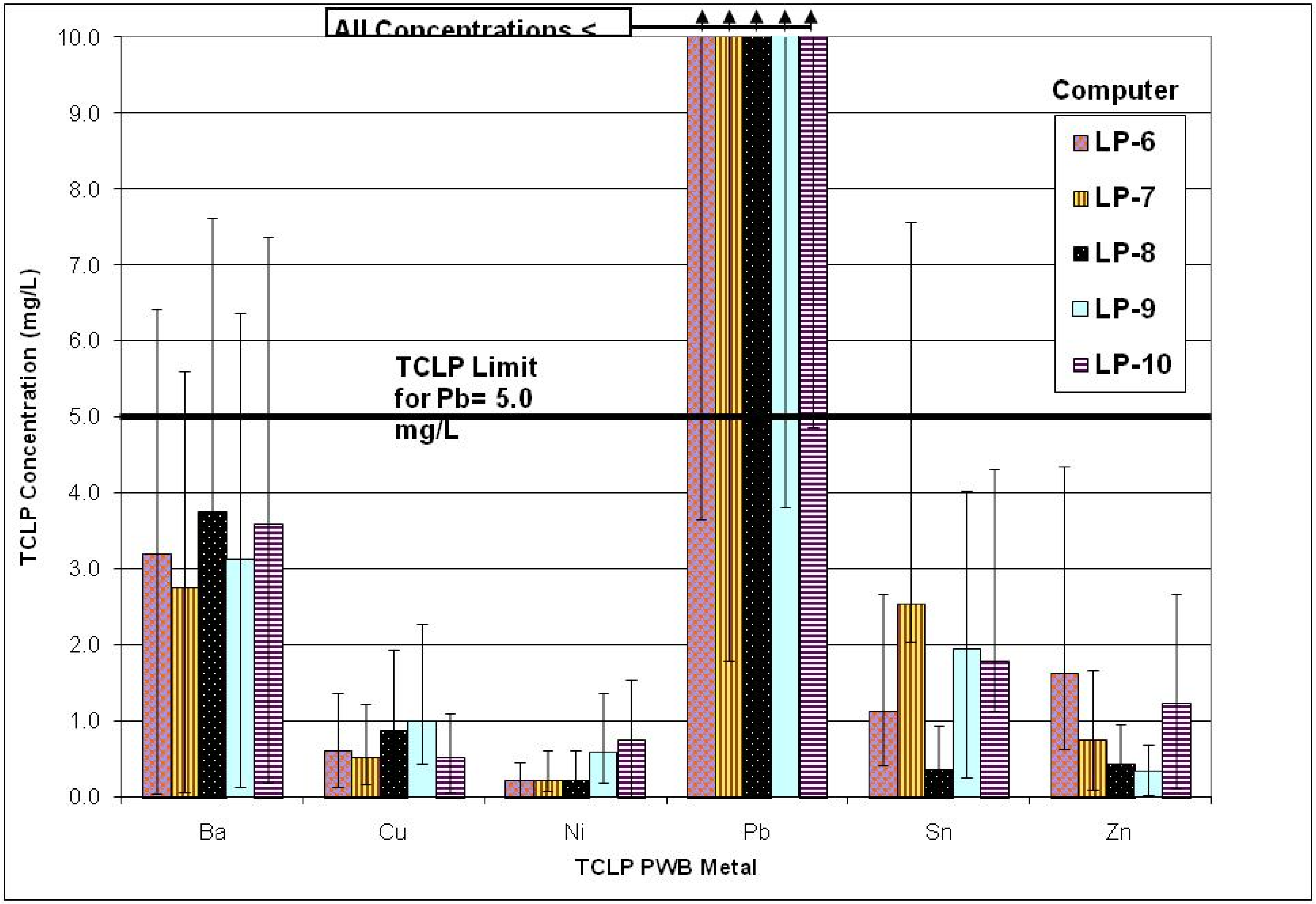


Figure 3.12 Average Over 3 Replicate Samples of TCLP PWB Metal Concentration with Scale Adjusted

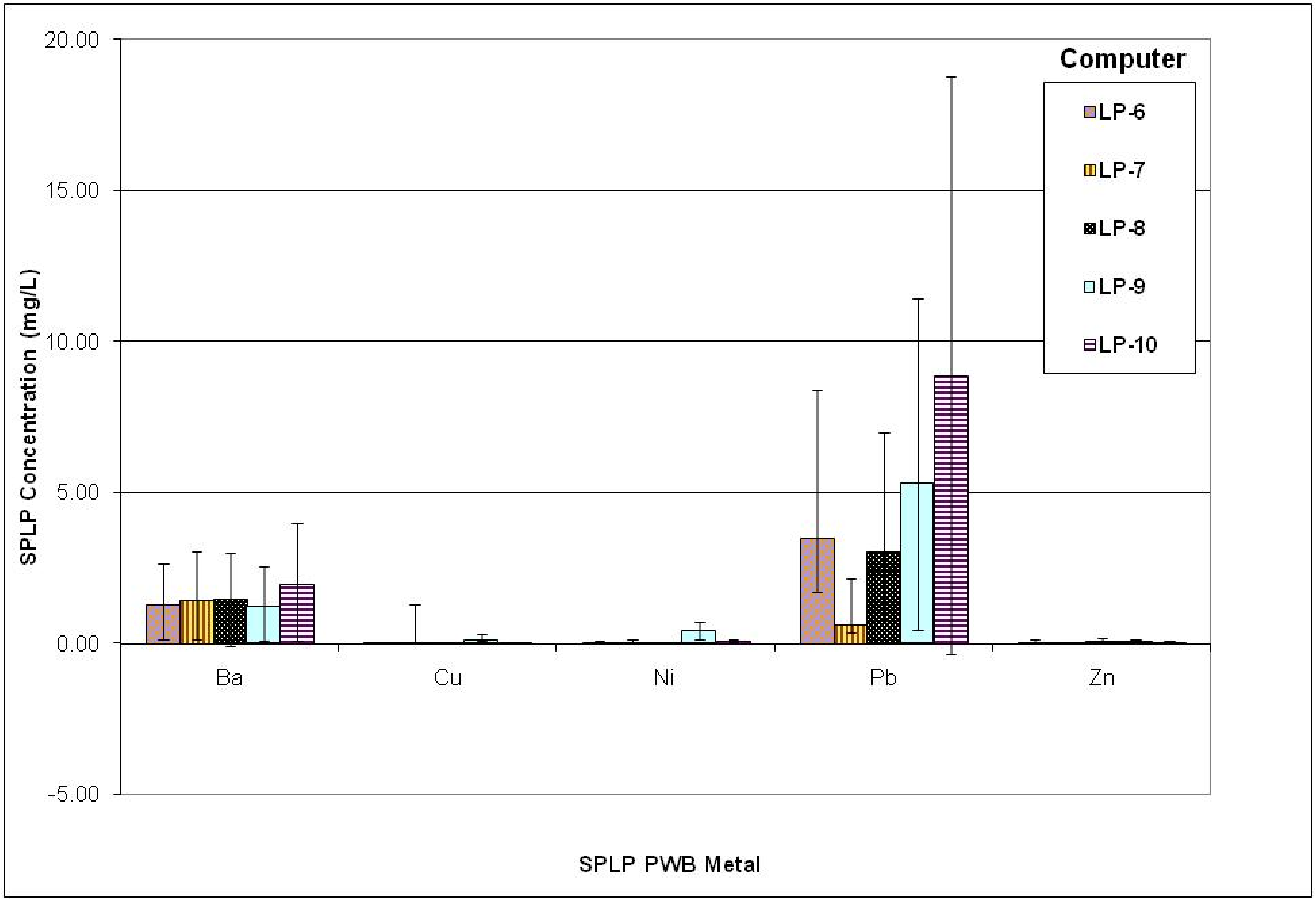


Figure 3.13 Average Concentration of Pb Leached from PWB during the SPLP Test

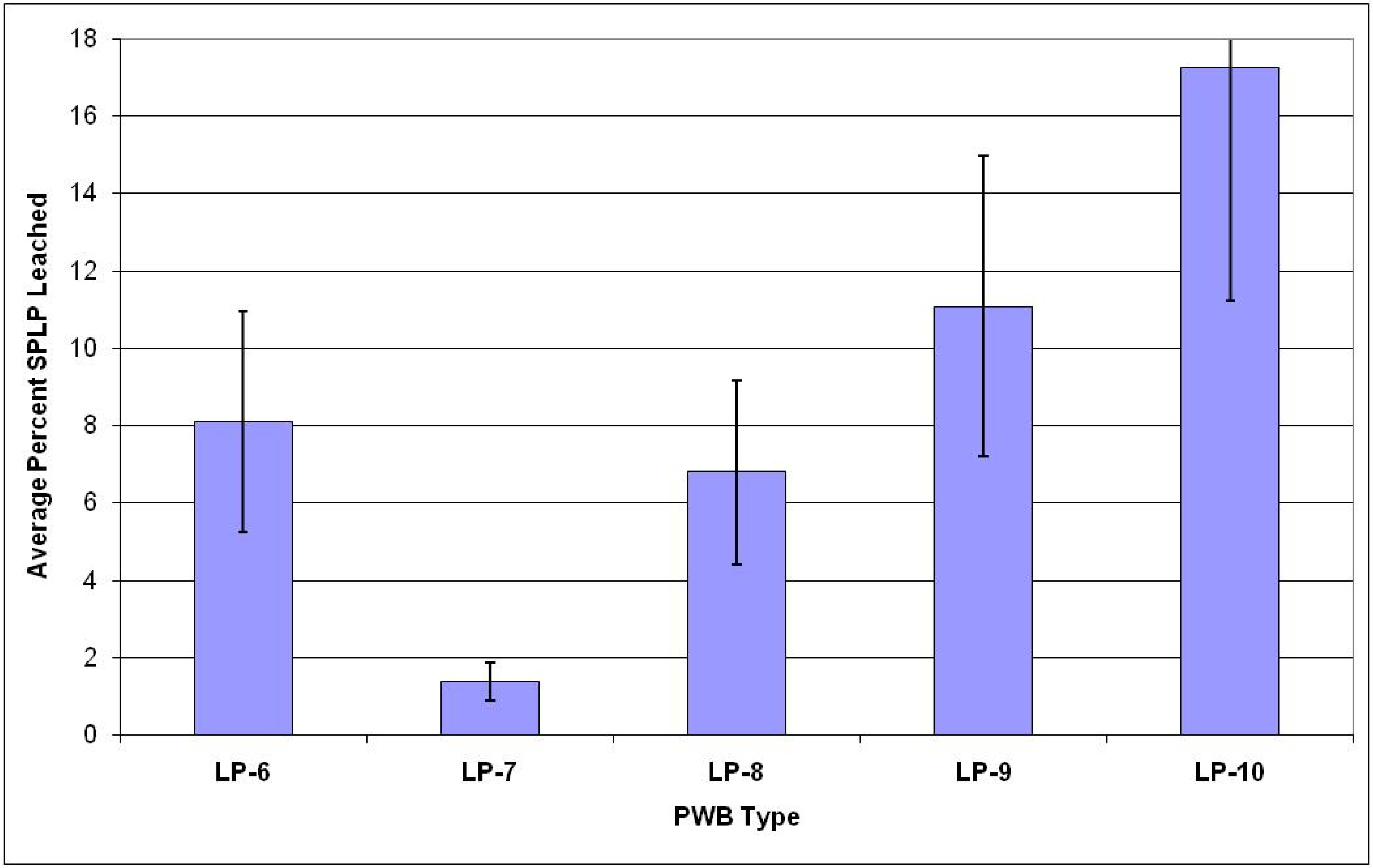


Figure 3.14 Average Percent of Pb Leached from the PWB in the SPLP vs. TCLP

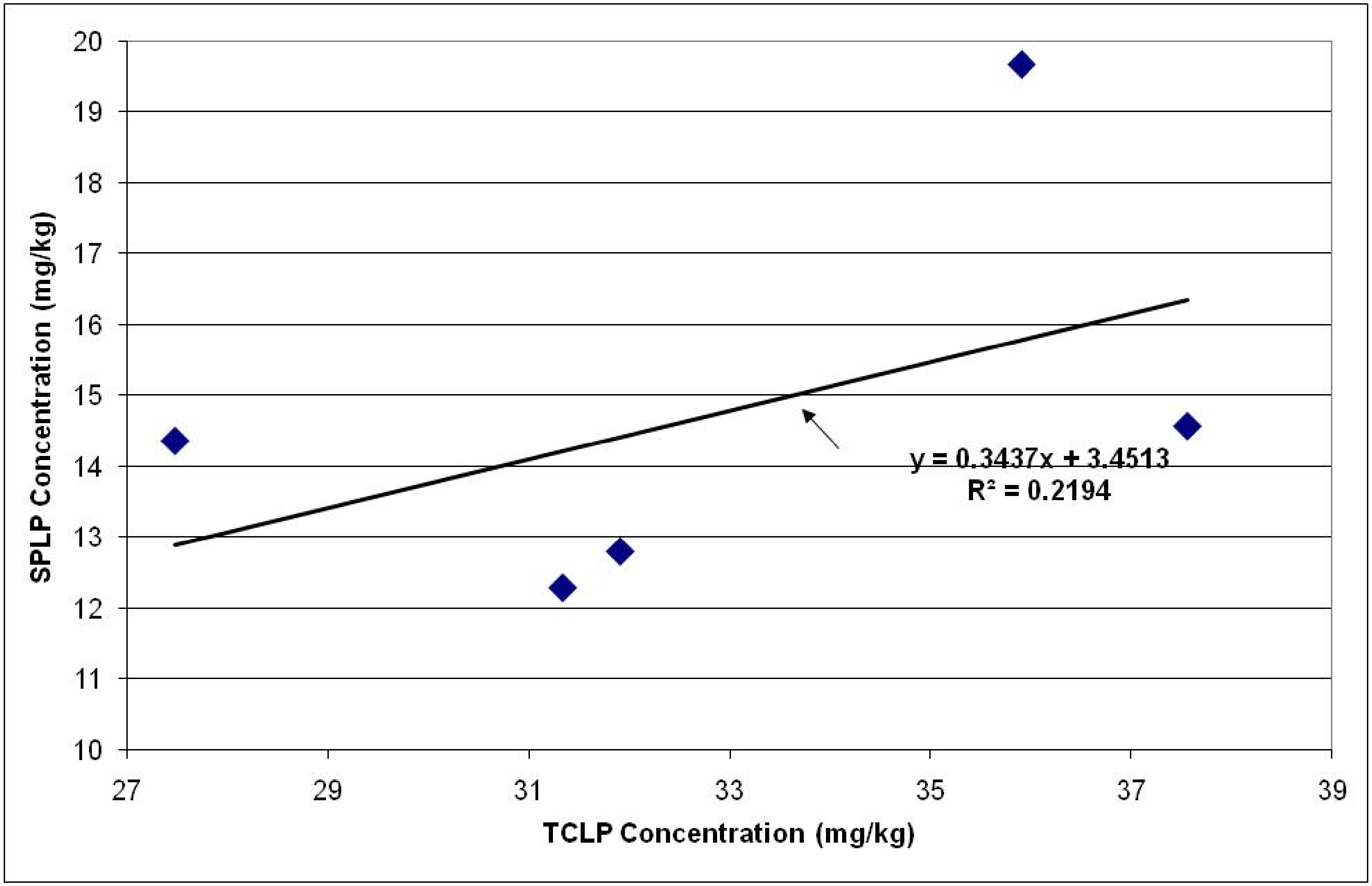


Figure 3.15 Actual Amount of Pb that Leached from the PWB of All Notebook Computers in the SPLP vs. TCLP

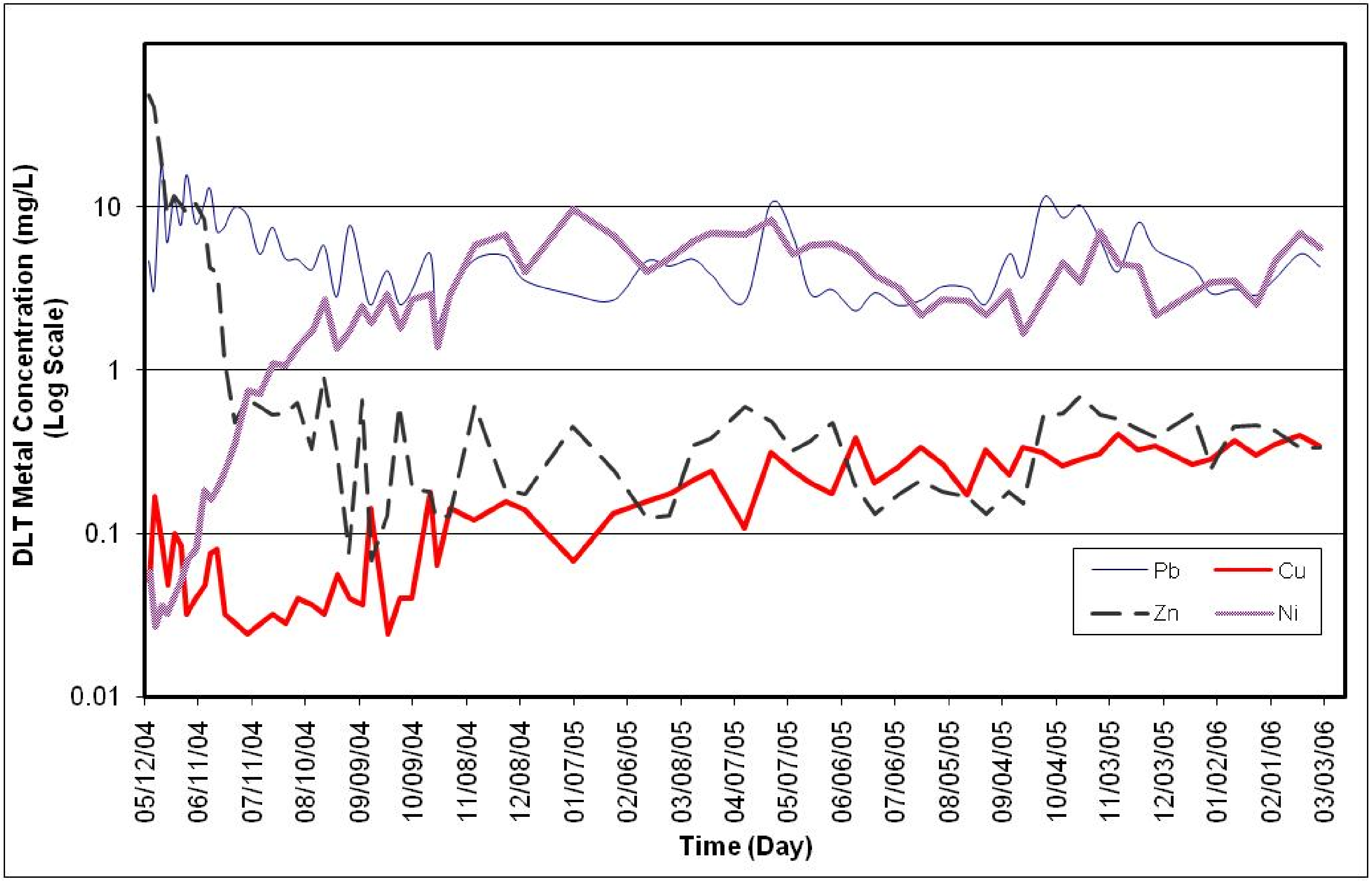


Figure 3.16 Average DLT Metals Leached From MB-21

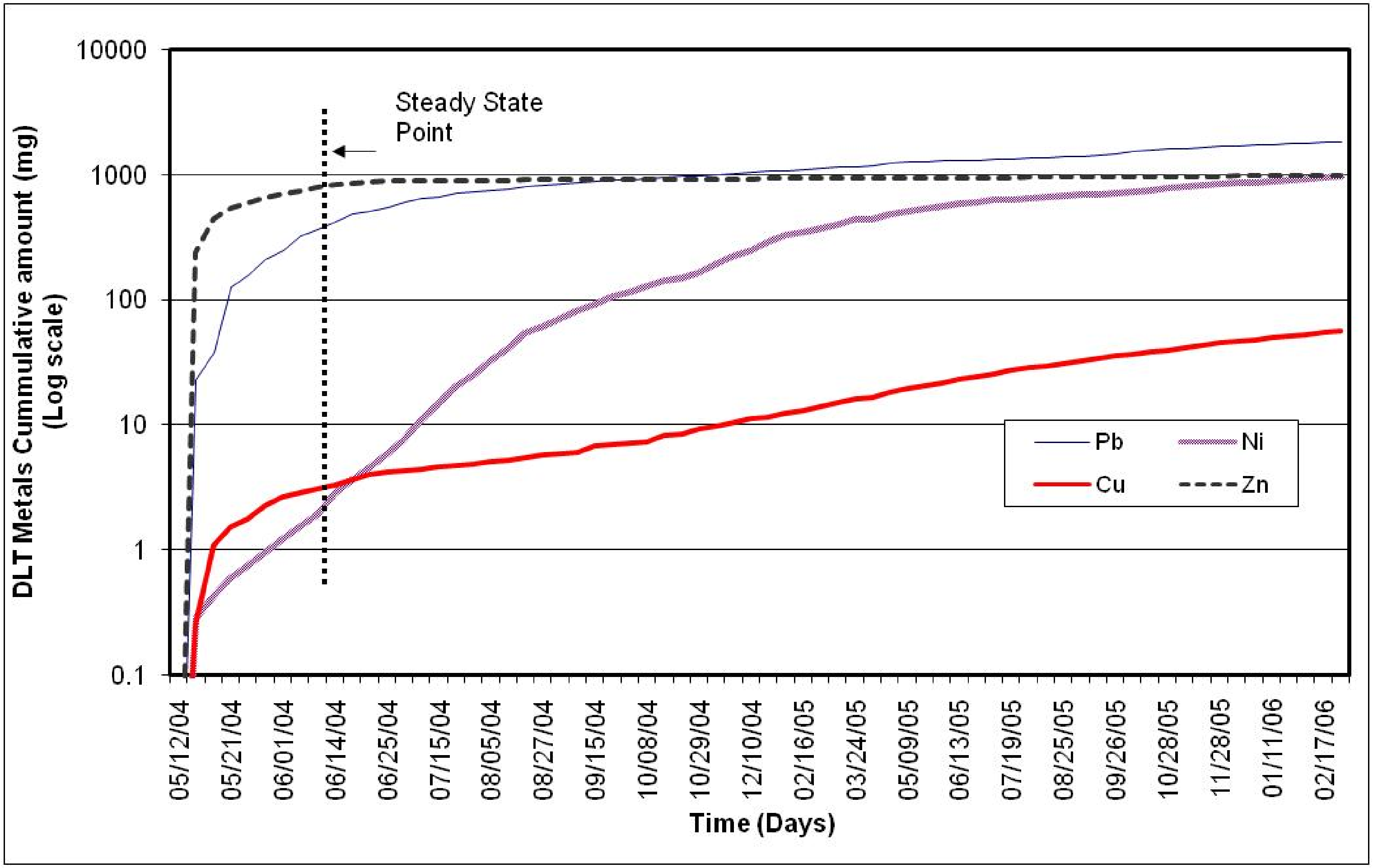


Figure 3.17 Cumulative DLT Metals Leached From MB-21

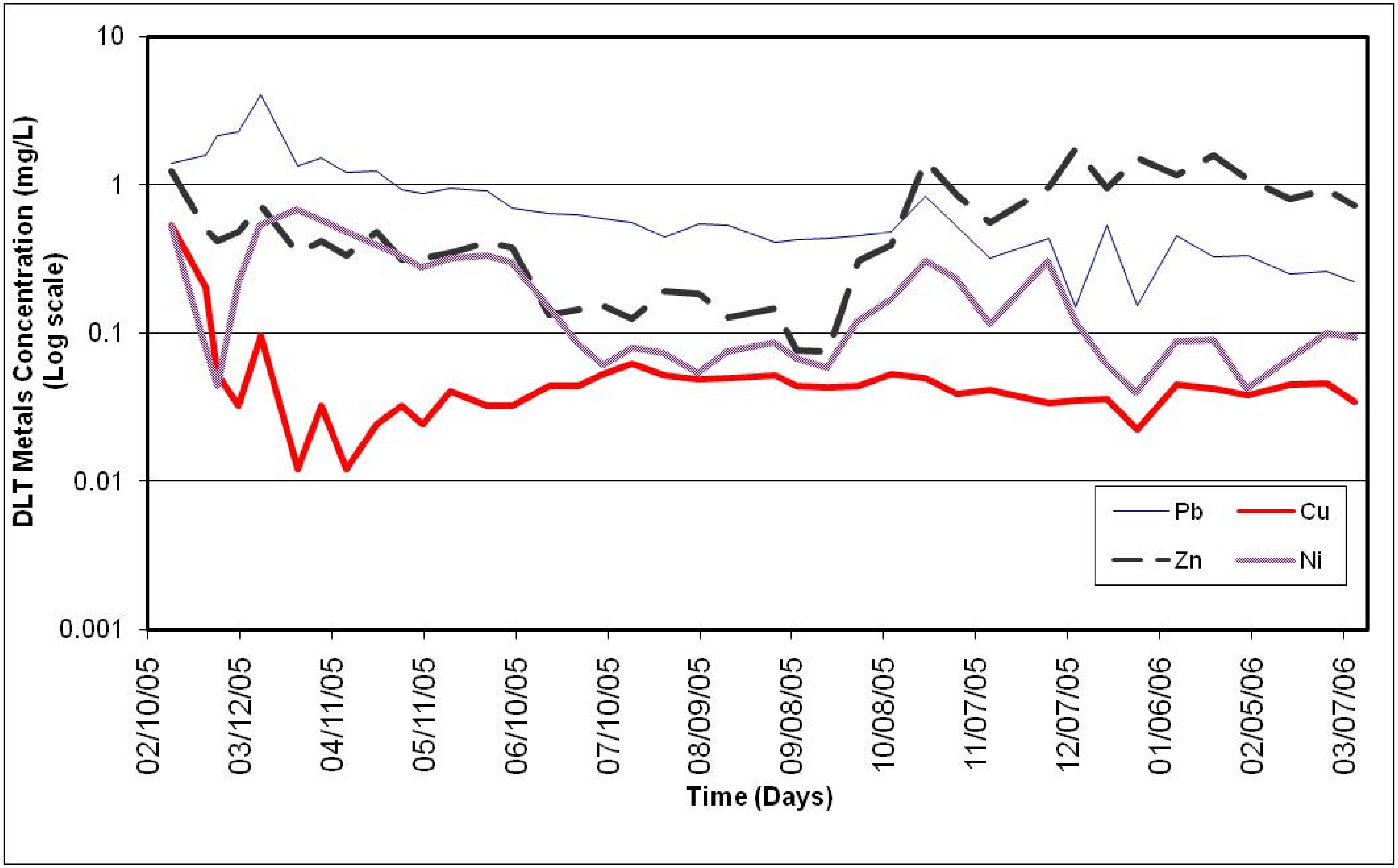


Figure 3.18 Average Amount of DLT Metals that Leached From MB-28

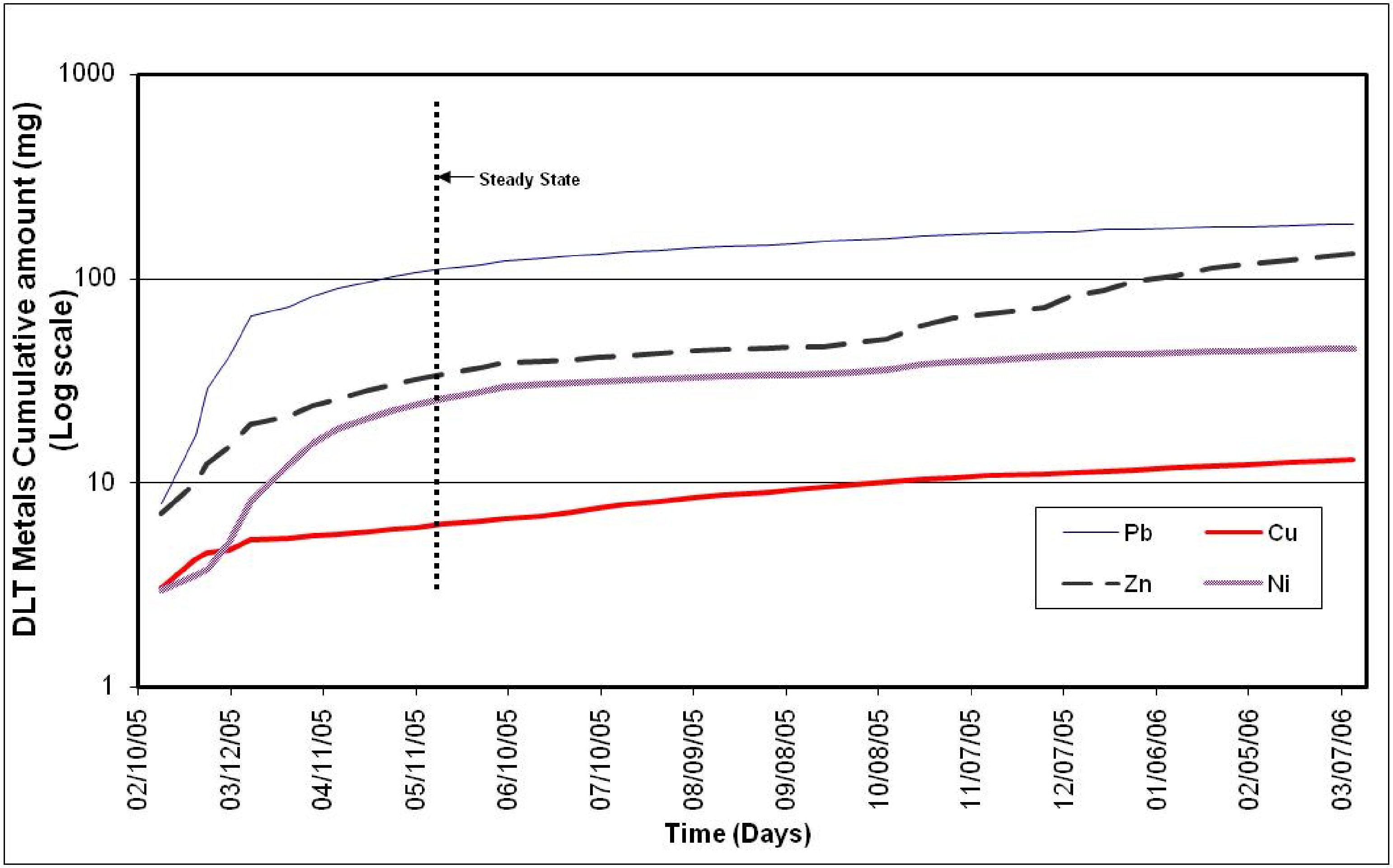


Figure 3.19 Cumulative Amount of Leached DLT Metals from MB-28

Table 3.1 Total Amount of Metals Present in the Totals

Totals (mg/kg)						
	PWB	**Std Dev (+/-)**	**LCD**	**Std Dev (+/-)**	**Casing**	**Std Dev (+/-)**
Al	14,862	19,694	232	228	148	120
Au	BDL	BDL	BDL	BDL	BDL	BDL
Ba	4901	1568	167	219	122	237
Be	BDL	BDL	BDL	BDL	BDL	BDL
Cd	BDL	BDL	BDL	BDL	BDL	BDL
Cr	18	6	8	4	12	4
Cu	185,432	18,256	47	34	43	32
Fe	2392	2744	53	32	6591	5204
Ni	3854	2090	47	82	1403	1763
Pb	24,258	9,129	77	172	9	5
Sb	1	2	8	10	3	1
Sn	152	164	33	14	2	5
Zn	6,610	10,576	27	17	93	40

BDL – Below Detection Limit

Table 3.2 Detection Limit for Tested Metals

Detection Limits (ppb)	
Al	2.0
Au	8.0
Ba	0.1
Be	0.08
Cd	0.3
Cr	0.6
Cu	0.4
Fe	0.5
Ni	0.7
Pb	0.8
Sb	0.2
Sn	60
Zn	0.1

Table 3.3 Total Weight of Each Notebook Computer and Components

Notebook Computer Tested				
Computer	**Total Notebook Weight (g)**	**PWB Weight (g)**	**Casing Weight (g)**	**LCD Screen Weight (g)**
LP-6	3,083	190	572	163
LP-7	3,050	254	628	287
LP-8	2,835	194	718	149
LP-9	1,966	177	533	130
LP-10	2,136	210	806	228

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusion

The purpose of this study was to investigate the leachablity and mobility of metals and brominated flame retardants in electronic waste. The metals analyzed included Sb, Al, Ba, Be, Cd, Cr, Cu, Au, Fe, Ni, Sn, Pb, and Zn. The BFRs analyzed include TBBPA, 2,2',4,4',5-pentaBDE, 2,2'4,4',6'-penta-BDE, deca-BDE, 2,4,4-triBDE, 2,2',4-triBDE, 2,2',4,4'-tetraBDE, 2,2',4,4',5,5'-hexaBDE, 2,2'4,4'5,6'-hexaBDE, and 2,2'3,4,4',5',6-heptaBDE. Three major components of notebook computers were used for this study: casing, LCD screens, and PWBs. These components were extracted from notebook computers manufactured in early 1990s. The notebook computers were selected based on manufacturer and availability of duplicate models.

4.1.1 Totals - Metals

- The PWB was the notebook computer component with the highest metal concentration when compared to the casing and LCD screen. Based on the amount of metals in each component, the components ranked as followed: PWB>Casing>LCD Screen.
- Cu and Pb were present in the highest concentrations in the PWB of each notebook computer tested.
- Based on the California regulation, the Cu, Pb, Ni, and Zn concentrations exceed the allowed TTLCs and all of the PWBs tested and LP-9 casing would be considered hazardous.

4.1.2 TCLP Test- Metals

- The concentration of Pb that leached from each PWB of the tested notebook computers exceeded the U.S. EPA TCLP limit and California STLC of 5.0 mg/L. Each of the PWBs leached more than 40.0 mg/L of Pb causing the PWBs to be considered a hazardous waste.

- Based on the results from the TCLP Test, Pb was determined to be the most leachable metal present in the PWBs of the notebook computers tested.

- LP-9 (Macintosh Power Book Duo 230) leached the highest concentration of Pb in casing when compared to the other computers.

- The TCLP test results suggest that although Cu was present in high concentrations in the Total metals analysis, it will not be highly mobile in the environment.

4.1.3 SPLP Test- Metals

- Pb leached noticeable concentrations from LP-9 (Macintosh Power Book Duo 230) and LP-10 (IBM Thinkpad 390E).

- Pb would leach more readily from LP-9 and LP-10 when compared to the other notebook computers tested. The results of the SPLP test support the TCLP results that LP-9 and LP-10 will be more likely to leach Pb in the highest concentration once in the environment.

4.1.4 Dynamic Leach Test – Metals

The leaching levels of these metals were much higher in TCLP extraction fluid than in SPLP extraction fluid. The toxic heavy metal Pb was found to continuously leach out of the components in the extraction fluids over the 1.5-year test periods. The cumulative amounts of Pb leached out of the motherboard in TCLP extraction fluid reached about 1.0 g per motherboard over the 1.5-year test period, and that of the mother board in SPLP extraction fluid were about 300 mg. The findings suggest that the PWBs of computers disposed of in landfills or discarded in the environment will be releasing the toxic heavy metal Pb continuously for a long time when subjected to landfill leachate or rain. Recycling obsolete PCs and recovery of materials from the PCs are highly important for the protection of the environment and human health.

4.1.5 BFR Analysis

- The analysis of the BFRs in each notebook component proved to be difficult. It was concluded that the tested BFRs were either not present in any of the notebook components tested or do not leach out in the TCLP, SPLP and Soxhlet Extraction tests.

4.2 Recommendations

- Test other computer manufacturers for there metal contents.
- Determine a better method for extracting, measuring, and analyzing BFRs in notebook computer components.
- Determine a method for segregating Pb containing components from notebook computer components before disposal.
- Perform Dynamic Leach Tests on a notebook computer and its individual components (casing, LCD Screen, and PWB).
- Perform TCLP and SPLP tests on the casings and LCD screens of notebook computers.

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APPENDIX A

METALS PROPERTIES

Table A.1 Physical Properties of Metals Analyzed

SYMBOL	FORMULA WEIGHT	SPECIFIC GRAVITY	MELTING POINT, ˚C	BOILING POINT, ˚C
Al	26.97	2.70^{20°	660	2056
Au	197.20	19.3^{20°	1063	2600
Ba	137.36	3.5	850	1140
Br	159.83	3.119^{20°	-7.2	58.78
Cd	112.41	8.65^{20°	320.9	767
Cu	63.57	8.92^{20°	1083	2300
Fe	55.85	7.03	1275	
Hg	200.61	13.546^{20°	-38.87	356.9
Ni	58.69	8.90^{20°	1452	2900
Pb	207.21	$11.337^{20^\circ/20^\circ}$	327.5	1620
Sn	118.7	7.31	231.85	2260
Zn	65.38	7.140	419.4	907

Note: Specific Gravity valves are given at room temperature (15˚C to 20˚C) unless otherwise indicated by the small figures which follow the valve: thus "11.33720˚/20˚ indicates a specific gravity of 11.337 for the substance at 20˚C to water at 20˚C. (Perry 1997

APPENDIX B

TOTAL METAL ANALYSIS DATA - PWB

Table B.1 Al Total Analysis Sample Data for Notebook Computer PWB

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.51	5,112	5,310 ± 229
	Sample #2	0.50	5,562	
	Sample #3	0.51	5,256	
LP-7	**Sample #1**	0.50	62,173	52,285 ± 8571
	Sample #2	0.51	47,715	
	Sample #3	0.50	46,967	
LP-8	**Sample #1**	0.51	6,182	6,311 ± 203
	Sample #2	0.50	6,207	
	Sample #3	0.50	6,545	
LP-9	**Sample #1**	0.51	7,257	6,923 ± 346
	Sample #2	0.50	6,946	
	Sample #3	0.51	6,566	
LP-10	**Sample #1**	0.51	2,348	3,480 ± 2306
	Sample #2	0.50	1,957	
	Sample #3	0.51	6,133	

Table B.2 Ba Total Analysis Sample Data for the Notebook Computer PWB

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.51	2,224	2,453 ± 224
	Sample #2	0.50	2,672	
	Sample #3	0.51	2,462	
LP-7	**Sample #1**	0.50	5,775	5,308 ± 572
	Sample #2	0.51	4,670	
	Sample #3	0.50	5,479	
LP-8	**Sample #1**	0.51	6,718	6,701 ± 179
	Sample #2	0.50	6,871	
	Sample #3	0.50	6,513	
LP-9	**Sample #1**	0.51	4,081	4,285 ± 197
	Sample #2	0.50	4,474	
	Sample #3	0.51	4,301	
LP-10	**Sample #1**	0.51	5,528	5,756 ± 1004
	Sample #2	0.50	4,886	
	Sample #3	0.51	6,854	

Table B.3 Cu Total Analysis Sample Data for the Notebook Computer PWB

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.507	205,127	203,301 ± 7,820
	Sample #2	0.498	210,047	
	Sample #3	0.506	194,730	
LP-7	**Sample #1**	0.500	150,624	174,722 ± 2,649
	Sample #2	0.505	170,522	
	Sample #3	0.500	203,020	
LP-8	**Sample #1**	0.506	166,597	167,905 ± 1,399
	Sample #2	0.503	169,380	
	Sample #3	0.500	167,738	
LP-9	**Sample #1**	0.505	186,929	190,552 ± 3,760
	Sample #2	0.499	194,436	
	Sample #3	0.506	190,290	
LP-10	**Sample #1**	0.505	193,821	190,680 ± 110,691
	Sample #2	0.503	207,985	
	Sample #3	0.506	170,232	

Table B.4 Fe Total Analysis Sample Data for the Notebook Computer PWB

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.51	67	69 $\pm$ 13
	Sample #2	0.50	82	
	Sample #3	0.51	57	
LP-7	**Sample #1**	0.50	7,048	7,533 $\pm$ 687
	Sample #2	0.51	8,019	
	Sample #3	0.50	Bad Data Point	
LP-8	**Sample #1**	0.51	82	89 $\pm$ 10
	Sample #2	0.50	Bad Data Point	
	Sample #3	0.50	96	
LP-9	**Sample #1**	0.51	2,894	2,841 $\pm$ 462
	Sample #2	0.50	2,355	
	Sample #3	0.51	3,275	
LP-10	**Sample #1**	0.51	1,702	1,429 $\pm$ 385
	Sample #2	0.50	Bad Data Point	
	Sample #3	0.51	1,157	

Table B.5 Pb Total Analysis Sample Data for the Notebook Computer PWB

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.51	29,623	30,356 ± 656
	Sample #2	0.50	30,555	
	Sample #3	0.51	30,889	
LP-7	**Sample #1**	0.50	17,296	17,306 ± 1278
	Sample #2	0.51	16,033	
	Sample #3	0.50	18,588	
LP-8	**Sample #1**	0.51	38,136	27,500 ± 9214
	Sample #2	0.50	21,955	
	Sample #3	0.50	22,408	
LP-9	**Sample #1**	0.51	14,116	14,088 ± 523
	Sample #2	0.50	13,552	
	Sample #3	0.51	14,596	
LP-10	**Sample #1**	0.51	42,527	32,042 ± 10302
	Sample #2	0.50	31,667	
	Sample #3	0.51	21,933	

Table B.6 Ni Total Analysis Sample Data for the Notebook Computer PWB

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.51	Bad Data Point	4,017 ± 474
	Sample #2	0.50	4,352	
	Sample #3	0.51	3,681	
LP-7	**Sample #1**	0.50	7,527	7,025 ± 715
	Sample #2	0.51	7,340	
	Sample #3	0.50	6,206	
LP-8	**Sample #1**	0.51	1,517	1,511 ± 519
	Sample #2	0.50	2,027	
	Sample #3	0.50	990	
LP-9	**Sample #1**	0.51	4,767	4,062 ± 617
	Sample #2	0.50	3,618	
	Sample #3	0.51	3,802	
LP-10	**Sample #1**	0.51	1,842	2,656 ± 1259
	Sample #2	0.50	4,106	
	Sample #3	0.51	2,021	

Table B.7 Sn Total Analysis Sample Data for the Notebook Computer PWB

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.51	21	23 ± 13
	Sample #2	0.50	11	
	Sample #3	0.51	37	
LP-7	**Sample #1**	0.50	Bad Data Point	76 ± 4
	Sample #2	0.51	73	
	Sample #3	0.50	79	
LP-8	**Sample #1**	0.51	54	40 ± 12
	Sample #2	0.50	31	
	Sample #3	0.50	35	
LP-9	**Sample #1**	0.51	366	224 ± 129
	Sample #2	0.50	115	
	Sample #3	0.51	189	
LP-10	**Sample #1**	0.51	570	395 ± 247
	Sample #2	0.50	220	
	Sample #3	0.51	Bad Data Point	

Table B.8 Zn Total Analysis Sample Data for the Notebook Computer PWB

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.51	23,565	23,688 ± 9244
	Sample #2	0.50	32,992	
	Sample #3	0.51	14,506	
LP-7	**Sample #1**	0.50	Bad Data Point	4,899 ± 1013
	Sample #2	0.51	4,183	
	Sample #3	0.50	5,615	
LP-8	**Sample #1**	0.51	347	318 ± 25
	Sample #2	0.50	305	
	Sample #3	0.50	302	
LP-9	**Sample #1**	0.51	209	171 ± 33
	Sample #2	0.50	147	
	Sample #3	0.51	158	
LP-10	**Sample #1**	0.51	2,086	1,803 ± 400
	Sample #2	0.50	1,520	
	Sample #3	0.51	Bad Data Point	

APPENDIX C

TOTAL METAL ANALYSIS DATA – LCD SCREEN

Table C.1 Al Total Analysis Sample Data for the Notebook Computer LCD Screen

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.49	66	62 ± 8.0
	Sample #2	0.51	66	
	Sample #3	0.50	52	
LP-7	**Sample #1**	0.50	427	392 ± 36
	Sample #2	0.51	355	
	Sample #3	0.50	394	
LP-8	**Sample #1**	0.50	85	81 ± 15
	Sample #2	0.50	93	
	Sample #3	0.50	64	
LP-9	**Sample #1**	0.50	45	45 ± 4.0
	Sample #2	0.51	41	
	Sample #3	0.50	48	
LP-10	**Sample #1**	0.51	495	585 ± 84
	Sample #2	0.50	601	
	Sample #3	0.50	660	

Table C.2 Ba Total Analysis Sample Data for the Notebook Computer LCD Screen

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	Sample #1	0.49	5.1	5.1 ± 0.4
	Sample #2	0.51	4.6	
	Sample #3	0.50	5.52	
LP-7	Sample #1	0.50	314	308 ± 7
	Sample #2	0.51	300	
	Sample #3	0.50	308	
LP-8	Sample #1	0.50	3.1	2.7 ± 0.4
	Sample #2	0.51	2.5	
	Sample #3	0.50	2.49	
LP-9	Sample #1	0.50	2.47	1.9 ± 0.5
	Sample #2	0.51	1.62	
	Sample #3	0.50	1.63	
LP-10	Sample #1	0.51	532	520 ± 18
	Sample #2	0.50	498	
	Sample #3	0.50	529	

Table C.3 Cu Total Analysis Sample Data for the Notebook Computer LCD Screen

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.49	83	87 ± 5.7
	Sample #2	0.51	Bad Data Point	
	Sample #3	0.50	91	
LP-7	**Sample #1**	0.50	11	13 ± 3.2
	Sample #2	0.51	16	
	Sample #3	0.50	10	
LP-8	**Sample #1**	0.50	65	84 ± 43.8
	Sample #2	0.51	103	
	Sample #3	0.50	Bad Data Point	
LP-9	**Sample #1**	0.50	14	16 ± 2.5
	Sample #2	0.51	16	
	Sample #3	0.50	19	
LP-10	**Sample #1**	0.51	Bad Data Point	33 + 10
	Sample #2	0.50	41	
	Sample #3	0.50	26	

Table C.4 Fe Total Analysis Sample Data for the Notebook Computer LCD Screen

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.49	Bad Data Point	25 ± 2.1
	Sample #2	0.51	24	
	Sample #3	0.50	27	
LP-7	**Sample #1**	0.50	18	16 ± 2.8
	Sample #2	0.51	Bad Data Point	
	Sample #3	0.50	14	
LP-8	**Sample #1**	0.50	Bad Data Point	101 ± 4.2
	Sample #2	0.50	104	
	Sample #3	0.50	98	
LP-9	**Sample #1**	0.50	56	59 ± 3.5
	Sample #2	0.51	61	
	Sample #3	0.50	Bad Data Point	
LP-10	**Sample #1**	0.51	55	64 + 12
	Sample #2	0.50	72	
	Sample #3	0.50	Bad Data Point	

Table C.5 Pb Total Analysis Sample Data for the Notebook Computer LCD Screen

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.49	5.2	3.9 ± 1.8
	Sample #2	0.51	2.6	
	Sample #3	0.50	Bad Data Point	
LP-7	**Sample #1**	0.50	3.2	3.2 ± 0.1
	Sample #2	0.51	Bad Data Point	
	Sample #3	0.50	3.1	
LP-8	**Sample #1**	0.50	307	371 ± 108
	Sample #2	0.50	310	
	Sample #3	0.50	497	
LP-9	**Sample #1**	0.50	Bad Data Point	2.4 ± 0.4
	Sample #2	0.51	2.7	
	Sample #3	0.50	2.1	
LP-10	**Sample #1**	0.51	4.0	3.8 ± 0.5
	Sample #2	0.50	4.2	
	Sample #3	0.50	3.3	

Table C.6 Ni Total Analysis Sample Data for the Notebook Computer LCD Screen

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.49	7.04	3.7 ± 3
	Sample #2	0.51	1.2	
	Sample #3	0.50	3.09	
LP-7	**Sample #1**	0.50	2.5	2.2 ± 0.4
	Sample #2	0.51	Bad Data Point	
	Sample #3	0.50	1.9	
LP-8	**Sample #1**	0.50	7.4	9.9 ± 2.2
	Sample #2	0.51	11	
	Sample #3	0.50	11	
LP-9	**Sample #1**	0.50	Bad Data Point	215 ± 75
	Sample #2	0.51	269	
	Sample #3	0.50	162	
LP-10	**Sample #1**	0.51	4.63	7.4 + 2.5
	Sample #2	0.50	8.47	
	Sample #3	0.50	9.28	

Table C.7 Sn Total Analysis Sample Data for the Notebook Computer LCD Screen

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.49	40	43 ± 5.7
	Sample #2	0.51	49	
	Sample #3	0.50	40	
LP-7	**Sample #1**	0.50	19	14 ± 10
	Sample #2	0.51	3.5	
	Sample #3	0.50	22	
LP-8	**Sample #1**	0.50	51	47 ± 6.1
	Sample #2	0.50	Bad Data Point	
	Sample #3	0.50	42	
LP-9	**Sample #1**	0.50	40	35 ± 4.7
	Sample #2	0.51	31	
	Sample #3	0.50	33	
LP-10	**Sample #1**	0.51	19	22 + 2.3
	Sample #2	0.50	24	
	Sample #3	0.50	22	

Table C.8 Zn Total Analysis Sample Data for the Notebook Computer LCD Screen

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.51	23,565	23,688 ± 9243
	Sample #2	0.50	32,992	
	Sample #3	0.51	14,506	
LP-7	**Sample #1**	0.50	Bad Data Point	4,899 ± 1012
	Sample #2	0.51	4,183	
	Sample #3	0.50	5,615	
LP-8	**Sample #1**	0.51	347	318 ± 25
	Sample #2	0.50	305	
	Sample #3	0.50	302	
LP-9	**Sample #1**	0.51	209	171 ± 33
	Sample #2	0.50	147	
	Sample #3	0.51	158	
LP-10	**Sample #1**	0.51	2,086	1,803 ± 400
	Sample #2	0.50	1,520	
	Sample #3	0.51	Bad Data Point	

APPENDIX D

TOTAL METAL ANALYSIS DATA – CASING

Table D.1 Al Total Analysis Sample Data for the Notebook Computer Casing

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.51	101	86 ± 12
	Sample #2	0.50	80	
	Sample #3	0.50	78	
LP-7	**Sample #1**	0.51	313	342 ± 48
	Sample #2	0.50	398	
	Sample #3	0.50	316	
LP-8	**Sample #1**	0.50	51	56 ± 7
	Sample #2	0.51	53	
	Sample #3	0.50	64	
LP-9	**Sample #1**	0.50	51	45 ± 7.8
	Sample #2	0.50	Bad Data Point	
	Sample #3	0.51	39	
LP-10	**Sample #1**	0.51	209	210 ± 20
	Sample #2	0.50	230	
	Sample #3	0.50	191	

Table D.2 Ba Total Analysis Sample Data for the Notebook Computer Casing

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.51	541	580 ± 33
	Sample #2	0.50	602	
	Sample #3	0.50	596	
LP-7	**Sample #1**	0.51	14	17 ± 3.1
	Sample #2	0.50	16	
	Sample #3	0.50	20	
LP-8	**Sample #1**	0.50	7.1	8.1 ± 1.0
	Sample #2	0.50	8.4	
	Sample #3	0.50	8.9	
LP-9	**Sample #1**	0.50	6.3	5 ± 1.2
	Sample #2	0.50	4.0	
	Sample #3	0.51	4.7	
LP-10	**Sample #1**	0.51	2.6	2.4 ± 0.8
	Sample #2	0.50	2.8	
	Sample #3	0.50	1.8	

Table D.3 Cu Total Analysis Sample Data for the Notebook Computer Casing

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.51	26	32 ± 12
	Sample #2	0.50	30	
	Sample #3	0.50	39	
LP-7	**Sample #1**	0.51	Bad Data Point	15 ± 2.8
	Sample #2	0.50	13	
	Sample #3	0.50	17	
LP-8	**Sample #1**	0.50	12	10 ± 2.4
	Sample #2	0.50	9.4	
	Sample #3	0.50	8.1	
LP-9	**Sample #1**	0.50	90.1	78 ± 17.7
	Sample #2	0.50	Bad Data Point	
	Sample #3	0.51	65	
LP-10	**Sample #1**	0.51	86	81 ± 9.5
	Sample #2	0.50	70	
	Sample #3	0.50	87	

Table D.4 Fe Total Analysis Sample Data for the Notebook Computer Casing

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.51	12,143	11,054 ± 1,109
	Sample #2	0.50	11,094	
	Sample #3	0.50	9,926	
LP-7	**Sample #1**	0.51	9,079	7,892 ± 1,057
	Sample #2	0.50	7,544	
	Sample #3	0.50	7,052	
LP-8	**Sample #1**	0.50	550	557 ± 9.2
	Sample #2	0.51	Bad Data Point	
	Sample #3	0.50	563	
LP-9	**Sample #1**	0.50	13,852	12,989 ± 1,220
	Sample #2	0.50	Bad Data Point	
	Sample #3	0.51	12,126	
LP-10	**Sample #1**	0.51	Bad Data Point	466 + 38
	Sample #2	0.50	434	
	Sample #3	0.50	497	

Table D.5 Pb Total Analysis Sample Data for the Notebook Computer Casing

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.51	8.1	7.2 ± 0.8
	Sample #2	0.50	6.6	
	Sample #3	0.50	6.8	
LP-7	**Sample #1**	0.51	Bad Data Point	3.5 ± 2.5
	Sample #2	0.50	1.5	
	Sample #3	0.50	5.1	
LP-8	**Sample #1**	0.50	6.8	6.5 ± 0.5
	Sample #2	0.51	Bad Data Point	
	Sample #3	0.50	6.07	
LP-9	**Sample #1**	0.50	12	13 ± 1.4
	Sample #2	0.50	Bad Data Point	
	Sample #3	0.51	14	
LP-10	**Sample #1**	0.51	15	17 ± 3.2
	Sample #2	0.50	16	
	Sample #3	0.50	21	

Table D.6 Ni Total Analysis Sample Data for the Notebook Computer Casing

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.51	1,084	1,373 ± 307
	Sample #2	0.50	1,697	
	Sample #3	0.50	1,339	
LP-7	**Sample #1**	0.51	1,463	1,427 ± 50
	Sample #2	0.50	Bad Data Point	
	Sample #3	0.50	1,391	
LP-8	**Sample #1**	0.50	2.1	2.40 ± 0.3
	Sample #2	0.50	2.4	
	Sample #3	0.50	2.6	
LP-9	**Sample #1**	0.50	5,963	4,209 ± 1559
	Sample #2	0.50	2,996	
	Sample #3	0.51	3,667	
LP-10	**Sample #1**	0.51	7.9	5.07 ± 2.7
	Sample #2	0.50	2.5	
	Sample #3	0.50	4.7	

Table D.7 Sn Total Analysis Sample Data for the Notebook Computer Casing

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.51	-2.2	-1.4 ± 0.7
	Sample #2	0.50	-0.7	
	Sample #3	0.50	-1.2	
LP-7	**Sample #1**	0.51	8.2	14.3 ± 8.3
	Sample #2	0.50	20	
	Sample #3	0.50	Bad Data Point	
LP-8	**Sample #1**	0.50	2.7	1.4 ± 1.8
	Sample #2	0.51	Bad Data Point	
	Sample #3	0.50	0.19	
LP-9	**Sample #1**	0.50	0.86	1.5 ± 1.0
	Sample #2	0.50	Bad Data Point	
	Sample #3	0.51	2.2	
LP-10	**Sample #1**	0.51	2.9	2.6 + 0.8
	Sample #2	0.50	1.7	
	Sample #3	0.50	3.3	

Table D.8 Zn Total Analysis Sample Data for Notebook Computer Casing

	Sample ID	Sample Weight (g)	Concentration (mg/kg)	Average Concentration (mg/kg)
LP-6	**Sample #1**	0.51	Bad Data Point	67 ± 14
	Sample #2	0.50	57	
	Sample #3	0.50	77	
LP-7	**Sample #1**	0.51	52	59 ± 11
	Sample #2	0.50	Bad Data Point	
	Sample #3	0.50	67	
LP-8	**Sample #1**	0.50	69	81 ± 16
	Sample #2	0.50	93	
	Sample #3	0.50	Bad Data Point	
LP-9	**Sample #1**	0.50	141	145 ± 34
	Sample #2	0.50	113	
	Sample #3	0.51	181	
LP-10	**Sample #1**	0.51	129	109 + 17
	Sample #2	0.50	99	
	Sample #3	0.50	99	

APPENDIX E

TCLP TEST DATA

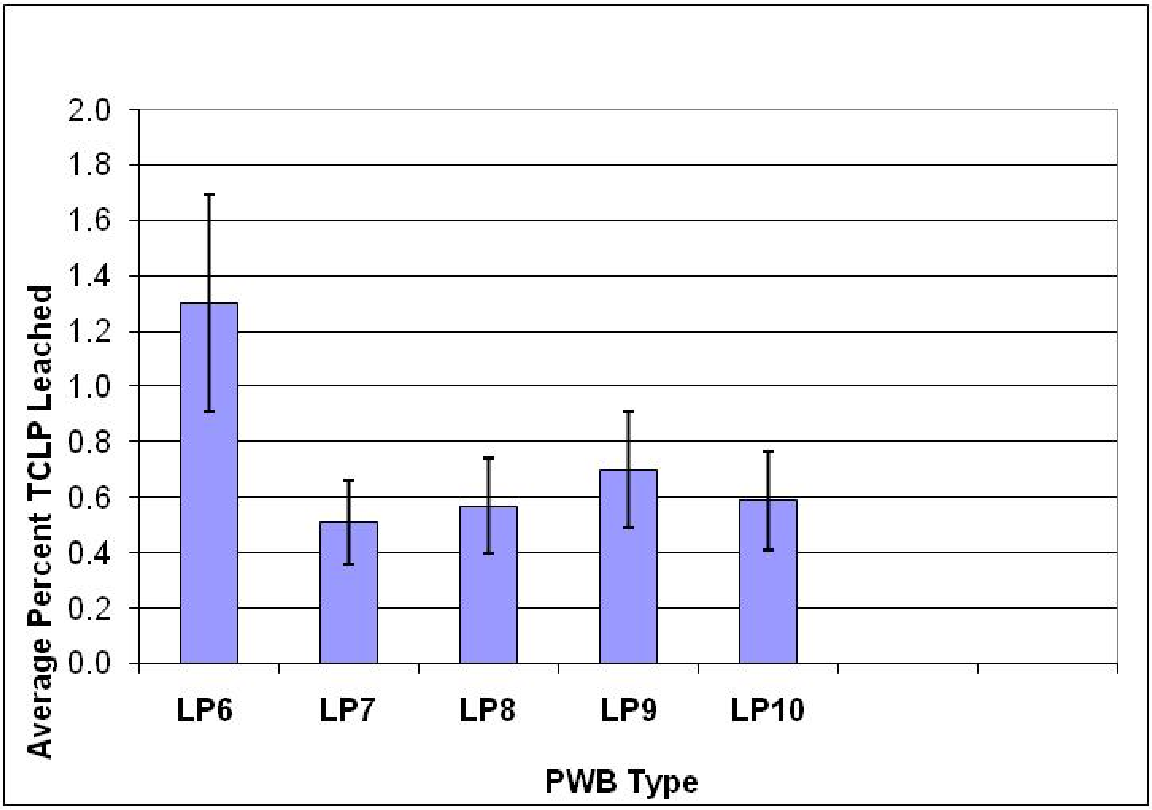

Figure E.1 Average Percent of Ba Leached from the PWB in the TCLP Test

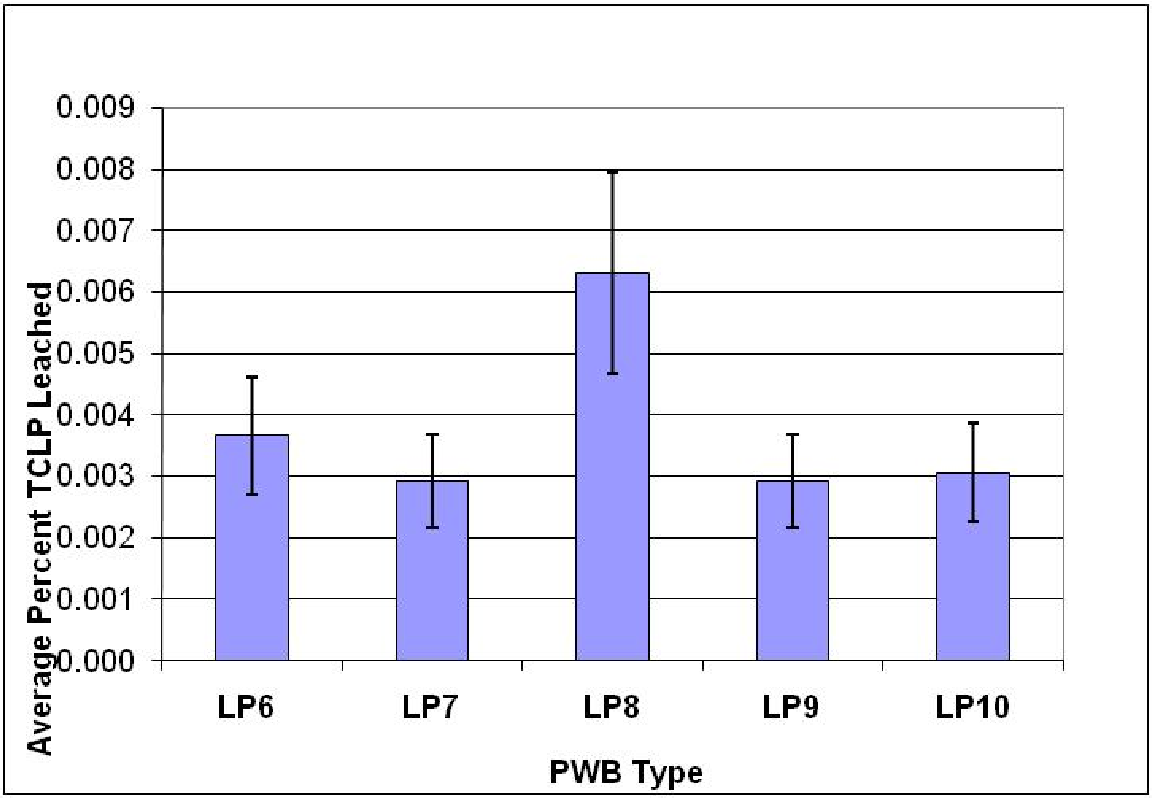

Figure E.2 Average Percent of Cu Leached from the PWB in the TCLP Test

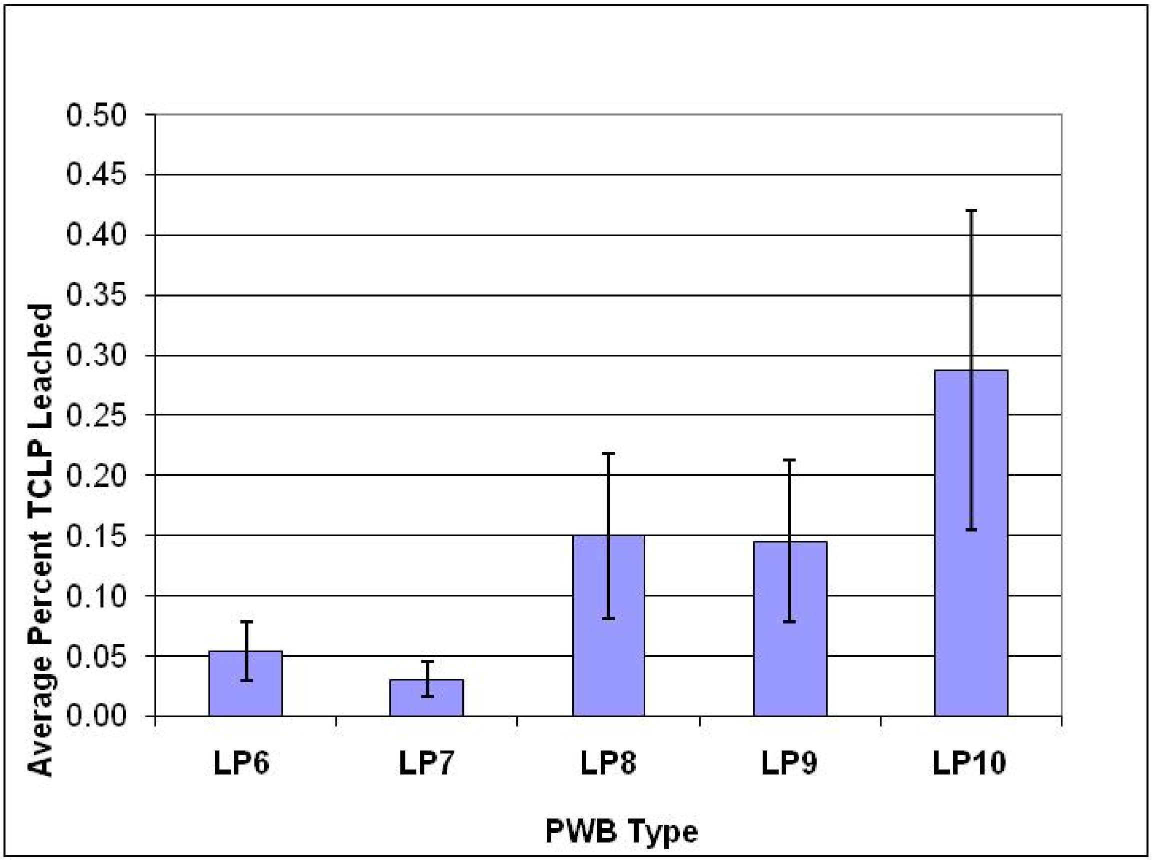

Figure E.3 Average Percent of Ni Leached from the PWB in the TCLP Test

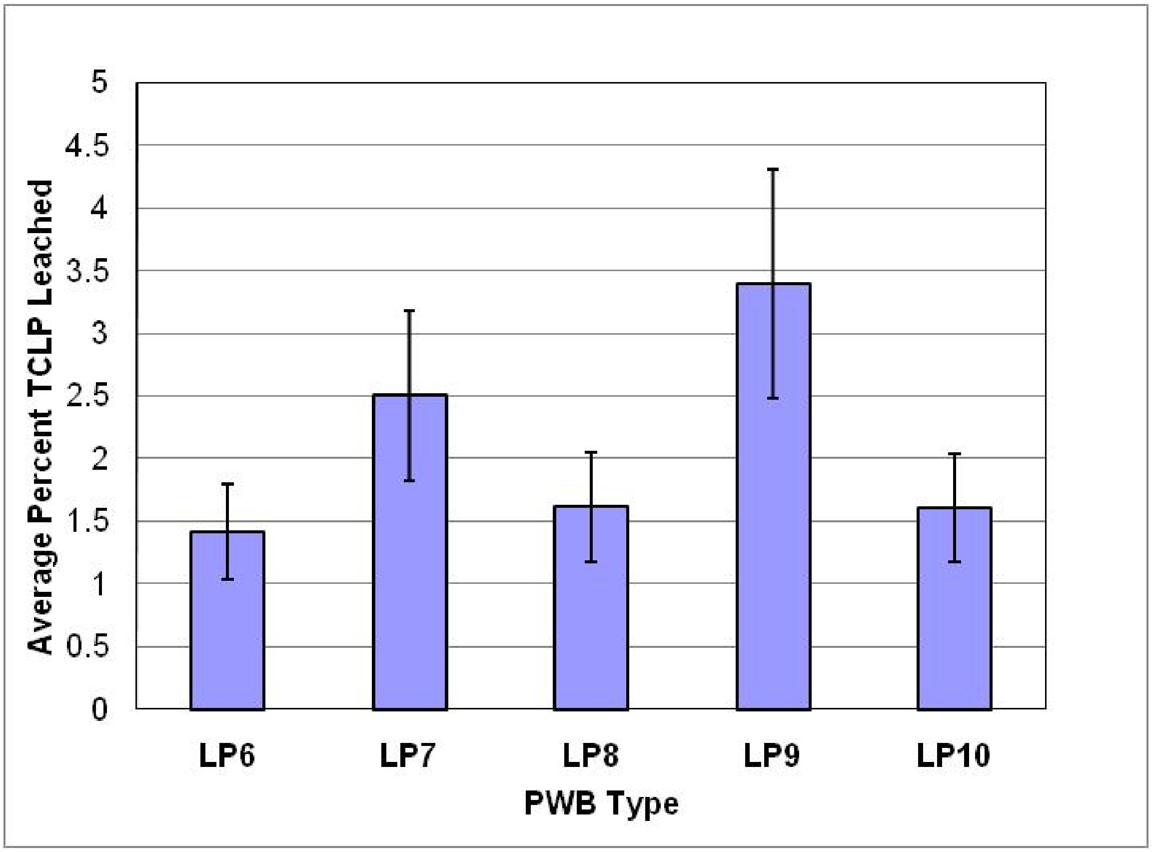

Figure E.4 Average Percent of Pb Leached from the PWB in the TCLP Test

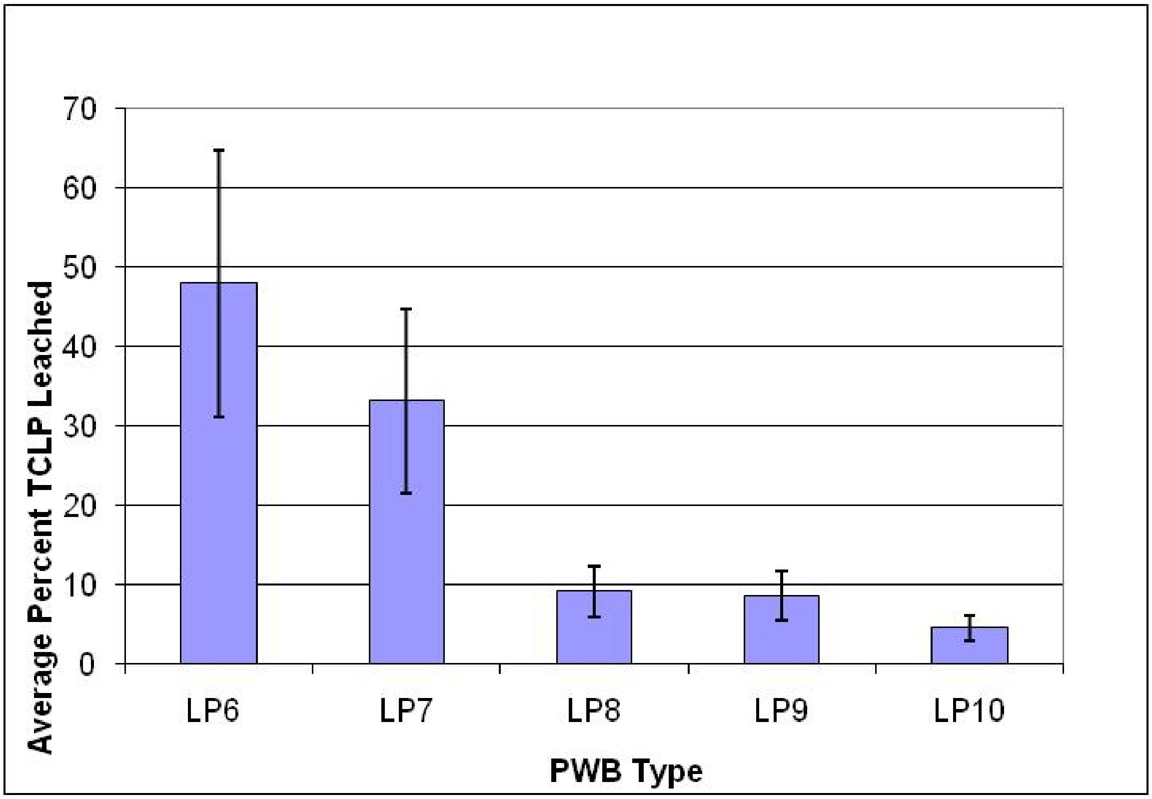

Figure E.5 Average Percent of Sn Leached from the PWB in the TCLP Test

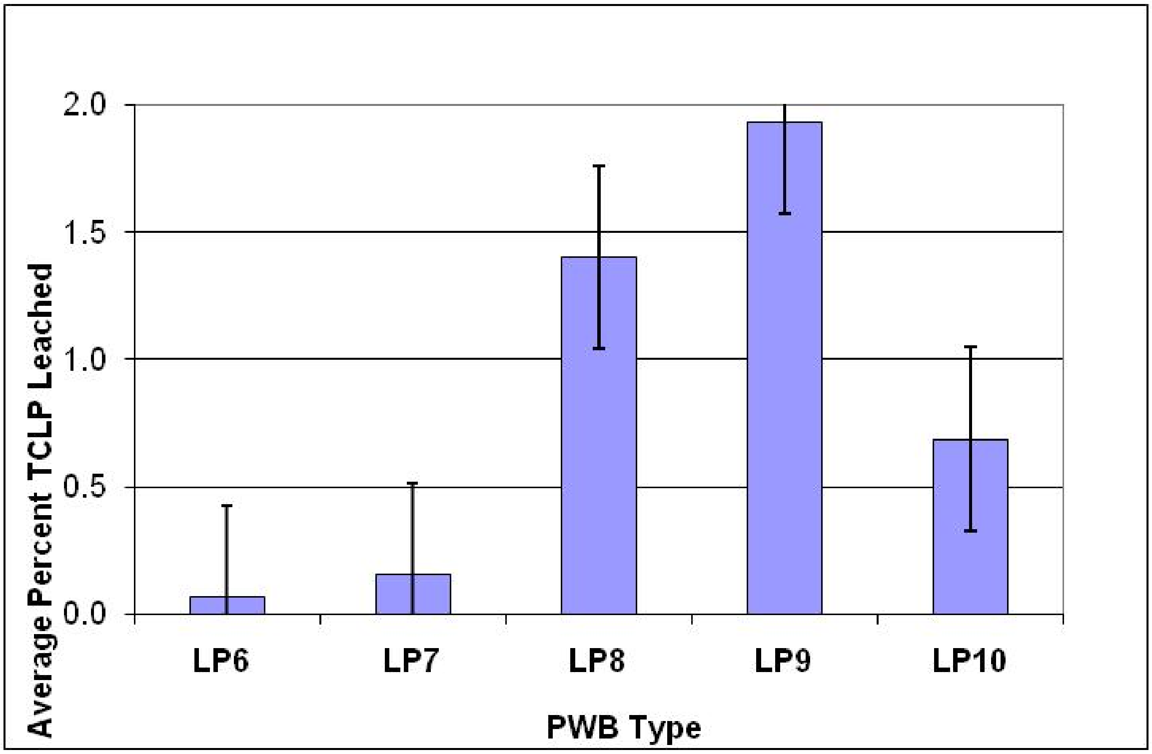

Figure E.6 Average Percent of Zn Leached from the PWB in the TCLP Test

Table E.1 Amount of Ba that Leached from the Notebook Computer PWB during the TCLP Test

	Sample ID	Sample Weight (g)	Concentration (mg/L)	Average Concentration (mg/L)	Average Concentration (mg/kg)
LP-6	Sample #1	5.01	3.19	3.19	31.91
	Sample #2	5.01	3.23		
	Sample #3	5.00	3.14		
LP-7	Sample #1	5.01	2.70	2.75	27.48
	Sample #2	5.02	2.68		
	Sample #3	5.02	2.84		
LP-8	Sample #1	5.02	3.82	3.76	37.56
	Sample #2	5.00	3.85		
	Sample #3	5.02	3.59		
LP-9	Sample #1	5.00	3.00	3.13	31.34
	Sample #2	5.01	3.16		
	Sample #3	5.00	3.24		
LP-10	Sample #1	5.01	3.39	3.59	35.91
	Sample #2	5.02	3.77		
	Sample #3	5.00	3.60		

Table E.2 Amount of Cu that Leached from the Notebook Computer PWB during the TCLP Test

	Sample ID	Sample Weight (g)	Concentration (mg/L)	Average Concentration (mg/L)	Average Concentration (mg/kg)
LP-6	Sample #1	5.01	0.744	0.62	6.20
	Sample #2	5.01	0.48		
	Sample #3	5.00	0.628		
LP-7	Sample #1	5.01	0.512	0.53	5.30
	Sample #2	5.02	0.708		
	Sample #3	5.02	0.360		
LP-8	Sample #1	5.02	1.06	0.89	8.90
	Sample #2	5.00	0.640		
	Sample #3	5.02	0.96		
LP-9	Sample #1	5.00	0.556	0.99	9.90
	Sample #2	5.01	1.292		
	Sample #3	5.00	1.136		
LP-10	Sample #1	5.01	0.584	0.52	5.20
	Sample #2	5.02	0.52		
	Sample #3	5.00	0.452		

Table E.3 Amount of Ni that Leached from the Notebook Computer PWB during the TCLP Test

	Sample ID	Sample Weight (g)	Concentration (mg/L)	Average Concentration (mg/L)	Average Concentration (mg/kg)
LP-6	Sample #1	5.01	0.204	0.22	2.17
	Sample #2	5.01	0.208		
	Sample #3	5.00	0.24		
LP-7	Sample #1	5.01	0.136	0.22	2.16
	Sample #2	5.02	0.313		
	Sample #3	5.02	0.199		
LP-8	Sample #1	5.02	0.396	0.23	2.27
	Sample #2	5.00	0.156		
	Sample #3	5.02	0.128		
LP-9	Sample #1	5.00	0.408	0.59	5.92
	Sample #2	5.01	0.568		
	Sample #3	5.00	0.800		
LP-10	Sample #1	5.01	0.764	0.76	7.64
	Sample #2	5.02	0.784		
	Sample #3	5.00	0.744		

Table E.4 Amount of Pb that Leached from the Notebook Computer PWB during the TCLP Test

	Sample ID	Sample Weight (g)	Concentration (mg/L)	Average Concentration (mg/L)	Average Concentration (mg/kg)
LP-6	Sample #1	5.01	44.09	43.00	430.0
	Sample #2	5.01	45.57		
	Sample #3	5.00	39.35		
LP-7	Sample #1	5.01	44.03	43.27	432.7
	Sample #2	5.02	44.32		
	Sample #3	5.02	41.47		
LP-8	Sample #1	5.02	42.11	44.33	443.3
	Sample #2	5.00	47.48		
	Sample #3	5.02	43.41		
LP-9	Sample #1	5.00	51.17	47.81	478.0
	Sample #2	5.01	43.99		
	Sample #3	5.00	48.26		
LP-10	Sample #1	5.01	52.84	51.35	513.4
	Sample #2	5.02	54.72		
	Sample #3	5.00	46.48		

Table E.5 Amount of Sn that Leached from the Notebook Computer PWB during the TCLP Test

	Sample ID	Sample Weight (g)	Concentration (mg/L)	Average Concentration (mg/L)	Average Concentration (mg/kg)
LP-6	Sample #1	5.01	0.71	1.13	11.29
	Sample #2	5.01	1.55		
	Sample #3	5.00	1.12		
LP-7	Sample #1	5.01	0.50	2.55	25.49
	Sample #2	5.02	2.12		
	Sample #3	5.02	5.02		
LP-8	Sample #1	5.02	0.22	0.37	3.69
	Sample #2	5.00	0.31		
	Sample #3	5.02	0.56		
LP-9	Sample #1	5.00	2.06	1.95	19.47
	Sample #2	5.01	2.08		
	Sample #3	5.00	1.69		
LP-10	Sample #1	5.01	0.66	1.80	17.99
	Sample #2	5.02	2.22		
	Sample #3	5.00	2.51		

Table E.6 Amount of Zn that Leached from the Notebook Computer PWB during the TCLP Test

	Sample ID	Sample Weight (g)	Concentration (mg/L)	Average Concentration (mg/L)	Average Concentration (mg/kg)
LP-6	Sample #1	5.01	1.13	1.62	16.19
	Sample #2	5.01	2.74		
	Sample #3	5.00	0.98		
LP-7	Sample #1	5.01	0.704	0.75	7.53
	Sample #2	5.02	0.912		
	Sample #3	5.02	0.644		
LP-8	Sample #1	5.02	0.504	0.45	4.47
	Sample #2	5.00	0.428		
	Sample #3	5.02	0.408		
LP-9	Sample #1	5.00	0.336	0.33	3.32
	Sample #2	5.01	0.304		
	Sample #3	5.00	0.356		
LP-10	Sample #1	5.01	1.15	1.24	12.41
	Sample #2	5.02	1.44		
	Sample #3	5.00	1.12		

APPENDIX F

SPLP TEST DATA

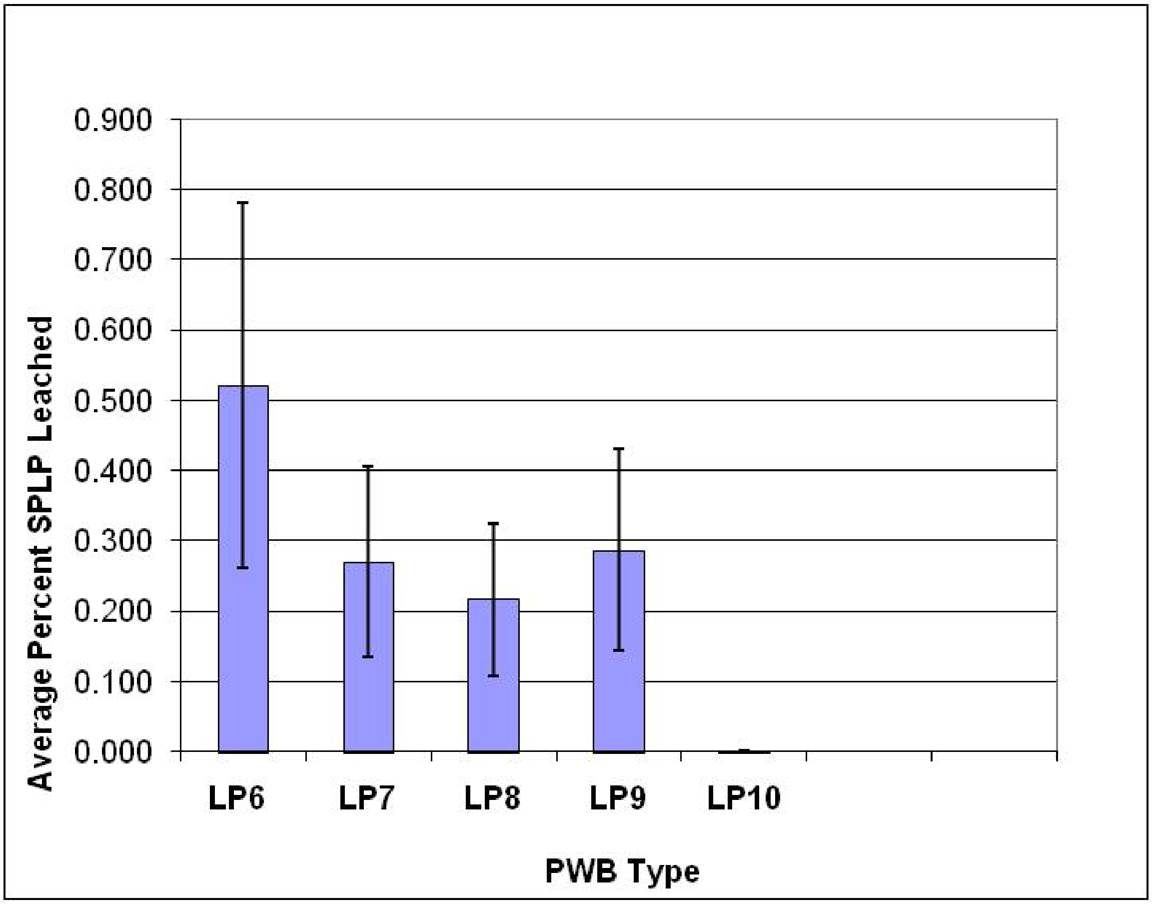

Figure F.1 Average Percent of Ba Leached from the PWB in the SPLP Test

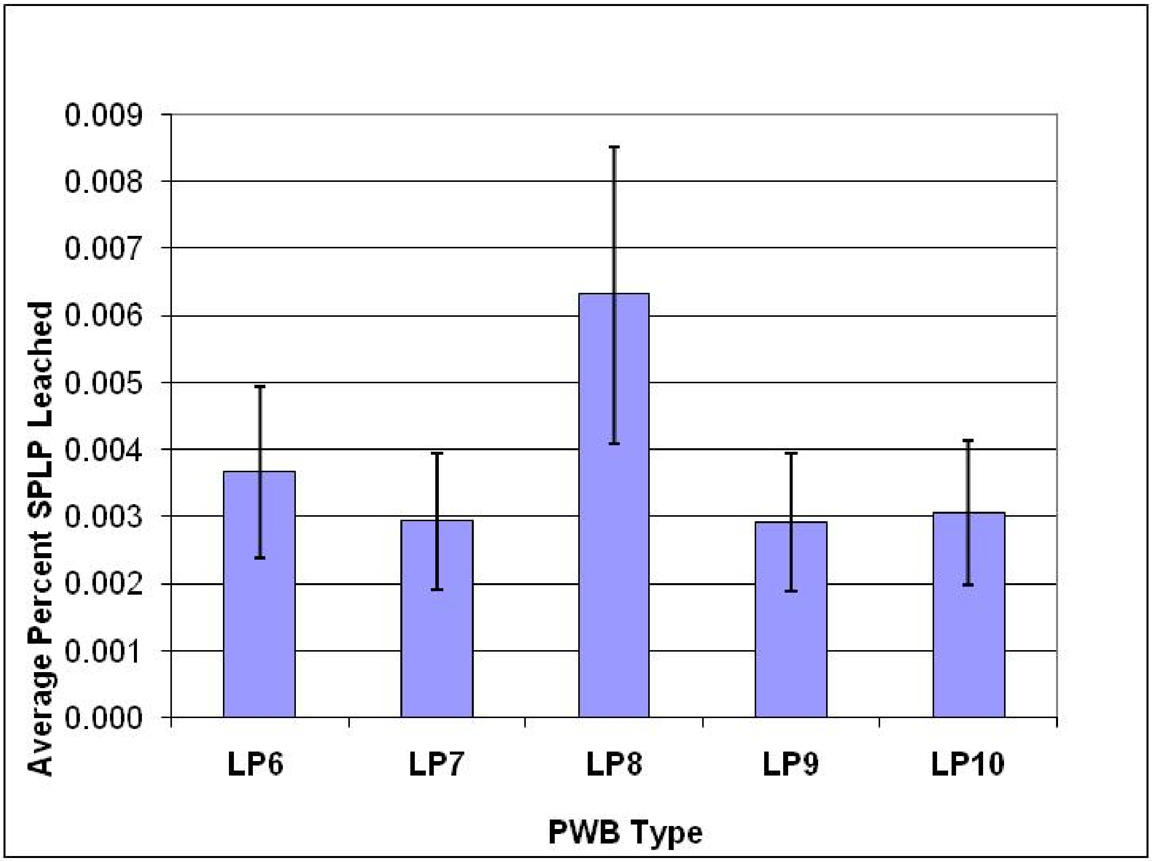

Figure F.2 Average Percent of Cu Leached from the PWB in the SPLP Test

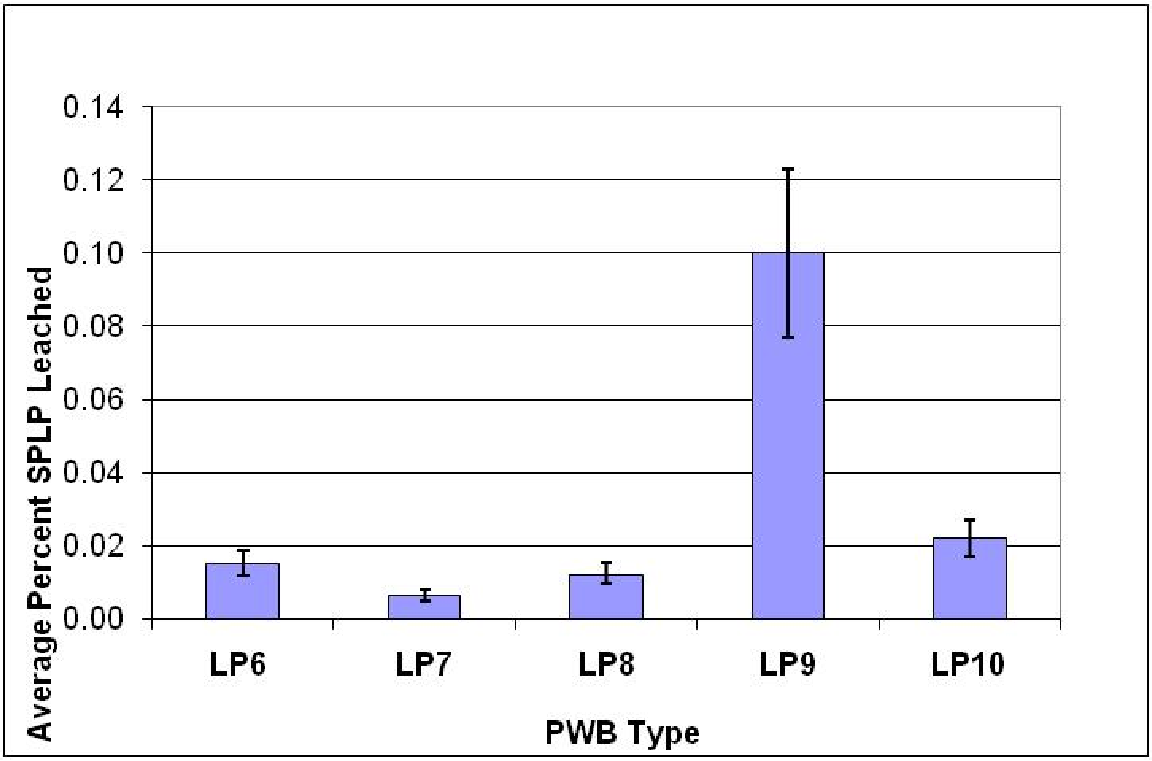

Figure F.3 Average Percent of Ni Leached from the PWB in the SPLP Test

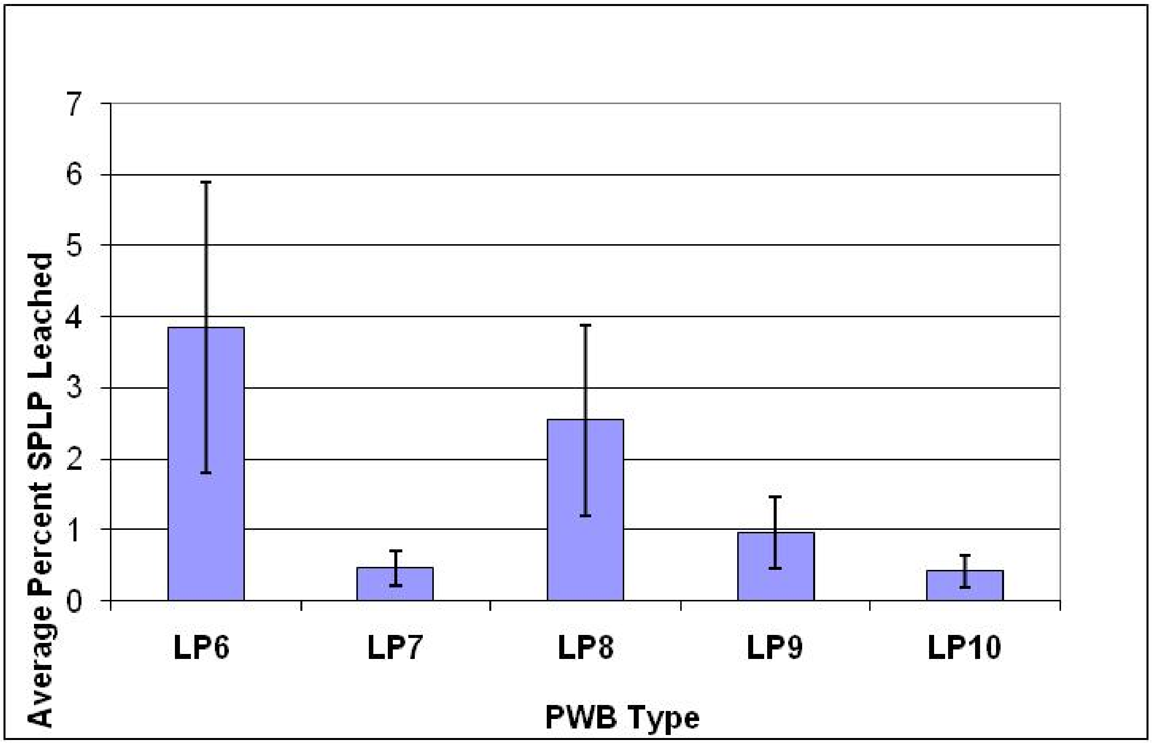

Figure F.4 Average Percent of Sn Leached from the PWB in the SPLP Test

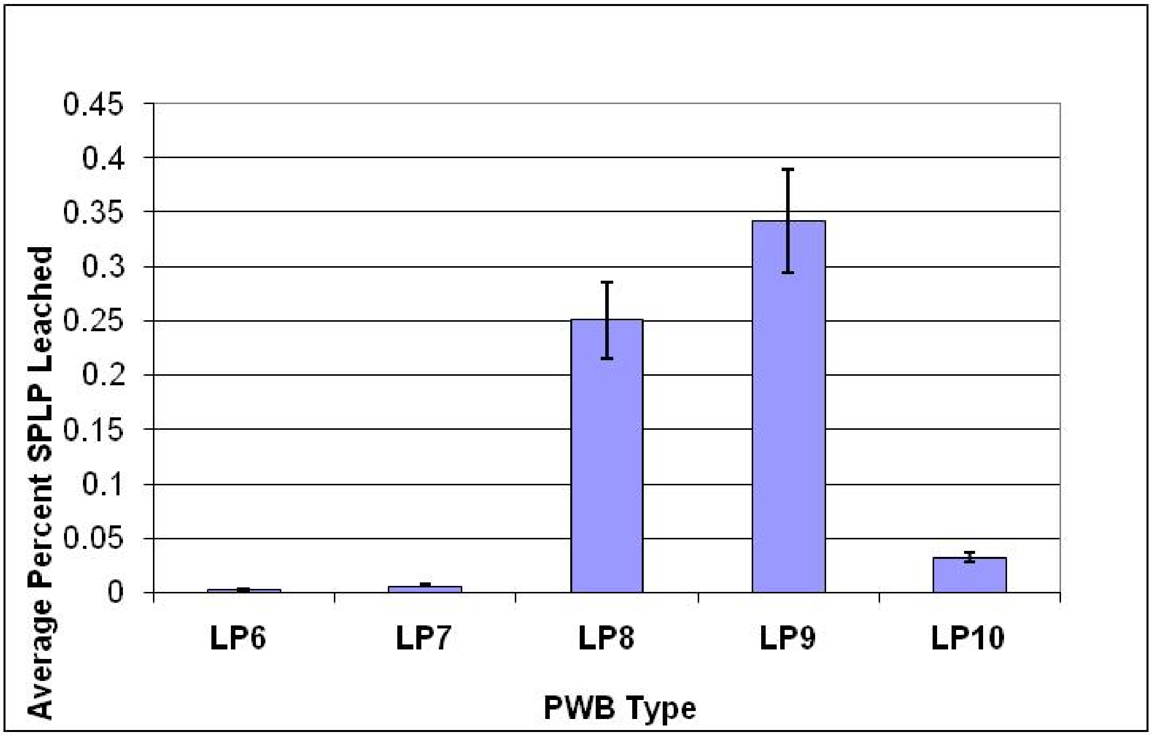

Figure F.5 Average Percent of Zn Leached from the PWB in the SPLP Test

Table F.1 Amount of Ba that Leached from the Notebook Computer PWB during the SPLP Test

	Sample ID	Sample Weight (g)	Concentration (mg/L)	Average Concentration (mg/L)	Average Concentration (mg/kg)
LP-6	Sample #1	5.01	1.35	1.28	12.8
	Sample #2	5.01	1.33		
	Sample #3	5.00	1.15		
LP-7	Sample #1	5.01	1.38	1.44	14.3
	Sample #2	5.02	1.29		
	Sample #3	5.02	1.63		
LP-8	Sample #1	5.02	1.53	1.46	14.5
	Sample #2	5.00	1.44		
	Sample #3	5.02	1.39		
LP-9	Sample #1	5.00	1.23	1.23	12.2
	Sample #2	5.01	1.33		
	Sample #3	5.00	1.12		
LP-10	Sample #1	5.01	1.89	1.97	19.6
	Sample #2	5.02	1.98		
	Sample #3	5.00	2.02		

Table F.2 Amount of Cu that Leached from the Notebook Computer PWB during the SPLP Test

	Sample ID	**Sample Weight (g)**	**Concentration (mg/L)**	**Average Concentration (mg/L)**	**Average Concentration (mg/kg)**
LP-6	Sample #1	5.01	0.004	0.01	0.12
	Sample #2	5.01	0.008		
	Sample #3	5.00	0.024		
LP-7	Sample #1	5.01	0.004	0.01	0.08
	Sample #2	5.02	0.016		
	Sample #3	5.02	0.004		
LP-8	Sample #1	5.02	0.012	0.01	0.09
	Sample #2	5.00	0.008		
	Sample #3	5.02	0.008		
LP-9	Sample #1	5.00	0.052	0.09	0.93
	Sample #2	5.01	0.208		
	Sample #3	5.00	0.02		
LP-10	Sample #1	5.01	0.024	0.02	0.19
	Sample #2	5.02	0.008		
	Sample #3	5.00	0.024		

Table F.3 Amount of Ni that Leached from the Notebook Computer PWB during the SPLP Test

	Sample ID	Sample Weight (g)	Concentration (mg/L)	Average Concentration (mg/L)	Average Concentration (mg/kg)
LP-6	Sample #1	5.01	0.040	0.05	0.47
	Sample #2	5.01	0.036		
	Sample #3	5.00	0.064		
LP-7	Sample #1	5.01	0.012	0.05	0.45
	Sample #2	5.02	0.104		
	Sample #3	5.02	0.020		
LP-8	Sample #1	5.02	0.016	0.02	0.19
	Sample #2	5.00	0.02		
	Sample #3	5.02	0.02		
LP-9	Sample #1	5.00	0.276	0.41	4.07
	Sample #2	5.01	0.62		
	Sample #3	5.00	0.324		
LP-10	Sample #1	5.01	0.084	0.06	0.59
	Sample #2	5.02	0.028		
	Sample #3	5.00	0.064		

Table F.4 Amount of Pb that Leached from the Notebook Computer PWB during the SPLP Test

	Sample ID	Sample Weight (g)	Concentration (mg/L)	Average Concentration (mg/L)	Average Concentration (mg/kg)
LP-6	Sample #1	5.01	1.80	3.50	35.0
	Sample #2	5.01	3.80		
	Sample #3	5.00	4.90		
LP-7	Sample #1	5.01	Bad Data Point	1.00	9.00
	Sample #2	5.02	1.50		
	Sample #3	5.02	0.30		
LP-8	Sample #1	5.02	2.30	3.02	30.20
	Sample #2	5.00	4.00		
	Sample #3	5.02	2.80		
LP-9	Sample #1	5.00	5.00	5.30	53.0
	Sample #2	5.01	6.10		
	Sample #3	5.00	4.80		
LP-10	Sample #1	5.01	9.90	8.90	89.0
	Sample #2	5.02	7.50		
	Sample #3	5.00	9.20		

Table F.5 Amount of Sn that Leached from the Notebook Computer PWB during the SPLP Test

	Sample ID	Sample Weight (g)	Concentration (mg/L)	Average Concentration (mg/L)	Average Concentration (mg/kg)
LP-6	Sample #1	5.01	0.08	0.09	0.91
	Sample #2	5.01	0.10		
	Sample #3	5.00	0.10		
LP-7	Sample #1	5.01	0.09	0.09	0.91
	Sample #2	5.02	0.10		
	Sample #3	5.02	0.08		
LP-8	Sample #1	5.02	0.10	0.10	1.03
	Sample #2	5.00	0.10		
	Sample #3	5.02	0.10		
LP-9	Sample #1	5.00	0.10	0.21	2.20
	Sample #2	5.01	0.43		
	Sample #3	5.00	0.11		
LP-10	Sample #1	5.01	0.10	0.12	1.16
	Sample #2	5.02	0.11		
	Sample #3	5.00	0.14		

Table F.6 Amount of Zn that Leached from the Notebook Computer PWB during the SPLP Test

	Sample ID	Sample Weight (g)	Concentration (mg/L)	Average Concentration (mg/L)	Average Concentration (mg/kg)
LP-6	Sample #1	5.01	0.03	0.05	0.52
	Sample #2	5.01	0.08		
	Sample #3	5.00	0.04		
LP-7	Sample #1	5.01	0.02	0.02	0.23
	Sample #2	5.02	0.02		
	Sample #3	5.02	0.02		
LP-8	Sample #1	5.02	0.12	0.08	0.80
	Sample #2	5.00	0.05		
	Sample #3	5.02	0.06		
LP-9	Sample #1	5.00	0.04	0.06	0.59
	Sample #2	5.01	0.06		
	Sample #3	5.00	0.08		
LP-10	Sample #1	5.01	0.06	0.04	0.43
	Sample #2	5.02	0.03		
	Sample #3	5.00	0.03		

APPENDIX G

SPLP VS TCLP DATA

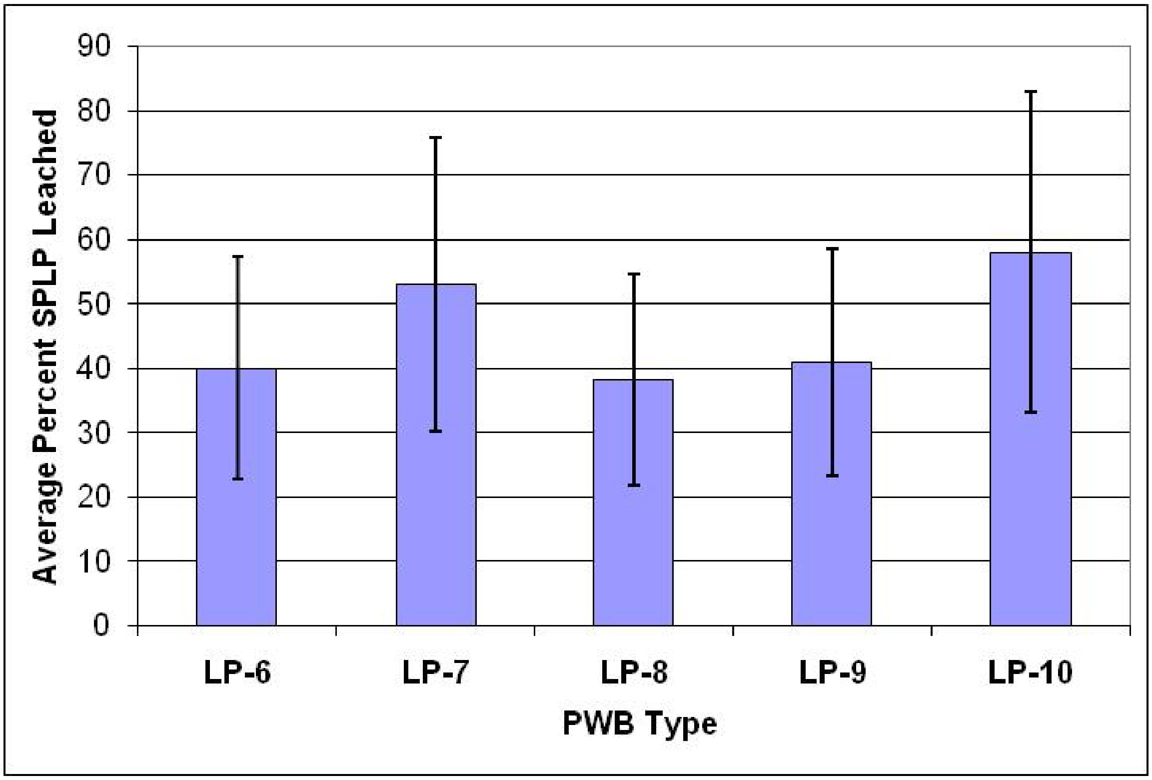

Figure G.1 Percentage of Ba Leached from the PWB in the SPLP vs TCLP

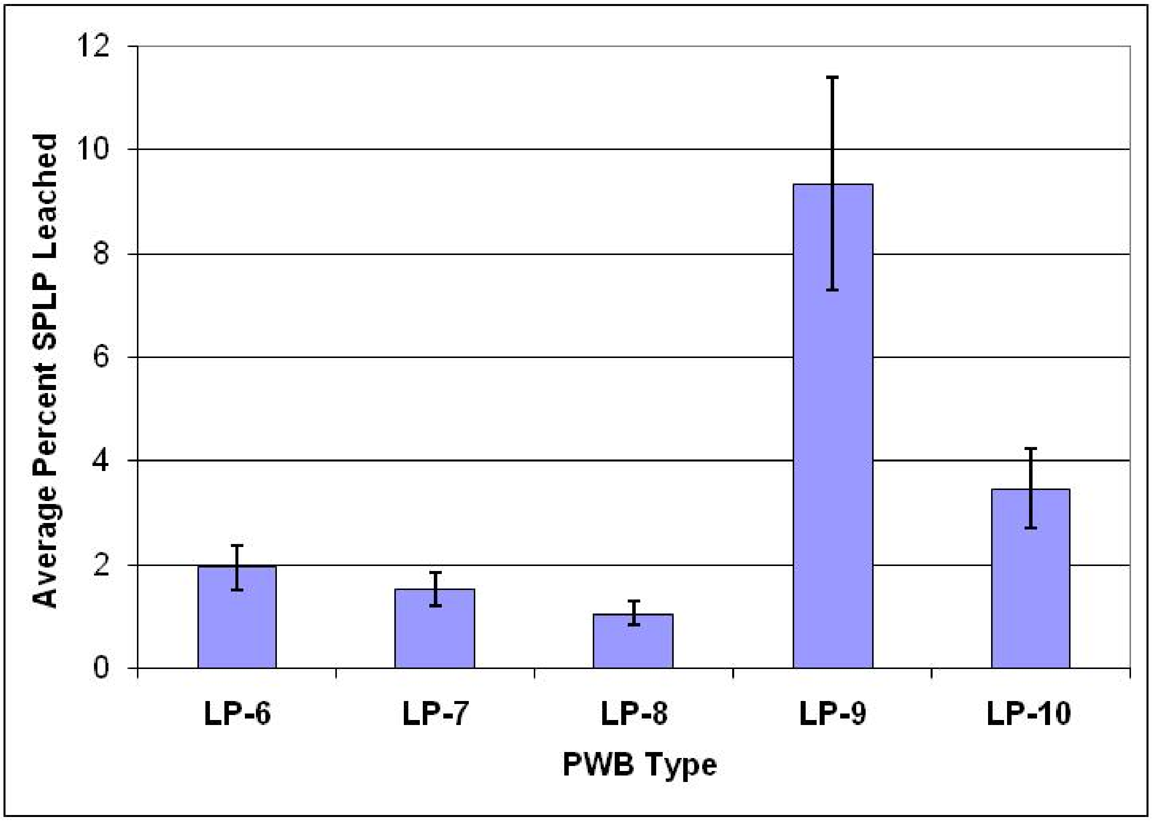

Figure G.2 Average Percent of Cu Leached from the PWB in the SPLP vs TCLP

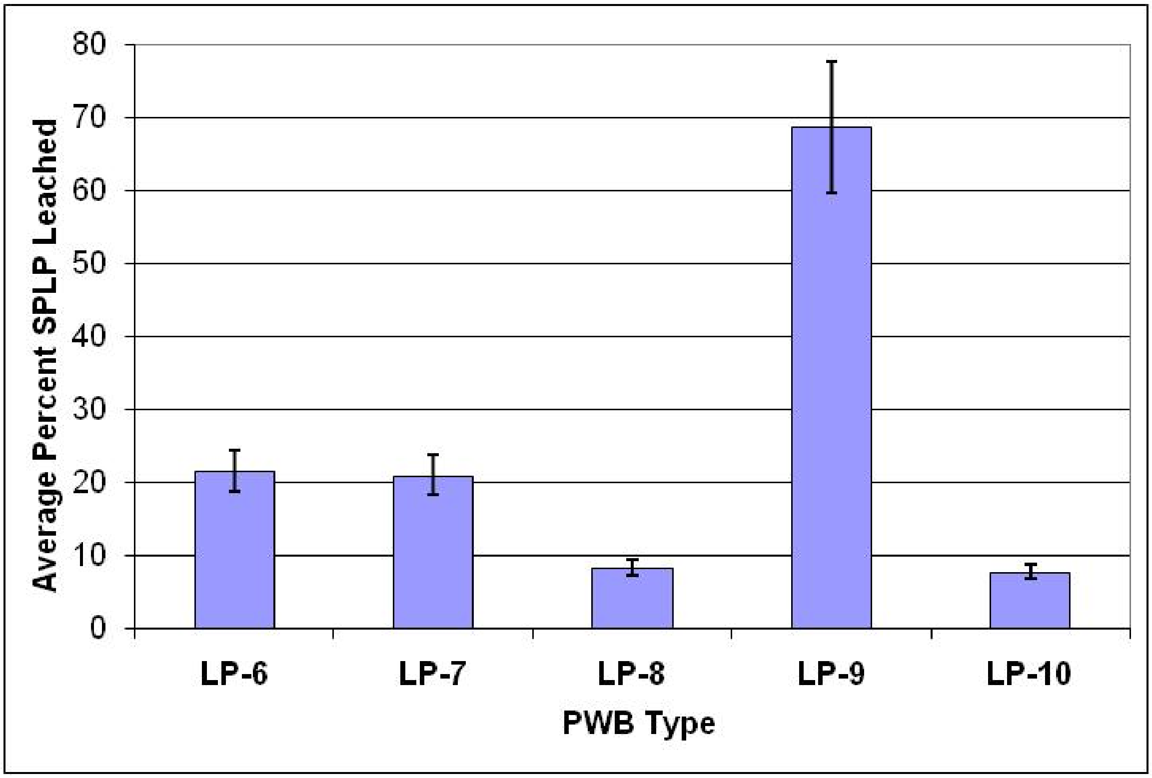

Figure G.3 Average Percentage of Ni Leached from the PWB in the SPLP vs TCLP

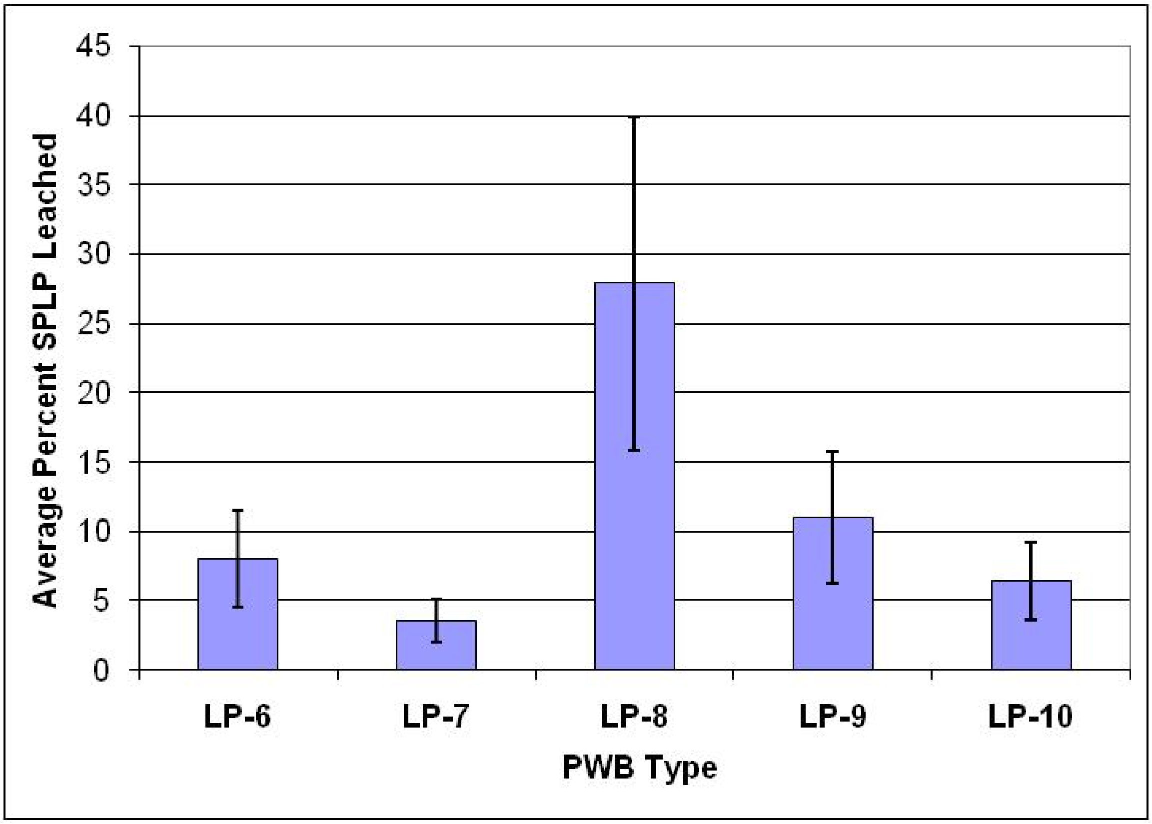

Figure G.4 Average Percentage of Sn Leached from the PWB in the SPLP vs TCLP

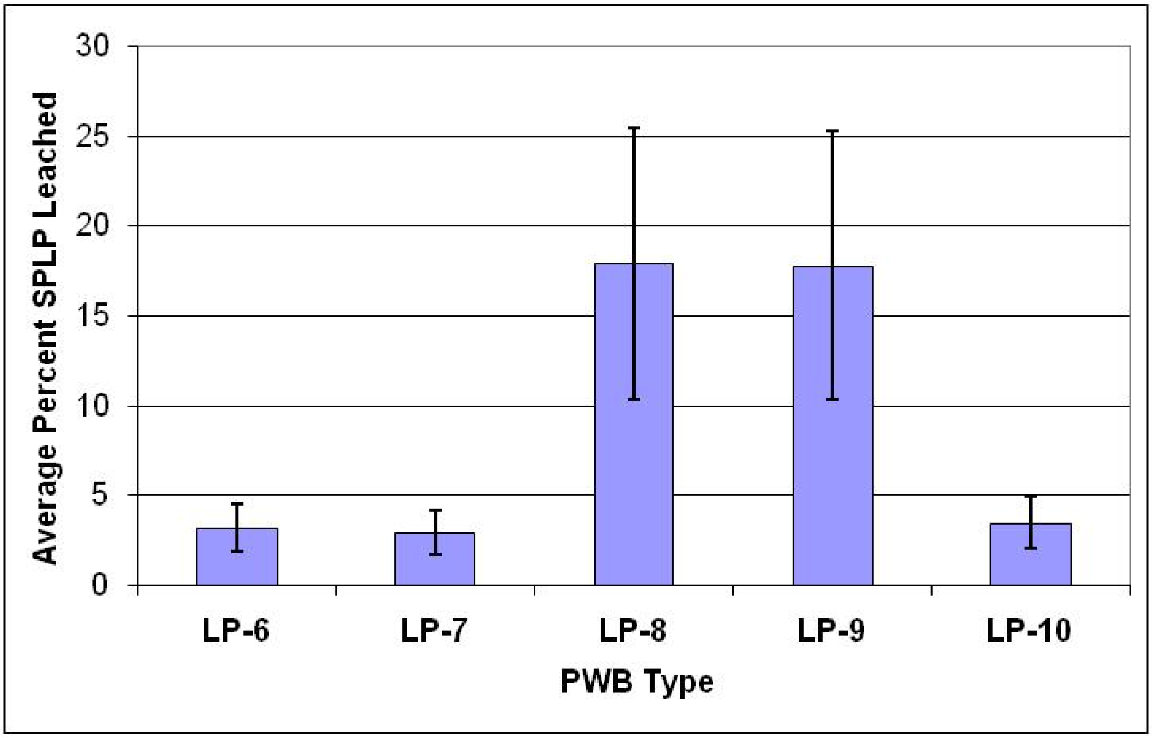

Figure G.5 Average Percentage of Zn Leached from the PWB in the SPLP vs TCLP

APPENDIX H

DYNAMIC LEACH TEST DATA- MB-21

Table H.1 Metal Concentration of MB-21 that Leached

MB-21 CONCENTRATION					
Time (Days)	**Sample #**	**Cu (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Zn (mg/kg)**
1	Leaching started	0.0	0.0	0.0	0.0
2	Sample # 1	0.5	0.6	46.5	484.0
5	Sample # 2	1.7	0.3	31.4	409.8
9	Sample # 3	0.9	0.4	179.3	203.2
12	Sample # 4	0.5	0.3	60.4	89.1
16	Sample # 5	1.0	0.4	109.5	117.0
21	Sample # 6	0.8	0.5	77.3	103.7
24	Sample # 7	0.3	0.7	157.4	93.2
29	Sample # 8	0.4	0.8	79.0	106.7
34	Sample # 9	0.5	1.8	103.8	83.3
37	Sample # 10	0.8	1.6	129.7	42.3
41	Sample # 11	0.8	1.9	70.6	39.6
45	Sample # 12	0.3	2.4	74.0	11.7
50	Sample # 13	0.3	3.6	99.3	4.7
57	Sample # 14	0.2	7.4	88.5	6.7
64	Sample # 15	0.3	7.2	51.1	5.9
71	Sample # 16	0.3	11.1	74.3	5.3
78	Sample # 17	0.3	10.6	48.3	5.4
85	Sample # 18	0.4	14.1	47.5	6.3
94	Sample # 19	0.4	17.8	41.0	3.3
101	Sample # 20	0.3	27.0	57.6	9.1
108	Sample # 21	0.6	13.6	27.9	3.2

Table H.1 (Continued)

MB-21 CONCENTRATION					
Time (Days)	**Sample #**	**Cu (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Zn (mg/kg)**
115	Sample # 22	0.4	17.7	76.7	0.8
122	Sample # 23	0.4	24.8	39.2	6.6
127	Sample # 24	1.4	19.5	24.9	0.7
136	Sample # 25	0.2	29.3	40.5	1.3
143	Sample # 26	0.4	17.9	25.2	6.1
150	Sample # 27	0.4	27.2	30.5	1.9
160	Sample # 28	1.8	29.2	51.7	1.8
164	Sample # 29	0.6	13.8	19.6	1.2
171	Sample # 30	1.4	28.9	28.9	1.3
185	Sample # 31	1.2	58.1	47.2	6.1
202	Sample # 32	1.6	67.4	49.8	1.9
214	Sample # 33	1.4	39.9	35.3	1.7
241	Sample # 34	0.7	97.6	28.9	4.5
264	Sample # 35	1.3	66.4	26.7	2.4
282	Sample # 36	1.6	39.8	46.2	1.2
295	Sample # 37	1.8	48.6	43.2	1.3
308	Sample # 38	2.1	61.7	47.7	3.5
318	Sample # 39	2.4	69.6	38.6	3.8
349	Sample # 40	1.1	67.6	26.0	6.0
364	Sample # 41	3.2	83.0	105.0	4.9
377	Sample # 42	2.4	51.1	66.3	3.2
387	Sample # 43	2.0	58.7	29.1	3.6

Table H.1 (Continued)

MB-21 CONCENTRATION					
Time (Days)	Sample #	Cu (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
402	Sample # 44	1.8	59.2	30.9	4.8
415	Sample # 45	3.9	51.0	23.0	2.0
426	Sample # 46	2.0	38.1	29.6	1.3
439	Sample # 47	2.6	32.2	24.7	1.7
451	Sample # 48	3.4	21.7	26.5	2.1
464	Sample # 49	2.7	27.2	32.4	1.8
478	Sample # 50	1.7	26.6	31.6	1.7
488	Sample # 51	3.3	21.8	25.3	1.3
500	Sample # 52	2.3	30.3	51.1	1.8
508	Sample # 53	3.4	16.7	37.3	1.5
519	Sample # 54	3.2	27.7	113.1	5.2
531	Sample # 55	2.6	45.6	85.3	5.4
541	Sample # 56	2.8	34.8	101.5	6.9
552	Sample # 57	3.1	70.2	62.4	5.4
562	Sample # 58	4.1	44.8	39.9	5.0
573	Sample # 59	3.2	43.6	79.9	4.3
583	Sample # 60	3.5	21.5	54.3	3.9
605	Sample # 61	2.7	29.5	42.0	5.4
615	Sample # 62	2.9	34.7	29.3	2.5
628	Sample # 63	3.7	35.5	31.0	4.5
640	Sample # 64	3.0	25.2	28.7	4.6
651	Sample # 65	3.5	46.4	36.3	4.2
665	Sample # 66	4.0	68.5	51.3	3.4
676	Sample # 67	3.4	56.5	42.8	3.3

APPENDIX I

DYNAMIC LEACH TEST DATA – MB-28

Table I.1 Metal Concentration of MB-28 that Leached

MB-28 CONCENTRATION					
Time (Days)	**Sample #**	**Cu (mg/kg)**	**Ni (mg/kg)**	**Pb (mg/kg)**	**Zn (mg/kg)**
1	Leaching started	0.01	0.01	0.01	0.01
2	Sample # 1	5.68	5.59	14.73	13.11
5	Sample # 2	2.18	0.90	16.78	5.34
9	Sample # 3	0.56	0.47	22.67	4.48
12	Sample # 4	0.34	2.35	24.25	5.17
16	Sample # 5	1.02	5.76	42.83	7.69
21	Sample # 6	0.13	7.39	14.30	3.71
24	Sample # 7	0.34	6.15	16.23	4.44
29	Sample # 8	0.13	5.17	12.90	3.59
34	Sample # 9	0.26	4.18	13.15	5.17
37	Sample # 10	0.34	3.59	9.82	3.37
41	Sample # 11	0.26	2.95	9.31	3.42
45	Sample # 12	0.43	3.42	10.12	3.71
50	Sample # 13	0.34	3.54	9.69	4.40
57	Sample # 14	0.34	3.20	7.43	4.06
64	Sample # 15	0.46	1.64	6.79	1.43
71	Sample # 16	0.47	0.91	6.64	1.54
78	Sample # 17	0.56	0.65	6.32	1.64
85	Sample # 18	0.67	0.85	5.97	1.34

Table I.1 (Continued)

MB-28 CONCENTRATION, mg/kg					
Time (Days)	Sample #	Cu (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
94	Sample # 19	0.54	0.79	4.72	2.06
101	Sample # 20	0.51	0.58	5.79	1.99
108	Sample # 21	0.53	0.80	5.64	1.35
115	Sample # 22	0.55	0.92	4.40	1.58
122	Sample # 23	0.47	0.73	4.56	0.82
127	Sample # 24	0.46	0.63	4.68	0.80
136	Sample # 25	0.47	1.29	4.83	3.28
143	Sample # 26	0.56	1.81	5.19	4.19
150	Sample # 27	0.53	3.32	8.85	15.51
160	Sample # 28	0.41	2.53	5.54	9.13
164	Sample # 29	0.43	1.23	3.44	5.91
171	Sample # 30	0.35	3.27	4.64	10.21
185	Sample # 31	0.37	1.28	1.61	18.53
202	Sample # 32	0.38	0.67	5.65	10.16
214	Sample # 33	0.24	0.42	1.63	16.07
241	Sample # 34	0.48	0.95	4.85	12.32
264	Sample # 35	0.44	0.97	3.48	16.66
282	Sample # 36	0.40	0.45	3.54	11.69
295	Sample # 37	0.48	0.73	2.65	8.51
308	Sample # 38	0.48	1.07	2.80	9.92
318	Sample # 39	0.37	1.01	2.39	7.75

APPENDIX J

BROMINATED FLAME RETARDANTS DATA – SOXHLET EXTRACTION

Table J.1 Concentration of BFRs in Total Extraction for Notebook Computer PWB

Sample	Sample ID	Volume (mL)	Compunds (mg/L)						
			Tri-BDE	TBDE	BDE-100	BDE-099	HX-BDE	HX-BDE	HP-BDE
LP-6	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-7	Sample #1	1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-8	Sample #1	1.0	0.14	0.00	0.44	0.00	0.00	0.00	0.00
	Sample #2	1.3	0.21	0.00	0.72	0.00	0.00	0.00	0.00
	Sample #3	1.0	1.44	0.00	0.26	0.00	0.00	0.00	0.00
LP-9	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-10	Sample #1	1.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table J.2 Concentration of BFRs in Total Extraction for Notebook Computer LCD Screen

Sample	Sample ID	Volume (mL)	Compunds (mg/L)						
			Tri-BDE	TBDE	BDE-100	BDE-099	HX-BDE	HX-BDE	HP-BDE
LP-6	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-7	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-8	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.0	0.00	0.00	0.26	0.00	0.00	0.00	0.00
LP-9	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-10	Sample #1	0.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table J.3 Concentration of BFRs in Total Extraction for Notebook Computer Casing

Sample	Sample ID	Volume (mL)	Compunds (mg/L)						
			Tri-BDE	TBDE	BDE-100	BDE-099	HX-BDE	HX-BDE	HP-BDE
LP-6	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-7	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-8	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.0	0.00	0.00	0.26	0.00	0.00	0.00	0.00
LP-9	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-10	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX K

BROMINATED FLAME RETARDANTS DATA - TCLP

Table K.1 Concentration of BFRs in TCLP Leachate for Notebook Computer PWB

Sample	Sample ID	Volume (mL)	Compunds (mg/L)						
			Tri-BDE	TBDE	BDE-100	BDE-099	HX-BDE	HX-BDE	HP-BDE
LP-6	Sample #1	1.20	0.00	0.93	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.00	0.00	6.64	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-7	Sample #1	1.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-8	Sample #1	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.00	0.00	0.00	0.42	0.00	0.00	0.00	0.00
	Sample #3	1.20	0.18	5.42	0.18	0.00	0.00	0.00	0.00
LP-9	Sample #1	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-10	Sample #1	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table K.2 Concentration of BFRs in TCLP Leachate for Notebook Computer LCD Screen

Sample	Sample ID	Volume (mL)	Compunds (mg/L)						
			Tri-BDE	TBDE	BDE-100	BDE-099	HX-BDE	HX-BDE	HP-BDE
LP-6	Sample #1	1.2	0.17	1.53	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.5	0.00	2.48	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.6	0.23	4.87	0.00	0.00	0.00	0.00	0.00
LP-7	Sample #1	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-8	Sample #1	1.50	4.63	76.44	5.05	0.00	7.37	2.66	5.48
	Sample #2	1.50	27.89	58.29	45.91	5.94	76.67	12.11	144.51
	Sample #3	0.60	153.72	828.29	33.06	5.01	61.21	18.30	134.12
LP-9	Sample #1	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-10	Sample #1	1	1.03	0.00	1.89	0.00	1.86	0.00	1.70
	Sample #2	1	0.26	4.80	0.49	0.00	0.54	0.00	0.70
	Sample #3	1	0.00	2.19	0.42	0.00	0.20	0.00	0.00

Table K.3 Concentration of BFRs in TCLP Leachate for Notebook Computer Casing

Sample	Sample ID	Volume (mL)	Compunds (mg/L)						
			Tri-BDE	TBDE	BDE-100	BDE-099	HX-BDE	HX-BDE	HP-BDE
LP-6	Sample #1	1.6	0.00	0.10	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.5	0.20	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.4	0.33	0.00	0.00	0.00	0.00	0.00	0.00
LP-7	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.5	0.00	0.81	0.30	0.32	0.00	0.00	0.00
	Sample #3	1.0	0.00	0.72	0.41	0.00	0.00	0.00	0.00
LP-8	Sample #1	1.0	25.88	80.74	76.41	0.00	80.06	21.61	159.14
	Sample #2	1.0	2.57	9.02	11.38	0.00	5.21	3.04	11.88
	Sample #3	1.0	2.39	6.32	4.06	0.00	4.57	0.00	12.59
LP-9	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-10	Sample #1	1.6	0.69	41.38	4.01	1.18	5.03	0.00	2.04
	Sample #2	1.0	20.51	134.06	48.74	6.11	72.35	0.00	0.00
	Sample #3	1.3	1.41	41.21	0.00	0.00	1.91	0.00	4.87

APPENDIX L

BROMINATED FLAME RETARDANTS DATA– SPLP

Table L.1 Concentration of BFRs in SPLP Leachate for Notebook Computer PWB

Sample	Sample ID	Volume (mL)	Compunds (mg/L)						
			Tri-BDE	TBDE	BDE-100	BDE-099	HX-BDE	HX-BDE	HP-BDE
LP-6	Sample #1	1.0	0.00	0.00	3.25	5.73	0.00	0.00	0.00
	Sample #2	1.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-7	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-8	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-9	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-10	Sample #1	1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table L.2 Concentration of BFRs in SPLP Leachate for Notebook Computer LCD Screen

Sample	Sample ID	Volume (mL)	Compunds (mg/L)						
			Tri-BDE	TBDE	BDE-100	BDE-099	HX-BDE	HX-BDE	HP-BDE
LP-6	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	0.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-7	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-8	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-9	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-10	Sample #1	1.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table L.3 Concentration of BFRs in SPLP Leachate for Notebook Computer Casing

Sample	Sample ID	Volume (mL)	Compunds (mg/L)						
			Tri-BDE	TBDE	BDE-100	BDE-099	HX-BDE	HX-BDE	HP-BDE
LP-6	Sample #1	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-7	Sample #1	1.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-8	Sample #1	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-9	Sample #1	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-10	Sample #1	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX M

BROMINATED FLAME RETARDANT DATA – SOXHLET EXTRACTION

Table M.1 Concentration of BFRs in Modified TCLP Leachate for Notebook Computer PWB

Sample	Sample ID	Volume (mL)	Compunds (mg/L)						
			Tri-BDE	TBDE	BDE-100	BDE-099	HX-BDE	HX-BDE	HP-BDE
LP-6	Sample #1	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-7	Sample #1	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-8	Sample #1	1.00	0.10	0.00	0.40	0.00	0.00	0.00	0.00
	Sample #2	1.60	0.20	0.00	0.70	0.00	0.00	0.00	0.00
	Sample #3	1.50	1.40	0.00	0.30	0.00	0.00	0.00	0.00
LP-9	Sample #1	1.40	0.00	0.0	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-10	Sample #1	1.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.30	0.00	0.00	0.000	0.00	0.00	0.00	0.00

Table M.2 Concentration of BFRs in Modified TCLP Leachate for Notebook Computer LCD Screen

Sample	Sample ID	Volume (mL)	Compunds (mg/L)						
			Tri-BDE	TBDE	BDE-100	BDE-099	HX-BDE	HX-BDE	HP-BDE
LP-6	Sample #1	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-7	Sample #1	1.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #2	1.30	0.33	1.67	1.16	0.00	0.00	0.00	0.00
	Sample #3	1.00	0.00	1.09	0.00	0.00	0.00	0.00	0.00
LP-8	Sample #1	1.00	0.41	1.64	0.00	0.00	0.21	0.00	0.20
	Sample #2	1.20	0.00	1.24	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.40	0.00	1.21	0.00	0.00	0.00	0.00	0.00
LP-9	Sample #1	1.00	0.00	0.00	0.28	0.00	0.00	0.00	0.00
	Sample #2	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Sample #3	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LP-10	Sample #1	1.00	0.00	0.00	0.00	0.00	0.72	0.40	0.00
	Sample #2	1.30	0.00	0.00	0.00	0.25	0.53	0.47	0.00
	Sample #3	1.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00