SCREENING LEVEL HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT FOR GENERIC E-WASTE PROCESSING FACILITY

September, 2004

Prepared for:

ICT Innovation and Computers for Schools Program,
Industry Canada and
National Office of Pollution Prevention, Environment Canada

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List of Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
ALM	Adult Lead Methodology
CCME	Canadian Council of Ministers of the Environment
COSEWIC	Committee on the Status of Wildlife in Canada
CFS	Computers for Schools
COC	Chemical of Concern
CofA	Certificate of Approval
CSF	Cancer Slope Factor
dB(A)	Decibels (average)
db(peak)	Decibels (peak)
EC	Environment Canada
EPA	United States Environmental Protection Agency
ERA	Ecological Risk Assessment
HC	Health Canada
HHRA	Human Health Risk Assessment
IEUBK	Integrated Exposure Uptake and Biokinetic Model
IOC	Intake of Concern
IRIS	Integrated Risk Information System
MOE	Ontario Ministry of the Environment
NSCER	National Steering Committee on Electronic Recycling
OEM	Original Equipment Maker
OH&S	Occupational Health & Safety
RfD, RfC	Reference Dose, Reference Concentration
SLRA	Screening Level Risk Assessment
SLERA	Screening Level Ecological Risk Assessment
SLHHRA	Screening Level Human Health Risk Assessment
TLV	Threshold Limit Value
TWA	Time Weighted Average
VEC	Valued Ecosystem Component
WEEE	Waste from Electrical and Electronic Equipment

Acknowledgement

MJC & Associates acknowledge Sara Mainguy, Senior Biologist of North-South Environmental, the main author of the Screening-Level Ecological Risk Assessment section of this report.

EXECUTIVE SUMMARY

Electronic waste ('e-waste') is becoming an increasing environmental concern. With faster devices replacing older or obsolete items, increasing amounts of electronic waste are being sent for final disposal in Canada.

A recent study commissioned by Environment Canada indicated that e-waste is known to contain various inherently hazardous substances, including mercury, cadmium, lead, and beryllium, which, if improperly managed (i.e., during e-waste processing) may pose significant human and environmental health effects.

In Canada, the electronics recycling ('e-waste recycling') industry, whose main purpose is to manage and dispose of the growing quantity and hazardous content of e-waste is generally considered to be a fast growing and rapidly evolving industry. The industry, although considered to be in its infancy, includes well over one-hundred different e-waste recycling facilities operating throughout Canada. In general, the industry is anchored by several large, state of the art recycling and processing facilities and many other small to medium sized operations which may use a variety of techniques and methods to separate and process e-waste.

In general, several issues have been identified with the processing and recycling of e-waste since this waste stream contains a number of heavy metals and other substance that, if managed improperly, and depending on the level of exposure could be potentially hazardous to both human health and the environment.

MJC & Associates ('MJC') were retained by Environment Canada and Industry Canada to conduct screening-level human health and ecological risk assessments (SLHHRA and SLERA) for a 'generic' e-waste processing facility to assess 'generic' waste flow processes. A generic facility is conceptual. It is meant to summarize the general features or characteristics of a typical e-waste processing facility in Canada. The use of a 'generic' facility and process was necessitated as there are many e-waste processing sites in operation in Canada using a variety of operational technologies, from small scale operations to more large-scale 'state of the art', well resourced facilities which employ a range of processing technologies. The risk assessment was conducted by applying an assessment framework to a 'generic e-waste facility' and 'waste-flow process', and included the formal identification of receptors of concern (both human health and ecological), in addition to identifying relevant exposure scenarios and exposure pathways for these receptors.

The general approach for the human health and ecological SLRA's were based, in part on the risk assessment frameworks provided by Health Canada and others (i.e., CCME, MOE, EPA, etc.) but tailored to address generic e-waste facilities and the unique consideration and reality that limited data (e.g., environmental monitoring data of air, soil, water, from or at these facilities etc.) were available for assessment.

Part A

Occupational Hazard Assessment

The principal findings of the occupational and human health risk assessments can be summarized as follows:

- An area of significant concern is the establishment of recycling facilities which are low-budget operations lacking resources to adequately equip the facilities to mitigate workplace hazards or to properly train their staff. The operational focus of such facilities should be limited to operations such as disassembly of equipment that will not result in exposure levels likely to cause harm. Such operations can still operate with minimum hazard to workers if they are able to form partnerships and/ or associations with other companies that have appropriately trained personnel to operate equipment to recycle the electronic waste produced by such operations. As an example, a piece of equipment called a shredder is very expensive to purchase and operate and smaller companies would be better served if they sent disassembled (and sorted) components to a larger facility that operates this equipment on a routine basis.

It is our opinion that training programs provided by the facility to the workers are the best means of mitigating risk in the absence of removing the hazardous process or preventing worker access to a hazardous aspect of the process.

It is our recommendation that training programs be developed for each of the waste flow processes taking place at a facility. The conceptual model provided in this document provides a framework on which the training programs may be based (however, the proper design of training programs is beyond the scope of this document.) This approach is preferred over a generic training program because of the diversity of the occupational risks associated with the different processes. In addition to training programs, the facility design could prevent worker access to hazardous processes and situations as dictated by a “Hierarchy of Controls”[1] approach to e-waste processing. This is generally addressed by individuals designing the e-waste facility.

Lastly, the formation of an industry-government group to specifically deal with electronic waste recycling issues in the context of occupational and environmental health is recommended. The mandate of this group would be to promote programs within recycling facilities to ensure worker safety and environmental stewardship (e.g., industry codes of practice and environmental management standards). Worker safety programs would deal with occupational and human health issues while the environmental stewardship programs could promote associations between smaller and larger recycling facilities. The group would also oversee the design and upkeep of the training programs as well as their delivery by establishing training and workplace

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[1] Hierarchy of Controls is essentially an operational strategy which promotes controlling the hazard at the source and using the best practices to reducing the hazard.

standards. In addition, it may be easier for a joint group to approach electronic manufacturers to discuss product stewardship as well as obtain expertise to design training programs.

Following the development of a generic facility and e-waste flow process model, and a review of the occupational hazards associated with typical e-waste facilities, a 'Screening Level Human Health Risk Assessment' ('SLHHRA') was conducted to assess the human health hazards associated with the processing of electronic waste and exposure to several chemicals of concern.

With respect to the chemical hazards associated with e-waste facilities, the principal findings can be summarized as follows:

- Exposure to the metals and chemicals of concern can occur throughout the e-waste processing cycle, including processes related to shredding, sorting, packaging, etc. and as a result of exposure to various media (e.g., air, dust, soil, etc.) through direct contact exposure pathways.

- Derived generic, e-waste specific exposure limits were ranked in terms of potential to cause human health toxicity from greatest to lowest, indicating that chromium > beryllium > nickel > cadmium > arsenic > azo-colourants > phthalate, following exposure of a female receptor of concern at a typical e-waste facility. This ranking is considered to be useful to identify chemicals or classes of chemicals for which practical mitigative measures could be developed to reduce and manage potential exposures. In addition, the exposure limits could be used in higher tiers of assessment, including site-specific risk assessments to 'screen' out potential chemicals and focus attention on those considered to be the most important.

- From the ranking, the metals and other compounds which can exist in particulate form and to which human receptors could be exposed to through the inhalation exposure pathway are considered to pose significant risks to human health for a generic e-waste facility. Therefore, to reduce the exposure of workers and others to these metals, personal protective clothing, including use of proper dust masks, gloves, and other protective gear (coveralls, boots, etc.) is considered to be a practical risk mitigation technique.

- A further chemical specific screening-level assessment was conducted for lead, a hazardous metal using the U.S. Environmental Protection Agency's Adult Lead Methodology (ALM) model. The model assumed that an adult female was exposed to an upper-bound maximum concentration of 1000 µg/g of lead in dust. The results indicated that there would be a 6.5% probability that the target blood-lead screening level of 10 µg/dL for the fetal blood lead level would be exceeded. This exposure level would be considered to present an unacceptable hazard to the fetus and to pregnant female adult workers exposed to lead in dust at these concentrations while working at an e-waste recycling facility.

- Overall, there is little available empirical data to evaluate the potential risks associated with residents being exposed to various chemicals of concern from living in proximity to an e-waste processing facility. Therefore, it is recommended that further environmental monitoring, such as stack and effluent testing, groundwater/drinking water monitoring and soil sampling in close proximity to these facilities be undertaken to reduce the uncertainties in the above findings.

- Likewise, there is a paucity of data concerning the concentrations of the identified chemicals of concern anticipated to be found within the work environment of an e-waste facility. Examining the data that were available concerning the concentrations of several metals within the work environment of e-waste facilities, it was concluded that, at the screening-level, workers may be at risk, as the levels of several metals, including lead and beryllium were found to be above the occupational exposure limits identified by the ACGIH.

- Further research addressing the potential for occupational exposure to CoCs within e-waste recycling facilities is recommended as an area of priority. To attempt to bridge this data gap and provide a means of quickly assessing the risks posed to e-waste workers, generic exposure limit criteria or screening level values were developed for a number of the CoCs.

- Given the differences in terms of operational capacity, and potential variety of e-waste processing methodologies currently available to recycle e-waste, it is recommended that individual e-waste facilities develop and complete, as a pro-active approach "potential problem analysis" or "failure model analysis" assessments or other suitable approach (e.g., Canadian Standards Association '*Standard CAN/CSA-Z731-03*' methodology) for their facility operations (infrastructure, socioeconomic, processes, etc.). This would aid in identifying those components of an operation which, if a failure mode or catastrophic event were to occur (e.g., failure of a bag-house, shredding of an ink cartridge, etc.), could potentially result in a significant and unacceptable human health or ecological event. This proactive approach is employed and very common to other industries, such as the mining and chemical sector.

- E-waste facilities should initiate and conduct pro-active approaches to systematically manage their environmental and occupational health and safety risks. Management systems (e.g., ISO 14001 and British Standards) provide structured approaches and processes for the achievement of improved environmental and safety performance.

- Given the evolving nature of the e-waste recycling and processing business in Canada, legislative requirements are one of several possible approaches to addressing the risks associated with e-waste processing. Further risk characterization, and enhanced environmental monitoring is necessary to determine if mandatory (i.e., legislative) or voluntary (ISO-based etc.) approaches are appropriate.

Part B

Screening Level Ecological Risk Assessment

A Screening Level Ecological Risk Assessment (SLERA) was conducted to assess the risk to the natural environment from processing electronic waste. For this component of the study, a 'generic facility' was defined, in order to allow analysis of exposure pathways and receptors based on a generalized concept of a typical environment where an electronics recycling plant might be located. Levels of chemicals of concern used in the risk assessment were taken from the very limited analyses of media (i.e., air, soil and dust) from e-waste processing plants where information was available. However, there is a significant level of uncertainty in the screening-level assessment as a result of the lack of available data.

For the purposes of a screening-level assessment, the generic facility was considered to be at the interface between the urban and agricultural landscape. Abandoned agricultural fields, hedgerows and small patches of woods would likely be in close proximity to the facility. Small drainage ditches or small creeks, connecting with larger creeks or wetlands downstream, may be found nearby. The native wildlife that uses these patches would mainly include those most familiar to urban residents, including mammals such as deer mice, short-tailed shrews, raccoons, skunks, foxes, birds such as blue jays and northern cardinals, reptiles such as garter snakes and amphibians such as toads and leopard frogs. However, it was assumed there could be significant species in the vicinity, for example, Red-shouldered Hawk, defined by the Committee on the Status of Wildlife in Canada (COSEWIC) as a Species of Special Concern, occasionally inhabits larger patches of forest in agricultural landscapes. The shorter list of Valued Ecosystem Components (VECs) were selected to represent those with a key role in wetland and upland ecosystems, as well as significant species.

There are three potential pathways by which chemicals of concern could enter the generic natural environment from processing electronic waste. The most important pathway is dispersal of dust from the shredding process, from the plant to the environment through doors, ventilation systems, etc., where it could become deposited in the soils and wetland sediments outside the plant and then ingested or absorbed by VECs. A second pathway would result if water were used in any part of the process, especially if dust were not controlled, and drains allowed the water to migrate from the site into soils and sediments. A third pathway would result if electronic components were stored outdoors before being disassembled. In this case, water could leach through and drain into the local watershed, carrying with it dissolved chemicals of concern that would then be deposited in soils or water. Leachate could also percolate through the ground and contaminate groundwater. Inhalation pathways are not likely to be significant, as dust in the air outside the plant would be dispersed by wind currents or deposited over long ranges.

The risk assessment was limited to those chemicals that were reported to be of most concern, considering the limited information available for e-waste. Lead is the substance of most concern, as it has the highest potential for leaching from electronic waste. However, there are known to be high proportions of cadmium, mercury, beryllium and polybrominated diphenyl ethers (PBDEs) in electronic waste.

This assessment shows there could be significant exposure of all trophic levels from processing electronic waste if contaminated dust is able to migrate outside the plant in air or water and become deposited in soils, sediments, surface water and ground water, and then is ingested directly by organisms in the environment. Water could possibly also become contaminated if recycled components were stored outdoors allowing rainwater to leach through the e-waste. However, the extent to which chemicals actually migrate into the environment through these mechanisms is not known.

The risk of toxicological effects from heavy metals could be highest for organisms that directly ingest or allow uptake of dust, including plants, amphibians, and burrowing mammals that ingest earthworms (since earthworms tend to contain soil in their gut). Risk of toxicological effects from heavy metals, particularly lead, is also likely to be high from exposure of organisms at a higher trophic level to plants or invertebrates that are exposed to dust on the site, as uptake rates for heavy metals in plants and invertebrates can, in some cases be very high. However, there is a high degree of uncertainty associated with this statement.

There are several factors contributing to the high degree of uncertainty associated with assessment of risk at the generic site. The most important factors are:

- there are almost no empirical measurements of concentrations of contaminants of concern in the vicinity of electronic waste processing sites in North America;
- the levels of contamination in dust are likely to be highly variable depending on the type of waste accepted by the recycling facility;
- levels of contaminants in soil, sediments and water outside a plant are likely to vary because of varying environmental practices, with some likely having negligible emissions;
- contaminants in dust may have variable bioavailability, depending on the other components in dust and leachate and the environment in which they are deposited;
- it is not known whether contaminants can move from dust to soil, sediments or water, or what form they may be found in those media;
- accurate benchmarks for some contaminants, most notably beryllium and PBDE, have not been derived.

Because of this uncertainty, it is recommended that a further tier of risk assessment be undertaken, which should include:

- measurement and characterization of metals and PBDEs in soils and aquatic sediments in the vicinity of electronic waste recycling plants. The sampling should be large enough to encompass an array of plants with a variety of environmental practices, and should be especially focused in areas most likely to be contaminated by dust in air or drainage water: in front of loading doors, near ventilation systems, near drain outfalls, and at points of groundwater discharge;

- bioassays should be conducted on uptake of contaminants in dust by earthworms and benthic organisms, to characterize the bioavailability of contaminants of concern in waste dust;
- when concentrations of chemicals of concern have been better characterized, a further tier of ecological risk assessment is warranted to better understand the risk to the ecosystem;
- Environment Canada should encourage the development of standards and guidelines for beryllium and PBDE;
- environmental standards and Best Management Practices should be established for all facilities, limiting the deposition of water and dust in the environment.

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Generic Electronic Waste Processing Site

1.0 Introduction

Electronics recycling ('e-waste recycling') is an emerging industry that is at a critical point in its development, in terms of both growth and challenges. The challenges related to proper disposal and efficient recovery of the material components of electronic waste ('e-waste') are becoming significant as the production and use of electronics products continues to increase dramatically throughout both the business world and public sectors.

In general, the e-waste stream is growing as a result of technological innovation and market expansion of computer equipment and software, resulting in personal computers becoming obsolete at increasing rates. On a global perspective, e-waste is one of the fastest growing components of municipal waste streams. Consider, for example, the following:

- The average first life (the amount of time a personal computer is useful to its original owner) is now 2-4 years. By the year 2005, a personal computers' first life is expected to decrease by another year.
- Considering reuse and storage options, the total lifespan (the period from manufacture to disposal) of a personal computer is estimated at 3-6 years.

(Source: Electronic Product Recovery and Recycling (EPR2) Baseline Report, US National Safety Council, 1999 and Information Technology (IT) and Telecommunications (Telecom) Waste in Canada, Environment Canada, 2001).

In general, the commercial sector has been recycling electronics for approximately 20 years and has largely been the driving force in creating and growing the electronics recycling industry. Up until recently, the major sources of electronics products for recycling have been manufacturers and large users. Although consumers own vast quantities of electronics products, until recently many have been disposed of in landfills or left unused in storage areas. It is widely understood that the number of electronic products becoming obsolete or replaced has been increasing significantly and is creating a need for recycling consumer electronics (EC, 2001).

A relatively small percentage (i.e. less than 10%) of obsolete electrical and electronic equipment is currently reused or recycled in Canada. This, in part, may be attributed to Canada's limited recycling infrastructure and lack of an economically sustainable market.

In Canada most e-waste is landfilled and some is incinerated. Disposed e-waste may leach hazardous substances in landfills. The incineration of e-waste may pose environmental problems because they can contain chlorine and brominated flame retardants (commonly found in plastics like PVC which may be found in e-waste) and heavy metals such as mercury, lead, cadmium and chromium. The increasing disposal of e-waste also represents an opportunity from a resource conservation and recovery perspective.

For example, in 1999, disposed personal computers contained approximately 4,400 tonnes of ferrous metal, 3,050 tonnes of aluminum and 1,500 tonnes of copper. In 2002 alone, approximately 158,000 tonnes (about 5.0 kg per capita) of e-waste was sent for final disposal. Combined, computer equipment and televisions accounted for a majority (60%) of this waste and contained an estimated 5,600 tonnes of lead, 6.1 tonnes of cadmium and 4.4 tonnes of mercury. These disposal quantities are anticipated to increase by approximately 30% by 2010 if nothing is done to address the situation.

The above numbers, including the amount of e-waste available for processing and recycling are predicted to increase each year. Therefore, the updated model suggests that more and more computers will be recycled – as opposed to incinerated or land-filled.

1.1 End-of-Life Issues for Electronic Waste

Electronic products include, but are not limited to personal computers, monitors, laptops computers, peripheral (printers, scanners, etc.), mobile phones, telephones, and facsimile machines among other equipment (EnvirosRIS, 2000; 2001). Several issues have been identified with the processing and recycling of e-waste since this waste stream contains a number of heavy metals and other substance that are potentially toxic to human health and the environment.

Recycling' refers to recovering the raw materials (i.e., in this case, taking a computer and physically breaking it down into its composite materials or glass. However, many sources and agencies discuss recycling when in fact they are actually re-using computers (i.e., where machines are simply donated, refurbished and reassigned to other people who can use them). In addition, 'remanufacturing' refers to disassembling computers and making new systems from parts (e.g. putting additional memory and larger hard drives into other CPUs). All options generally prevent the land-filling and incineration of equipment, and thus have environmental benefits. A figure of the current flow diagram for electronics is depicted in Figure 1.

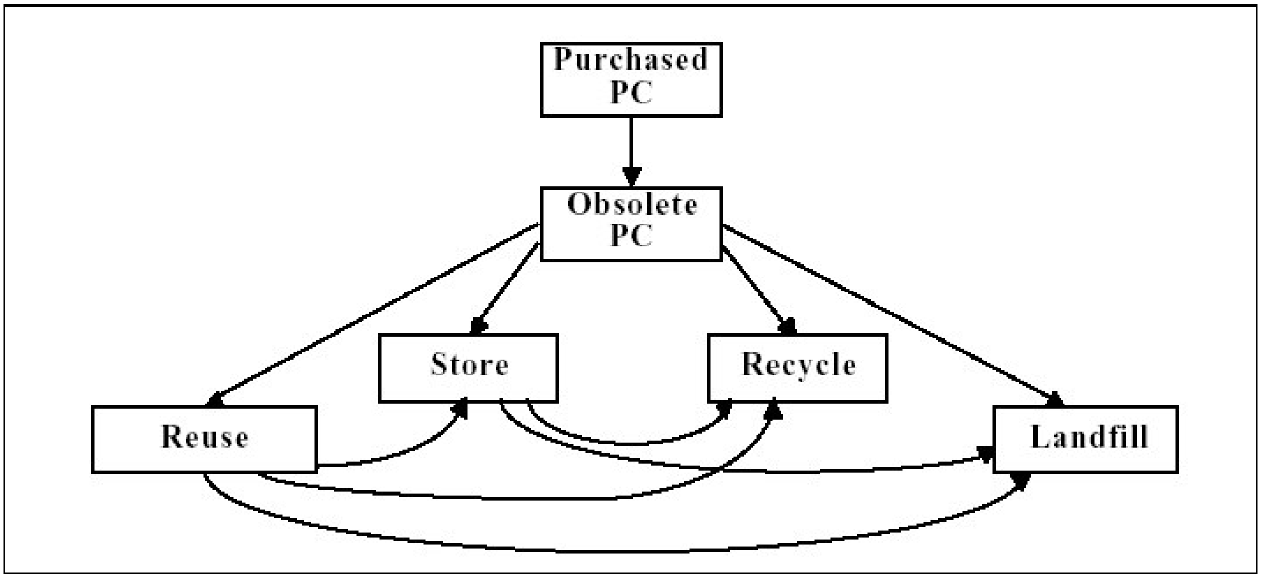

Figure 1. Mass Flow Model for Electronic Products

One other type of service often mentioned is 'Asset Recovery', which is essentially a contract between a service provider and an organization to take away excess equipment and refurbish, recycle and to guarantee safe disposal, perhaps with some economic value returned to the organization. This could imply ensuring and proving that no e-waste components were sent to landfills.

The increasing volume of e-waste – combined with the hazards associated with managing it has led to several studies such as Environment Canada's 2000 report entitled: IT and Telecom Waste in Canada (EC, 2001) and others (CEIA, 2001). The studies have collectively revealed that e-waste subject to recycling contains a number of inherently hazardous substances such as heavy metals (e.g., mercury, cadmium, lead, etc.), fire retardants (e.g., pentabromophenol, PBDE's, TBBPA, etc.,) and other inherently hazardous chemical compounds. Improper handling and management of e-waste during the recycling process may result in unacceptable occupational exposures to chemicals, and may also pose a potential significant health hazard to both human health and if released to the environment various ecological receptors (i.e. plants, animals, etc.). Lastly, the physical or ergonomic hazards associated with e-waste processing have been identified as an issue of concern which may potentially impact upon the occupational health and safety of receptors (e.g., laborers, etc.) involved in e-waste processing/recycling.

Table 1. Materials used in a desktop computer and the efficiency of current recycling processes

Composition of a Desktop Personal Computer Based on a typical desktop computer, weighing ~60 lbs.				
Name	**Content (% of total weight)**	**Weight of material in computer (lbs.)**	**Recycling Efficiency (current recyclability)**	**Use/Location**
Plastics	22.9907	13.8	20%	includes organics, oxides other than silica
Lead	6.2988	3.8	5%	metal joining, radiation shield/CRT, PWB
Aluminum	14.1723	8.5	80%	structural, conductivity/housing, CRT, PWB, connectors
Germanium	0.0016	< 0.1	0%	Semiconductor/PWB
Gallium	0.0013	< 0.1	0%	Semiconductor/PWB
Iron	20.4712	12.3	80%	structural, magnetivity/(steel) housing, CRT, PWB
Tin	1.0078	0.6	70%	metal joining/PWB, CRT
Copper	6.9287	4.2	90%	Conductivity/CRT, PWB, connectors
Barium	0.0315	< 0.1	0%	in vacuum tube/CRT
Nickel	0.8503	0.51	80%	structural, magnetivity/(steel) housing, CRT, PWB
Zinc	2.2046	1.32	60%	battery, phosphor emitter/PWB, CRT
Tantalum	0.0157	< 0.1	0%	Capacitors/PWB, power supply
Indium	0.0016	< 0.1	60%	transistor, rectifiers/PWB

Vanadium	0.0002	< 0.1	0%	red phosphor emitter/CRT
Terbium	0	0	0%	green phosphor activator, dopant/CRT, PWB
Beryllium	0.0157	< 0.1	0%	thermal conductivity/PWB, connectors
Gold	0.0016	< 0.1	99%	Connectivity, conductivity/PWB, connectors
Europium	0.0002	< 0.1	0%	phosphor activator/PWB
Titanium	0.0157	< 0.1	0%	pigment, alloying agent/(aluminum) housing
Ruthenium	0.0016	< 0.1	80%	resistive circuit/PWB
Cobalt	0.0157	< 0.1	85%	structural, magnetivity/(steel) housing, CRT, PWB
Palladium	0.0003	< 0.1	95%	Connectivity, conductivity/PWB, connectors
Manganese	0.0315	< 0.1	0%	structural, magnetivity/(steel) housing, CRT, PWB
Silver	0.0189	< 0.1	98%	Conductivity/PWB, connectors
Antinomy	0.0094	< 0.1	0%	diodes/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
Cadmium	0.0094	< 0.1	0%	battery, blue-green phosphor emitter/housing, PWB, CRT
Selenium	0.0016	0.00096	70%	rectifiers/PWB
Niobium	0.0002	< 0.1	0%	welding allow/housing
Yttrium	0.0002	< 0.1	0%	red phosphor emitter/CRT
Rhodium	0		50%	thick film conductor/PWB
Platinum	0		95%	thick film conductor/PWB
Mercury	0.0022	< 0.1	0%	batteries, switches/housing, PWB
Arsenic	0.0013	< 0.1	0%	doping agents in transistors/PWB
Silica	24.8803	15	0%	glass, solid state devices/CRT,PWB
Table presented in: Microelectronics and Computer Technology Corporation (MCC). 1996. Electronics Industry Environmental Roadmap. Austin, TX: MCC.				

Note: plastics contain polybrominated flame retardants, and hundreds of additives and stabilizers ***not*** *listed separately.*

All of the compounds listed above are known to be inherently hazardous to both human health and ecological receptors following sufficient exposure. For example, lead exposure at sufficient levels is associated with developmental toxicity in children and mercury is a known neurotoxicant. The hazards associated with e-waste would depend on the level of exposure and depend on the inherent toxicity of the compound. In general, hazard can be defined using the following equation:

$$\text{Hazard} = \text{Toxicity} \times \text{Exposure}$$

Although the compounds associated with e-waste processing that are listed in Table 1 may present a hazard following sufficient exposure, few risk assessment studies (which includes an assessment of exposure) are available which provide an assessment of the hazards and risks associated with e-waste recycling processes which may be encountered at typical e-waste recycling facilities in Canada.

The management of waste electrical and electronic equipment (WEEE) is raising concerns in Canada and elsewhere (NSCER, 2004). The concerns primarily stem from the fact that WEEE may contain varying quantities of hazardous substances, and that quantities of WEEE in waste disposal streams continue to grow.

1.2 Project Objectives and Deliverables

Based on the above noted concerns, the National Steering Committee on Electronic Recycling (NSCER), a committee established to help promote, coordinate and facilitate a nationally consistent approach to managing WEEE in Canada, have identified a need to investigate and prepare a study that addresses the potential environmental and occupational health and safety hazards associated with e-waste processing in Canada. To address these concerns, Environment Canada requested a human health and ecological risk assessment, at the 'screening-level', which identifies the hazards associated with e-waste processing, and outlines 'practical risk control options' and measures which may be taken to mitigate any hazards and risks associated with e-waste recycling. Therefore, Environment Canada has outlined a number of preliminary objectives to address these concerns in a screening-level risk assessment study including:

Project Objectives:

(1) identify the potentially significant environmental and occupational health and safety risks associated with e-waste processing;

(2) identify relevant legislated environmental, occupational health & safety requirements associated with these risks, and lastly;

(3) to identify best management practices, monitoring, and mitigative measures that may be needed should significant risks be identified.

The Project Deliverables are identified as follows:

(1) to provide a 'generic' description of the physical, chemical, and environmental features of 'typical' e-waste processing facilities and effects on receptors in Canada;

(2) to identify the environmental and OH&S hazards and risks associated with e-waste processing;

(3) to identify potential receptors of concern and both exposure scenarios and pathways deemed relevant from e-waste processing;

(4) to determine the acceptable hazard levels; including identification, description and comparative review of the Canadian environmental and OH&S regulatory requirements associated with e-waste processing (i.e., Federal, provincial and if applicable, municipal);

(5) to conduct a screening-level risk analysis, evaluation, and provide conclusions and recommendations on the environmental and OH&S hazards associated with e-waste processing;

(6) to identify risk management options (e.g., monitoring and best management practices) to mitigate or eliminate the environmental, OH&S risks associated with e-waste processing in general, and lastly;

(7) to identify training and awareness requirements and competency requirements for workers or supervisors associated with e-waste processing.

Scope of Study:

The scope of the study was outlined in the terms of reference for the project. The scope of study included an assessment of the potential environmental and occupational health and safety risks associated with e-waste processing in Canada. The scope of the assessment involved a preliminary analysis of the risks, scoping and hazard identification, risk analysis and evaluation, and an investigation of risk control measures and recommendations. Secondary hazards and potential risks associated with recycling and smelting of metals, plastics and glass processing were not the focus of the current study

To address the deliverables outlined above, a preliminary screening-level risk assessment was conducted, focusing on both human health and the environment. The technical methodology and approaches that will be used to meet the needs and expectations of Environment Canada for this project are outlined in the following sections.

In general, risk assessment is a process used to assess the potential risk to human and ecological receptors resulting from one or more environmental stressors. In doing so, the risk assessment takes into account the concentrations of the chemicals to be evaluated (i.e., measured concentrations obtained from empirical studies, or by using concentrations reported from the literature for similar sites), the manner in which receptors may be exposed and the toxicity associated with each chemical.

Screening-level risk assessments differ from higher tier (i.e., more refined and site-specific) risk assessments, in that they generally involve a non-quantitative assessment of the likelihood of an adverse effect resulting from conditions present at a site (e.g., a generic e-waste processing facility). A screening-level assessment can provide valuable information on degree of risk that may be associated with a particular site or as a result of general operations without the need for undertaking detailed or complicated modeling.

1.3 Generic E-Waste Facilities and Processing Options

There are four main types of electronic waste processing options: disassembly, refurbishing; shredding and smelting. Smelting is not addressed in this study as it is considered to be a downstream, established, and highly regulated industry.

In general, the following activities (i.e., operations) are assumed to occur at a typical generic e-waste facility, including:

- Asset management (i.e., accepting; sorting; and prioritizing e-waste);
- De-manufacturing (i.e., shredding, crushing, etc);
- Materials recovery (i.e., eddy current separation, etc.), and;
- Materials processing.

These processes are described and expanded upon in more detail in the occupational health and safety (OH&S) assessment section (Section 3 below) of this report. In general, some of these activities may contribute to significant hazards and risks to both human health and the environment.

In general, Kopacek and Kopacek (1999) have identified that automated disassembly is the key to recycling e-waste and technological improvements are considered to be necessary in order to make recycling more efficient and cost effective.

The solution provided by Cui and Forssberg (2003) is to shred the waste and sort it using a variety of techniques including eddy current, corona electrostatic, and shaking processes. This shredding technique appears to be the method predominantly used and most efficient for a "generic" e-waste process. Currently, there are manufacturers that develop specialized e-waste shredding equipment which is currently used in Canada. Some of these large pieces of machinery are depicted in Photo 1. A conceptual model of a "generic" e-waste shredding process is depicted in Figure 2.

However, other approaches may also be used in Canada (e.g., manual disassembly and de-manufacturing) followed by additional methods as discussed in a paper by Veglio et al. (2003) which focused on the recovery of valuable metals: i.e., copper and nickel. The technique described therein included acid leaching followed by an electrowinning process. The leaching process is achieved using an acid (H_2SO_4) solution, following this the metal separation technique called electrowinning is used to separate the metals. This technique apparently has 94-99% efficiency (Veglio et al., 2003). However, the hazards associated with these activities have not been fully assessed.

Photo 1. An industrial scale e-waste shredding machine

A typical e-waste flow process depicting a shredding process is illustrated in Figure 2. It should be noted that there would be a different flow-chart for "disassembly/refurbishment" process options.

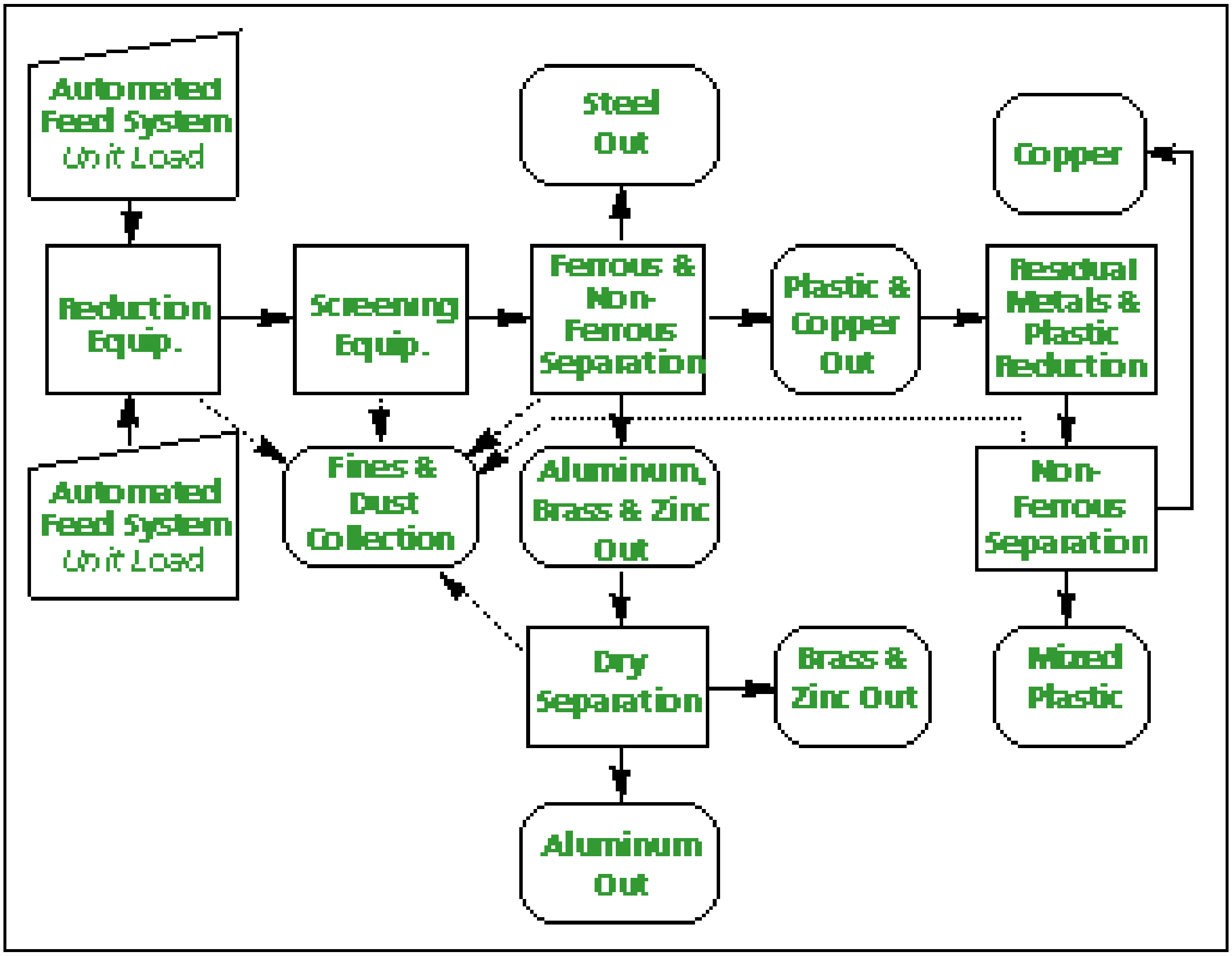

Figure 2. Generic E-waste Shredding Process

2.0 Generic E-Waste Facility Features

Currently, the electronics industry in Canada is estimated to comprise approximately 200 companies that are involved primarily in computer waste recycling and disposal (CEIA, 2001). In general, the industry is a mix of small, and medium sized businesses with several larger companies (i.e., Original Equipment Manufacturers (OEMs), metal refiners, general waste and recycling companies, etc.) anchoring the market (CEIA, 2001). There were approximately 137 companies reportedly involved directly in services related to dismantling and destruction (i.e., shredding, etc.) of e-waste and/or specialized recycling such as monitor recycling (CEIA, 2001) in Canada.

In general, the IT equipment recycling infrastructure in Canada is considered to be non-uniform and limited in terms of coverage. It is considered to be an immature, but rapidly growing industry in Canada (EnvirosRis, 2000). For example, some recycling facilities are known to use manual separation to dismantle and sort the IT equipment into its material streams (i.e., in some cases, separation into approximately 40 different components in order to get the highest market price for high quality material streams - i.e., wire, circuit boards, semi-precious and other base metals, etc.), whereas others rely on more automated disassembly. In general, it is accepted and agreed in the e-waste industry that manual disassembly is too costly and labour intensive, and not likely the way of the future.

To define and conceptualize a ‘typical (i.e., “generic”) e-waste facility, the Study Team initially investigated (and visited) several large facilities/ operations located in south-central Ontario (i.e., facilities able to easily process ~1500 tonnes/month; generally considered more state of the art). In addition, the Study Team investigated several medium-sized operations, which in general, process approximately 10-20 tonnes/month. In some cases, full access to the sites was not possible. Furthermore, a company directory and literature search was conducted to identify smaller operations which would provide useful information in defining a “generic” e-waste facility.

In addition to the large and medium sized operations known to process and recycle (i.e., dismantle, shred and recover precious and non-precious metals) significant quantities of electronic waste, the Study Team also investigated other types of facilities whose primary function is to facilitate the reuse of personal computers. This is facilitated by either using the computer after assessing that it is fully functional or by re-assembling components from a number of different computers to refurbish a working unit(s). Such an approach is favored over the traditional processing as it results in a useful product with minimum hazards to the worker when compared to destructive processing. For example, a number of large organizations (e.g., federal and provincial governments, private sector etc.) may send their computers to government-led programs such as the federally sponsored “Computers for Schools” (CFS) organization. In general, the CFS program collects and refurbishes a significant number of donated surplus computers from government and other private sector sources and redistributes them free of charge to schools and libraries throughout Canada. Although the CFS program is involved in e-waste ‘processing’, the operations are more accurately described as refurbishing as opposed to recycling and workers in the “refurbishing” plants are not exposed to nearly the same hazards. In fact, individual program offices typically send unusable equipment or components (considered to be defined as e-waste) to recyclers and larger processing facilities, which recycle the disposed or unwanted material.

In general, programs and organizations such as CFS provide significant environmental benefits by ensuring that computer systems are reused and refurbished with minimum waste being sent to recyclers or landfill sites and can be regarded as a “best practice” program for extending the useful life of electronic equipment and keeping material, often considered to be potentially toxic, out of landfill sites. For example, 86,760 refurbished computers were diverted from landfills and donated to schools (CFS, 2003-04).

It should be noted that the generic recycling facility discussed in this report is based on a realistic hazard scenario consistent with material (i.e., precious and non-precious metals, plastics, etc.) recovery based on current practices which include destructive processes such as shredding and electrochemical processing. Workers employed at facilities which simply rebuild personal computers with components recovered from other obsolete or unwanted computers, as described above, are not expected to have significant exposure to potentially hazardous metals and other compounds. Therefore, the hazards and risks associated with these types of activities are considered to be negligible.

Generic Description

Although there are differences related to the capacity of e-waste processing facilities, and a variety of processing options, overall, for the purposes of conducting a ‘screening level’ assessment, the following generic facility was defined:

(1) The generic facility was considered to be at the interface between the urban and agricultural landscape;
(2) The generic facility was considered to have a mix of automated (i.e., mechanized shredding) and non-automated (hand separation and destruction) processes occurring within the facility; the sum of which could contribute to human or ecological exposures if improperly undertaken and managed;
(3) Abandoned or unused agricultural fields, hedgerows and small patches of woods were considered to be in close proximity to the facility. Small drainage ditches or small creeks, connecting with larger creeks or wetlands downstream, were considered to be found nearby;
(4) The native wildlife that uses these patches would mainly include those most familiar to urban residents, including mammals such as deer mice, short-tailed shrews, raccoons, skunks, and foxes, birds such as blue jays and northern cardinals, reptiles such as garter snakes and amphibians such as toads and leopard frogs. However, it was assumed there could be significant species in the vicinity, for example, Red-shouldered Hawk, defined by the Committee on the Status of Wildlife in Canada (COSEWIC) as a Species of Special Concern, occasionally inhabits larger patches of forest in agricultural landscapes.

Occupational Health and Safety Assessment

3.0 Part A - Occupational Health & Safety Assessment

This section identifies the major occupational hazards associated with e-waste processing, including physical and ergonomic hazards identified through investigations and describes their potential to cause harm to workers.

3.1 Introduction – Occupational Health and Safety Conceptual Model

The rationale for developing a conceptual model for assessing occupational health risk was based on the observation that a number of factors are involved in worker exposure to hazardous substances that originate from electronic waste handling and reclamation at different points of the process. Exposure to various forms of hazardous substances can occur at different points of the process. In addition, manual handling of equipment can lead to both ergonomic stress as well as exposure to various chemicals and compounds associated with e-waste. As a consequence, the proposed model integrates occupational health and safety with physical factors as well as chemical exposures.

It should also be noted that the processing of electronic waste is carried out for an economic benefit to the company that runs such a facility. An economic benefit to the company operating such a facility only results when precious (e.g., gold, silver) and non-precious (e.g., copper, iron, lead, mercury, beryllium, cadmium, etc.) metals are recovered from the waste equipment and resold on the market, or functional components removed from the equipment are sold at a market-bearing price that exceeds the cost of recovery. To this end, electronic waste is a potentially valuable commodity and processing plants must handle the equipment accordingly. Functional components can only be recovered with appropriate handling of delicate parts. Parts such as memory modules, motors, optical components that can be resold require care in removal, testing, and packaging for transport. The recovery of the precious metals is typically facilitated by shredding of the equipment into the smallest possible particle sizes, separating particles containing metals from those not containing metals, and further processing the particles containing metals using acid leaching followed by electrochemical reclamation (electrowinning).

Workers at these plants are cautious with their handling practices- a clear difference when compared with other types of recycling facilities. As a result, greater caution given to handling of the equipment leads to greater contact time between the worker and equipment leading to exposure to various contaminants.

The electronic waste processing facility is not significantly different from other manufacturing facilities were the basic safety rules are followed and the workers are equipped with the proper safety boots, eye protection, ear protection, and gloves, as appropriate for the task at hand. Also, equipment such as forklifts or mechanized pneumatic dollies, for the handling of heavy products have training programs associated with their use and should be followed in all facilities in which they are used. The workplace safety rules that govern precautionary principles are readily available in the operation of these types of facilities and will not be further discussed in this report. The occupational safety issues germane to the processing of electronic waste will be the focus of the risk mitigation strategy.

The following sections discuss the various steps involved in e-waste processing and the occupational health concerns that arise from each of the steps.

3.1.1 E-Waste Receiving Area

The electronic waste receiving area may pose a number of different hazards for the workers. Often times, equipment (in whole or in part) is received on wooden palettes that are wrapped in a vinyl shrink-wrap. Once the palettes are unloaded from the truck onto the floor area, the personnel in the area have to identify the contents and rip open the plastic to access the equipment. Some of the loads that come to the plant also arrive in boxes, bins, or as individual equipment. The unloading of this equipment is a manual task requiring various levels of exertion. The greatest risk is posed by the variability in the center of mass of the load. Moving bulky objects which often have loose parts on the inside poses ergonomic risks. In addition, stacking of the bins can lead to situations where equipment could fall and risk injury or exposure to hazardous materials.

3.1.2 Hazards in the Receiving Area

Workers in the receiving area may be exposed to sharp plastic and metal objects, broken glass from video displays and lamps, partially filled laser toner cartridges containing dyes and very fine or pasty graphite powder, rechargeable batteries, and wiring/power cords which can pose a tripping hazard. Much of the hazard stems from the damage incurred during transit resulting in parts coming loose or breaking.

The primary danger faced by personnel in the receiving area is dermal and inhalation hazard. Receiving a cut from either broken glass or sharp metal pieces can result in exposure to materials such as phosphor coating that is contained inside monitor tubes or to various other chemicals that may be on the sharp metal pieces. The exposure resulting from such cuts can lead to direct exposure to various metals and other materials.

3.1.3 Risk Mitigation in the Receiving Area

Risk mitigation in this area of the plant is based on reducing ergonomic stress as well as recognition of the exposure hazards posed by incoming equipment. Prior to the removal of the equipment, a thorough visual inspection should be carried out. Special care must be taken to identify spills of liquids from the equipment, sharp edges on the equipment, and broken equipment that may break apart upon unloading. Facility personnel should not take responsibility for equipment that has not been packaged adequately; such loads should be refused or accepted only after a proper clean-up by the shipping party. Ergonomic stress can be greatly reduced by the use of forklift or other mechanical means to unload the incoming equipment. In the event that this is not possible, a team approach should be used for unloading heavy equipment. When the loads are received in plastic bins or boxes, every effort should be made to use a ramp system to minimize lifting.

Personnel who are directly handling the equipment should use appropriate personal protective equipment which includes the use of safety boots, gloves for maintaining proper grip as well as reducing the likelihood of sharp equipment penetrating the skin. Appropriate clothing, preferably overalls, as well as head protection such as a helmet, should be worn. In the event where a visual inspection of the incoming equipment has identified equipment contaminated with a spill of some kind (laser toner, liquid toner, etc), disposable coveralls should be worn during the physical handling of this equipment. Respiratory protection may also be necessary in case of fine dust and solvents. Personnel should be trained for identifying appropriate respiratory protection when visual inspection identifies a potential hazard from the incoming equipment.

A storage system that makes use of a large area of the floor is preferable to a vertical stacking system to reduce the risk of waste equipment falling on personnel in the work area. Such a configuration will also facilitate the classification of the equipment, and important steps in protecting the workers.

3.1.4 Classification of Equipment

For electronic waste processing plants, the classification of equipment is an important step in identifying equipment containing parts that can be used for resale on the used part market to either build refurbished products or sold “as is” from that part of the shipment which must go on for mechanical processing to recover various materials. Both the economic success of the plant and protection of plant personnel depend on proper classification.

3.1.5 Hazards Associated with Classification of Equipment

The classification of electronic waste equipment is an important step in reducing the overall occupational exposure. For example, personnel receiving the waste equipment must be able to identify the component parts. There are significant differences between equipment that comes from home or office environments to that which may come from a hospital or a research laboratory environment. It is possible to receive medical equipment which may contain radioactive compounds or liquid reservoirs that contain cleaning solvents. In this case, the personnel in this area must be able to identify this equipment and to take appropriate precautions to prevent exposure. Personnel working in this area may require training to operate equipment capable of detecting radioactive decay products (e.g., Geiger counters, etc). Equipment that is not suitable for processing because it is dangerous or because the plant does not have the appropriate means to recycle it should be refused at this stage. Equipment from residential waste is more likely to be in poor shape and refurbishing of parts from this stream is unlikely.

It is at this point of the process where a decision of how the equipment is to be processed is carried out. For example, a load which contains computers may be diverted toward refurbishing where functional parts are taken out and reassembled into a functional computer that may be sold, as in the case of the CFS (Computers for Schools) program. Alternatively, parts such as memory chips, central processing units, power supplies, and hard drives may the removed for resale. Other parts, such as batteries and cases may be removed and sent to other recycling centers for processing.

Equipment that is not suitable for refurbishing may be directed to other processing paths. The end result of a proper equipment classification is the streamlining of the waste to the appropriate disassembly station/line.

3.1.6 Risk Mitigation Strategies Associated with Classification of Equipment

Exposure to hazardous situations during classification of the equipment should be minimal with appropriate care. For the most part, only a visual inspection will be used to divert the equipment to the appropriate stream. However, personnel may be exposed to dusts or fumes if some of the equipment has to be opened in order to assess the internal components. The use of personal protective equipment (e.g., proper clothing, dust masks, etc.) would minimize exposure of workers to potentially toxic chemicals and other hazardous materials (e.g., sharps, etc.).

3.2 Manual Disassembly

Manual disassembly of the electronic equipment is necessary to retrieve various parts for either refurbishing for sale or for further recycling to reclaim precious metals. There is typically a considerable amount of handling of the equipment during this step. In addition to the initial lifting of the equipment, opening up the equipment can also result in exposure to various contaminants. In order to gain access to some of the components, physical breakage of the outer shell is necessary in some instances. For example, removal of the picture tube from the monitor requires physical breakage of the outer casing. Removal of the picture tube is necessary to remove the lead, phosphor as well as other surface mounted boards from inside the monitor. The outer casing is made up of a polybrominated flame retardant (BFR) plastic. As a result, personnel removing the picture tubes from the monitors are exposed to a variety of hazardous compounds as the process of breaking the shell can release dusts that can be inhaled. Handling other equipment such as photocopiers, printers, and facsimile machines may also result in exposure to various compounds such as dry inks, liquid ink, and other chemicals.

Parts from certain display equipment such as flat panel displays or hard drives and rechargeable batteries (lithium-ion and nickel-cadmium) from laptops have resale value and every reasonable attempt is made at recovering these parts.

In some cases, waste recycling facilities are specifically contracted to process equipment such as photocopiers, cheque printing machines, and postal stamp printing machines when the equipment comes off-lease and the leasing company or manufacturer requires the equipment to be removed from the market to maintain a higher value for newer equipment. While such practices are not environmentally desirable, they are governed by the market at the present time.

Certain pieces of equipment removed from the waste products may need to be tested to determine whether the sub-components should the used in the production of refurbished equipment or if they should be recycled. This may require bench-level testing. This type of a testing procedure requires the use of power supplies of various voltage and current. Typically, extensive training is required to test electronic equipment and part of the training program is the safety training required to protect the worker.

3.2.1 Hazards Associated with Manual Disassembly

This step of the process has the greatest potential for long-term dermal and inhalation exposure because of the potentially long contact time involved in taking apart some of the equipment. The potential for ergonomic stresses from using repeated motion to lift equipment as well as the use of various tools to pry apart or even break the outer shell by drilling, cutting or grinding of some of the equipment has the potential to cause muscle stress and strains and allow the possibility of direct contact with electrical currents from small batteries or capacitors bearing high voltage, and contact with flying objects of various size and hardness.

Inhalation exposure will result from the intake of dusts generated from the mechanical process used on the equipment. The composition of the dusts formed during this process includes plastics, metals, ceramic, and silica (glass and silicon dust). The formation of dust from removal of outer casings is likely to be in a particle size range exceeding the PM_{10} size[2] . Particles in this size range are not likely to penetrate into the lower respiratory tract but will cause irritation of the upper respiratory tract and possibly lead to aggravation of respiratory difficulties (e.g., a person pre-disposed with emphysema, COPD, etc.). In general, those individuals who have a compromised respiratory system are at a higher risk of developing adverse reactions in comparison to the healthy population.

The actual toxicity of these particles is dependent on their composition. Particles that are composed primarily of silica (glass and silicon dust), ceramic, or plastics are likely to cause

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[2] PM_{10} describes particle matter with average radii less than 10 microns in diameter. Most agencies recommend a guideline or maximum threshold for particles in this size range to be below 20 micrograms per cubic meter (20 g/m^3) averaged annually.

irritation of the upper respiratory tract resulting in the production of excess mucus to trap/bind these particles.

Particles that are metallic in nature are a cause for greater concern. For example, particles containing metals such as cadmium, lead, copper, beryllium, and mercury have the potential to cause a variety of adverse health effects ranging from neurotoxicity (lead) to lung cancer (cadmium). Metals such as thallium[3] (used to make optical lenses, semiconductors, and switching devices) and cadmium (used in nickel-cadmium rechargeable batteries as well as semiconductors) also have very long half-lives (decades) of elimination from the body and accumulate in various organs (primarily kidneys) resulting in toxicity. The acute and chronic nature of the toxicity of these contaminants is discussed in Section 4.0.

Mercury, found within light sources (fluorescent tubes in scanners, photocopiers, etc.) as well as switches is released into the air upon breakage of the shell. A study[4] carried out in the United States found that between 17 and 40% of the mercury in broken low-mercury fluorescent bulbs is slowly released to the air over a two-week period following breakage. Almost one-third is lost in the first 8 hours after breakage. Depending on the incoming waste supply, persistently elevated airborne levels of mercury are likely to exist in the vicinity of broken bulbs. Depending on the number of bulbs, it is conceivable that air-borne mercury concentrations could exceed occupational exposure limits for inhalation.

Similar concerns are raised by laser toners and dyes. Many laser toners are based on styrene polymer and also contain trace quantities of polycyclic aromatic hydrocarbons[5] (PAHs). Workers who are handling toners will be exposed to these components through the inhalation and dermal routes of exposure. PAH exposure is associated with a substantial risk of lung, skin, and bladder cancer in many animal studies. The lung appears to be a major target organ of PAH carcinogenicity and presents a significant concern in the e-waste processing plant due to the continuous handling of toner cartridges. PAHs present both a dermal and an inhalation risk and must be dealt with appropriately.

Dermal exposure can result from spills (i.e., such as toners and inks from cartridges in printers and photocopiers) as well as from direct contact resulting in the attachment of loose particles present inside the enclosures onto the skin. The particles inside the enclosures have different properties given the ability of electronic currents to attract various dust particles. Various studies have shown that dermal exposure can lead to a variety of human health effects with the most common being acute dermatitis which results in itching, blisters, and sometimes, a skin

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[3] Moore, D., I. House, et al. (1993). "Thallium poisoning. Diagnosis may be elusive but alopecia is the clue." Bmj 306(6891): 1527-9.

[4] Aucott, M., M. McLinden, et al. (2003). "Release of mercury from broken fluorescent bulbs." J Air Waste Manag Assoc 53(2): 143-51.

[5] Boffetta, P., N. Jourenkova, et al. (1997). "Cancer risk from occupational and environmental exposure to polycyclic aromatic hydrocarbons." Cancer Causes Control 8(3): 444-72.

rash. Indeed, studies have demonstrated the causal link between dermal exposure to ceramic particles and dermatitis[6] .

Other studies have also investigated the dermal exposure from contact with metal cutting equipment including equipment that uses cutting fluids[7] and also with dermal occupational exposure to metals in general. The studies on the operation of machines that use metal cutting fluids indicate that the degree of automation of the removal of chips and shreds dictates the worker exposure. Machines that clear away the chips and shreds automatically result in lower dermal exposure to the operator; machines requiring the operator to clear away the shreds result in higher dermal exposure. The health impacts of dermal exposure to metals have been shown to be harmful[8]. The evaluation of a number of studies by (Hostenyk et al., 1993) suggested that dermal contact to metals causes health effects that are far greater than allergenicity.

The disassembly of equipment could result in noise from both hand-held tools as well as pneumatic or electric tools. The workers in this area will be exposed to significant levels of noise. The generic facility should be considered to have a variety of manual and power tools. The current legislation for noise controls at manufacturing facilities will adequately protect the worker. A table of the current noise guidelines is shown in Table 2.

Table 2. A survey of the maximum permitted noise exposure limits in Canada.

Jurisdiction (federal, provincial, territorial)	**Continuous Noise**		**Impulse / Impact Noise**	
	Maximum Permitted Exposure Level over an 8 Hour Shift: dB(A)	**Exchange Rate dB(A)**	**Maximum Peak Pressure Level dB(peak)**	**Maximum Number of Impacts**
Canada (Federal)	87	3	-	-
British Columbia	85	3	135 dB(A)*	-
Alberta	85	5	140	100
Saskatchewan	85	Not Specified	-	-
Manitoba	90	3	-	-
Ontario	90	5	140	100
Ontario (draft regulations)	90	3	140	-
Quebec	90	5	140	100
New Brunswick	85	5	140	100
Nova Scotia	85	5	140	100
Prince Edward Island	85	3	140	-
Newfoundland	85	3	-	-

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[6] Wojtczak, J., M. Kiec-Swierczynska, et al. (1997). "[Exposure to ceramic fibers in the work environment. III. occupational exposure to ceramic fibers in plants which produce and apply insulation materials made of ceramic fibers]." Med Pr 48(1): 51-60.

[7] Wassenius, O., B. Jarvholm, et al. (1998). "Variability in the skin exposure of machine operators exposed to cutting fluids." Scand J Work Environ Health 24(2): 125-9.

[8] Hostynek, J. J., R. S. Hinz, et al. (1993). "Metals and the skin." Crit Rev Toxicol 23(2): 171-235.

Jurisdiction (federal, provincial, territorial)	Continuous Noise		Impulse / Impact Noise	
	Maximum Permitted Exposure Level over an 8 Hour Shift: dB(A)	**Exchange Rate dB(A)**	**Maximum Peak Pressure Level dB(peak)**	**Maximum Number of Impacts**
Northwest Territories	85	5	140	140
Yukon Territories	85	3	140	90

From: http://www.ccohs.ca/oshanswers/phys_agents/exposure_can.html, accessed on 2004/02/18.
Note: British Columbia employ the same scale to determine peak pressure as for the permitted level.

3.2.2 Risk Mitigation Strategies during Testing of Components

The risk mitigation strategies during the testing of the components are based on the type of test required to assess the functionality of the sub-components removed from the waste electronic product. Almost all testing requires the proper use of a power supply. The use of a power supply requires training to protect the worker from electrical shock. The risk from such occurrence can be reduced by using a work station that is properly grounded and has a rapid fault-detection circuit breaker installed on the power supply. It is also conceivable that equipment that has been exposed to water during transport or during storage, could overheat during the testing and result in the production of fumes or acrid smoke. The testing of the components should ideally be carried out in fumehoods or in areas where rapid air exchange system is in operation. A fire extinguisher with the appropriate classification should be readily available. The workers who are testing the components must be trained to rapidly react to such situations and take appropriate precaution to protect themselves as well as other individuals in the plant.

Certain equipment, such as video displays, have capacitors that become charged during the testing phase. It is important that these be discharged when the testing is complete to protect workers downstream from electrocution danger.

3.2.3 Risk Mitigation Strategies during Manual Disassembly

The risk mitigation in this step of the process can be facilitated by providing a work area that is ergonomically appropriate for the type of equipment being handled. In general, disassembly of the products should take place in processing lines that are specifically designed for a particular product. Heavy items such as photocopiers or network printers should remain low to the ground until hazardous materials (toner containers, light sources, etc.) have been removed. It would be desirable to have the hazardous materials removed in an area which is vented away from the plant personnel carrying out the disassembly process. Once the hazardous materials have been removed, reclamation of parts typically begins.

A separate line could be devoted to handle desktop and laptop computers. The ergonomic requirements on such a line are clearly less stringent because computer units (desktop/tower case or laptops) typically do not have a significant weight. However, in order to scavenge the parts inside the computer, antistatic mats should be used to reduce electrostatic damage to potentially useful parts such as memory, central processing unit, cables, power supplies, and various input/output cards such as those used for network, video and sound. Computer motherboards typically have button cell batteries that can pose a fire hazard if they are shorted out in the presence of materials that are flammable. These batteries should be removed and sent for proper disposal at a specialized battery-recycling facility. Batteries inside laptop computers and cell phones are also hazardous and require similar careful handling.

Where power tools are employed in the disassembly process, the workstation should be efficiently organized so that workers are not exposed to hazards from the tools. One of the simplest ways of achieving this is to use power tools that are cordless to minimize tripping hazards.

Manual disassembly of computer monitors and televisions to recover the cathode ray tubes is one of the most dangerous tasks that can be undertaken by an electronic waste recycling facility. Recycling of cathode ray tubes results in exposure to heavy metals such as lead, zinc, cadmium, and trace levels of metals found in phosphor such as silver, manganese, yttrium, terbium, and europium. Also, exposure to brominated flame retardants from the breaking and shredding of the plastic housing also occurs. In addition, recently tested cathode ray tube units may have charged capacitors and pose and electrocution hazard. These work stations should be well grounded to reduce the risk from electrocution. Workstations that concentrate primarily on computer monitors should be in an area which can be well ventilated to reduce the worker exposure. It is highly desirable that disassembly operations carried out in this area be as automated as possible and appropriate barriers to reduce or eliminate exposure to facility staff are the preferred risk mitigation option. Individuals working in this area should be provided with overalls that can be frequently changed depending on the amount of exposure and be provided with a cleansing station area to frequently to remove particles that may contain various substances. This area should be equipped with eyewash stations, sinks and perhaps showers. Workers should be equipped with appropriate personal protection such as gloves, goggles, and breathing masks and trained to use the appropriate equipment for the task at hand. Workers should also be trained to identify when personal protective equipment needs to be changed and this practice must be enforced by the plant management as well as the regulatory authorities.

3.3 Classification of Parts

At an operational level, the classification of parts occurs simultaneously with the manual disassembly. The purpose of this step is to differentiate between parts that are destined for the various streams such as part recovery for refurbishing/resale and those which will be subject to further processing for reclamation of metals or plastics. However, there is a step where the sorting has to be carried out and which requires a certain amount of handling.

3.3.1 Hazard Identification Associated with Classification of Parts

For the most part, components such as memory modules, power supplies, motherboards, and circuit boards do not result in adverse exposure to the workers. There are other components, however, such as lamps, capacitors, metal and plastic cases that may be coated with spilled solvents or particles containing hazardous chemicals, which have the potential for exposure. The scheme provided in a research article[9] for parts that are not used for refurbishing (Cui and Forssberg, 2003) has steps that differentiate between further treatment (possibly at a specialized facility) of certain components like batteries due to the nickel-cadmium or lithium hydride content as opposed to components such as metal, printed circuit boards, and glass that can be further refined at more conventional recycling centers.

3.3.2 Risk Mitigation Strategies for Classification of Parts

In general, the risk mitigation process for this step is similar to that described for the previous step. Differentiating between such parts for the purpose of diverting the parts to the appropriate facility in addition to mitigation steps to reduce exposure becomes a training issue for the plant personnel.

3.4 Shredding of Components for Separation

Shredding of components is carried out for several reasons. The primary one being that separation of shredded pieces is easier with existing techniques such as screening through various sized meshes for size separation, followed by magnetic separation and conductivity separation (i.e., Eddy current separation or corona electrostatic separation or tribo-electric separation). The end result of shredding followed by the separation process is that the relatively uniform makeup of the shreds results in an energy efficient recycling operation. Table 3 describes the separation process and the materials collected. A discussion on occupational hazards will follow. In realistic terms, a generic facility is most likely to have magnetic separation apparatus and a corona discharge or Eddy separation apparatus of various sizes dependent on plant capacity.

Table 3. A description of various processes used.

Separation Process	Basis for Separation	What is for Separated	Size of Particles obtained
Magnetic	Magnetic susceptibility	Ferrous from Non-ferrous including alloys	Large or small-based on magnetic field strength

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[9] Cui, J. and E. Forssberg (2003). "Mechanical recycling of waste electric and electronic equipment: a review." J Hazard Mater 99(3): 243-63.

Separation Process	Basis for Separation	What is for Separated	Size of Particles obtained
Eddy	Conductivity and density	Metals from non-metals	Particles over 5 mm in size
Corona	Conductivity	Metals from non-metals	0.1-5 mm
Triboelectric	Dielectric Constant	Non-metals (plastics)	Less than 5 mm

Adopted from Cui and Forssberg, 2003.

Shredding of electronic components into the smallest size possible is a necessity for efficient separation. As a result, sophisticated shredding machines are used. The occupational hazards associated with shredders include noise with a variable pitch depending on the materials being processed, the generation of flying objects of various hardness and sharpness, and risk of injury from the shredder to the operator as a result of operator error.

Typically associated with the shredding machines is a bag house to collect fugitive emissions, which may pose an inhalation hazard for maintenance workers in addition to the entire staff on the processing floor of the plant if not properly maintained.

3.4.1 Hazards Associated with the Shredding Process

The primary hazards associated with the shredding process are exposure to dusts, noise, and contact with airborne shredded parts of various sizes. The primary route of exposure to dusts is through inhalation and dermal exposure. Assessment of air quality in the vicinity of electronic waste shredders has shown that cadmium and lead levels as high as 0.27 and 1.4 $\mu g/m^3$, respectively, have been detected[10]. While the facility in which these readings were obtained was a well-run facility, and the study was commissioned by the facility itself, there is every indication that continuous exposure to low levels of metals is possible. Long term exposure to cadmium at the levels cited is potentially hazardous to health and there is a carcinogenic risk associated with inhalation exposure to cadmium.

One of the questions that the article above raises from a risk assessment viewpoint is the appropriateness of using permissible environmental levels of metals which were developed for other industries. The reason why this is a concern is because occupational limits were developed for other industries such as mining and smelting. The exposure to metals in such industries is based on industry-specific processes which are different from processes used in electronics recycling industries. For example, one would expect that the exposure to metals in electronics recycling facilities is qualitatively different because the exposure is to more refined metals. This raises the questions of whether the occupational exposure limits based on a

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[10] Peters-Michaud, N., J. Katers, J. Barry (2003) Occupational risks associated with electronics demanufacturing and CRT glass processing operations and the impact of mitigation activities on employee health and safety. Web article available upon request. Accessed December 20, 2003.

particular molecular species of a metal are appropriate in this situation. It is difficult to resolve this issue without a more detailed risk assessment that looks at the speciation of the metals found in these plants.

3.4.2 Risk Mitigation Strategies for the Operation of the Shredder and Particle Separation System

The risk mitigation steps for the shredder operator are based on limiting contact between the moving parts of the shredder and the operator. The moving parts of a shredder should be made inaccessible through the use of guards with proper functioning shut-off mechanisms. This is a concept taken from the *hierarchy of controls* to limit access through equipment design. The mitigation of risk for this part of the process is based both on the use of appropriate shielding such as protection of eyes, ears, as well as appropriate masks to prevent the inhalation of fine dusts. Appropriate foot protection as well as dermal shielding (overalls) to prevent contact with fine dusts is desirable. In addition, maintenance workers who may be involved in repairing and maintaining the shredding equipment may require special personal protective equipment and additional training to mitigate the risks associated with these activities. Although maintenance operations may be less frequent, there may be special hazards associated with this type of work, for example, risk of electrocution or accidental start up of equipment may occur if procedures and protocols (e.g., lock out, tag-out) are not followed. In addition, bag-houses must be properly maintained on a schedule that ensures optimum performance to reduce occupational hazard for all staff at the facility.

3.4.2.1 Packaging of Shreds and Bag-House Material for Transport

Once the shredding has been completed, there is still the risk from dusts that will be re-entrained to the ambient air if the shreds are in an open area. This poses a potential risk to the plant personnel from the possible inhalation of various dusts. In addition, the dusts that will be experienced in the maintenance of the bag house will have a potential toxic composition because it is a mixture of every component being processed by the plant. The handling of bag house dusts is an arduous task and it is difficult to avoid some exposure unless very stringent precautions, such as appropriate respiratory gear and full overalls with gloves are worn.

Operational failure of the bag-house could pose a significant risk of exposure to inhalable particles containing toxic agents for facility staff as well as to individuals who are off-site. As a result, bag house operation and clean-up is an important part of the risk management program and individuals with specialized training are required for optimum operation that combines human health factors with plant efficiency.

3.5 Other Considerations in E-Waste Processing

It is conceivable that some facilities may choose to extract the precious metals from either the metal containing shreds or even whole printed-circuit boards after the surface mounted components have been stripped on site. This is facilitated by using electrochemical or electrowinning technology[11] where metal shreds are dissolved in an acidic solution (typically concentrated sulfuric acid and peroxide at elevated temperatures, and also hydrogen cyanide in some cases) and the precious metals are removed from the solution using an electric current.

3.5.1 Hazards Associated with Electrowinning Process

Such a step in the operation will result in higher levels of exposure to other chemicals such as acid fumes, acid in its liquid form, as well as cleaning solvents which may be used to prepare the shreds for acid etching.

The route of exposure for these chemicals is dermal and inhalation. Acid fumes are hazardous to human health as they irritate the nasal mucosa and are generally irritating to the upper respiratory system. An additional problem posed by fumes is that they can end up in the lungs and result in direct damage to the pulmonary tissue. This process can result in exposure to metal fumes that get carried along with the acid fumes resulting in adverse effects on human health.

There are also several types of by-products that result from electrowinning of metals. These by-products may require disposal procedures that are likely to require special training and monitoring. At the writing of this report, electrowinning processes were found to be carried out by specialized facilities associated with mining and metal refining.

3.5.2 Risk Mitigation Strategies Associated with the Electrowinning Process

The risk mitigation strategy to deal with acid fumes is to use a system which is vented away from enclosed areas where staff can be exposed as well as specialized training for the electronic equipment being used for electrolysis and reclamation of the metals. Personnel who are in the vicinity of the electrowinning system should have access to self contained breathing apparatus in the event of a spill as well as an emergency protocol to ensure spill containment and notification with appropriate emergency response authorities. In addition, cleansing station in this area should be equipped with an eye-wash station, shower, and a sink for use by the personnel in this area. Lastly, this area should also have an emergency vent fan to carry away the fumes that could arise in the normal operation of this system.

Personal protective equipment for the plant personnel operating the electrowinning apparatus includes rubber overalls, gloves, head protection, eye protection, and acid resistant footwear.

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[11] Oh, C. J., S. O. Lee, et al. (2003). "Selective leaching of valuable metals from waste printed circuit boards." J Air Waste Manag Assoc 53(7): 897-902.

3.6 Environmental Monitoring Programs

It is imperative that electronic waste processing facilities establish an air monitoring program to continually assess worker exposure to various hazards discussed in this document. Air monitoring can be carried out by either personal monitoring devices or stationary devices strategically located in areas frequented by personnel. Devices capable of quantifying heavy metals as well as organic compounds in the air should be monitored on a continuous basis to ensure worker safety.

The present limits for occupational exposure to metals such as lead, cadmium, mercury, beryllium, and particulate matter could serve as baseline values to which the plants must adhere. However, these values may need to be reassessed in the future because of the relative purity of the metals to which plant personnel are exposed.

3.7 Risk Management Options and Training Programs

An appropriately developed safety management system is the most effective means of managing risk at any facility housing and utilizing specialized equipment. An electronic waste processing facility is no exception. The electronic waste processing plant encompasses various industrial disciplines such as heavy equipment handling, operation of process control machinery that control mechanical processes which requires constant vigilance, and incoming equipment that can pose a hazard even before processing commences. This is further complicated by the fact that each load of waste that arrives at the plant has to be individually classified. The generic facility is expected to have multiple process-dependent hazard points governed by the specific task being carried out. As a result, training programs at electronic waste processing sites must be governed by the specific processes taking place at the plant.

There are a number of occupational safety programs in Canada such as WHMIS (Workplace Hazardous Materials Information System). The main elements of the system are cautionary labeling of containers of WHMIS "controlled products", requirement mandating the availability of material safety data sheets (MSDS) containing pertinent information for the workplace, and, worker education programs. In addition, equipment used the facility may have safety programs that mitigate risk from improper use. Safety programs do not only refer to hazardous materials but also to equipment such as forklifts, ladders, personal protective equipment, and fire detection and extinguishing equipment. The workplace that implements workplace-specific safety programs and ensures that the programs are stringently maintained with buy-in from all facility staff (management and employees) will generally be ensuring adequate safety controls.

For the waste processing/recycling stream, the effectiveness of the training program will be governed by the accuracy in the identification of the equipment coming to the plant. The actual use of various equipment such as shredders or particle separation equipment also requires that appropriate training manuals be provided from the manufacturer of the equipment being used. In addition, processing e-waste using the proper equipment designed for that specific waste product is also critical to worker safety.

Certain tasks that must be carried out at an electronic waste processing facility require a high level of technical literacy in identifying various parts and mechanical aptitude or expertise in using various types of equipment; the ability to use various sources of information; and, knowledge of the implementation of risk mitigation strategies. As will be outlined in this section, one of the dangers of working with electronic waste equipment is the diversity of the products. Each product has its unique hazard that must be dealt with appropriately. Accordingly, a rationale for training in the context of occupational safety is provided with an outlines of the objectives.

Hazard to the staff at the facility can be mitigated by safety management programs that must be stringently maintained. Each product has its unique hazard that must be dealt with appropriately.

An electronic waste processing facility carries out a number of processes of differing complexity and the potential of workers to be exposed to a range of hazards is very high. In addition to the worker training programs, facility design and the way the operations are carried out can have a significant impact on worker safety. Safety Management Systems (SMS) should be used in the operational aspects of an electronic waste processing facility to reduce hazard to the staff. One aspect of SMS is the concept of "Hierarchy of Controls" which can be independently applied to each element of the process being carried out at the processing facility as discussed below.

3.7.1 Hierarchy of Controls

A "Hierarchy of Controls" refers to a series of control measures where the most effective controls (based on mitigating risk to facility workers) are employed for the task of concern. The following steps describe the salient features of this approach:

1. Eliminate the hazard, for example:
- Use a different less dangerous piece of equipment to carry out the desired task
- Fix faulty machinery to reduce harm to users and bystanders
- Redesign the workplace to eliminate physical pathways that can cause harm
- Use safer materials or chemicals whenever possible

2. Isolate the hazard from the people, for example:
- Redesign the equipment, use guards etc.
- Remove dust or fumes with exhaust system
- Use lifting equipment or trolleys
- Prohibit access to non-functioning or broken equipment

3. Change the way the job is done, for example
- Change work practices if it results in reduced risk to workers
- Provide training, information and signs

4. Use personal protective equipment (PPE)
- Mandate specific PPE for specific job
- Training and information for all PPE used required to be displayed

Another aspect of the Safety Management System is the development of workplace-specific training programs to deal with processes being carried out at the facility. These programs, if developed with the appropriate rationale for the facility, can provide a considerable margin of safety.

3.7.2 Rationale for Training

Training programs at an electronic waste processing plant should be designed to fulfill the following objectives:

- Appropriate classification of the equipment coming into the plant
  - Plant personnel must be able to identify the equipment and have access to components inside the equipment.
  - Training in using various databases that identify electronic equipment to evaluate the components is required.

- Recognition of the inherent danger posed by the components within the waste, for example:
  - Is there a likelihood of spills (e.g., toners, dry inks) inside the equipment?
  - Are there any sources of radiation within the equipment?
  - Are there any lamp sources within the equipment?

- Implementation of the appropriate risk management strategy on the basis of the classification of incoming electronic waste products.
  - If any dangers associated with the equipment are identified, the personnel must be trained to take appropriate action.

- Streamlining of the electronic waste to the appropriate disassembly line.
  - Appropriate streamlining of the electronic waste has an economic benefit for the facility as the appropriate methods to retrieve valuable parts can be implemented. Workers at the facility should be trained to properly identify equipment and have reference materials to identify any equipment.

- Testing and Retesting Worker Knowledge. It is important that workers be continually trained and tested in their knowledge of waste electronics equipment because of the continuous process changes occurring in this industry.

- Identifying general hazards. Workers at electronics waste processing facilities must be able to identify the nature of the hazard based upon visual identification, auditory identification, as well as odor detection. Workers should be able to assess hazard upon the observation of smoke of a particular color or odour, or if equipment is making unfamiliar sounds, or general change in the plant which could be indicative of several types of dangers. If air quality monitoring equipment is installed at the plant, the facility staff must be trained to recognize if an alarm condition has occurred.

- The risk of fire at such facilities is relatively high if proper precautions are not in place. Such situations will require the workers to invoke an emergency response plan. It will also require training in the use of fire detection and fire extinguishing equipment depending on the nature of the fire.

- Lastly, in order to familiarize the workers in these plants with the various dangers, and to reduce the operational risks that arise from task saturation, it is recommended that workers in electronic waste processing plant's be rotated from task to task in order to enhance knowledge and training as well as become familiar with the plant operation and the associated dangers.

- In order to maintain a high training level among the staff, it is recommended that the training programs be documented so that training gaps can be identified and corrected.

3.8 Occupational Health and Safety Conclusions and Recommendations

Based on the foregoing, we offer the following recommendations:

- A worker’s potential exposure to various hazards cited in this section of the screening level risk assessment report is based on the premise that the facility carries out the particular task resulting in the potential worker exposure.

- The application of the occupational risk assessment will require delineating the various generic processes in the facility and then applying the risks associated with the specific processes.

- The generic facility should be assumed to carry out all of the processes covered in this risk assessment but the actual occupational hazards will be dependent on a number of factors including the type of process, processing equipment used, work practices and the proper use of proper personal protective equipment used at the specific facility.

- An area of significant concern is the establishment of recycling facilities which are low-cost operations using staff without adequate training. These facilities may begin operations with the primary goal of recovering parts to assemble functional computers. The end result of these plants may be a large amount of unusable electronic waste with a small number of working computers. Furthermore, it is important that the electronic waste (i.e., whole components that cannot be used) be removed from the site as soon as possible and shipped to a facility where further processing/recycling will take place. This approach will result in reduced worker exposure to hazardous compounds.

- Training programs aimed at informing the staff of the means of reducing risk by using appropriate equipment, workstation design, safe work practices, and appropriate personal protective equipment are the best means of mitigating risk. It is our recommendation that training programs be developed for each of the processes taking place at a facility. The conceptual model provided in this document provides a framework for which to base the training programs. This approach is presented because of the range of the occupational risks associated with the different processes and the variety of electronic equipment that can be handled at these facilities. We recommend that training programs that emphasize worker awareness of the various dangers and promote task competency be developed for each of the elements in the conceptual model.

    - General Safety: Training programs that emphasize task hazard analysis and reinforce safe work procedures in the workplace must be developed. These programs should be reviewed by management and facility workers, for example through a health and safety committee, and assessed periodically to ensure that the content is appropriate. An external consultant could be utilized to promote discussion and ensure that concerns are addressed. Use of personal protective equipment appropriate for the operational task such as proper clothing and safety gear (overalls, eye protection, gloves, face masks, steel-toe shoes or boots, etc.) should be emphasized. Additional care should be taken to minimize off-site transport of contaminants. For example, clothing worn at the facility should be washed in a separate load to minimize transfer of contaminants to other clothing.

    - Receiving: Proper handling (unloading) of equipment that may not be properly packaged. Ability to make decisions on protective gear required to handle the shipment.

    - Classification of Shipment: Recognition of equipment which is handled by the plant to equipment not handled at the plant. This training program has to be continuously updated due to changing nature of equipment.

    - Manual Disassembly: Handling of bulky objects, appropriate use of tools, protective equipment, streaming removed parts to appropriate location (bins).

    - Classification of Individual Parts: Recognition of electronic parts containing various hazardous chemicals. Testing of parts for functionality using various test equipment.

    - Shredding: Extensive training on using complex machinery, ability to discern when equipment function is inadequate, and dealing with equipment breakdown resulting in a possible emergency situation.

    - Packaging of shreds for transport: Proper operation of bag-houses and other collection systems is an important aspect in reducing risk to the facility personnel and individuals in surrounding (off-site) area. The training program should stress the importance of proper bag-house operation to reduce risk of exposure to inhalation hazards.

- Lastly, the formation of an industry-government group to specifically deal with electronic waste recycling and processing issues in the context of occupational and environmental health is recommended. The mandate of this group would be to promote programs within recycling facilities to ensure worker safety and environmental stewardship. Worker safety programs to deal with occupational and human health issues while the environmental stewardship programs could promote partnerships between smaller and larger recycling facilities. Such a group is ideally suited to carry out research programs in the context of recycling facilities to deal with various issues such as real-time monitoring of particulates for metal species, evaluate protection offered by various personal protective equipment, and evaluate e-waste recycling programs in other jurisdictions. The group would also oversee the design and upkeep of the training programs as well as their delivery. In addition, it may be easier for a joint group to approach electronic manufacturers to discuss product stewardship by promoting the design of electronic devices to reduce hazard when these items are recycled as well as provide expertise to design training programs at electronic waste processing/recycling facilities to enhance worker safety.

3.9 Considerations

The prior discussion has been largely technical in nature. However, there is no question that development of effective training programs will require a significant amount of resources from the management operating such a facility. Furthermore, a significant level of cooperation between the management and the workers will be required. It is beyond the scope of this report to outline a structure for the cooperation but proper planning of educational programs and an agreement on the implementation of the programs is essential.

A properly designed health and safety program is an integral part of a safety management system and is fundamental to any organization. It is a core business conducted by the organization. It is designed with a buy-in from all levels from management to staff with an understanding that all staff members have responsibility for plant safety and that all staff members benefit from following such a program. There must be adequate resources provided to initiate and maintain such a program.

It is also recognized that various levels of government have jurisdiction with respect to occupational health and safety programs. While the current status of legislation has been discussed elsewhere in this report, this section is only concerned with an occupational health and safety risk assessment with respect to the process but not with respect to jurisdiction issues

Screening Level Human Health Risk Assessment

4.0 Screening-Level Human Health Risk Assessment for Generic E-Waste Processing Facility

The assessment of the potential human health risks associated with exposure to chemicals associated with the recycling of e-waste is based, in general on the risk assessment frameworks recommended by the CCME in their document entitled 'Guidance Document on the Management of Contaminated Sites in Canada' and the Ontario Ministry of the Environment's 'Guideline for use at Contaminated Sites in Ontario' (CCME, 1997; MOE, 1997).

Although there are subtle differences in the approaches and terminology for each of the agencies listed above, the general approach for completing a screening-level risk assessment[12] (SLRA) includes the following steps:

- Problem Formulation: In this step, information is gathered to describe a facility and focus the risk assessment on the critical issues of concern. Briefly, chemicals of concern (CoCs) are identified; possible exposure pathways (i.e., routes by which individuals may be exposed to the chemicals of concern) are determined, and hypothetical receptors (i.e., individuals potentially exposed to the chemicals originating from the site being evaluated) are chosen.

- Exposure Assessment: In this step, estimates of the potential chemical exposures that receptors would potentially receive from the predominant exposure pathways are calculated based on measured or modeled chemical concentrations in the environment (i.e., air, dust, etc.). Where quantitative empirical data are lacking, the screening-level methodology allows information from peer-reviewed literature and other supporting studies to be in the exposure assessment.

- Toxicity Assessment: In this step, health hazards that could result from exposure to the chemicals of concern are identified and assessed based on dose-response principles. Exposure limits, or estimates of the amount of exposure to these chemicals that could occur without significant or unacceptable risks to health, are determined, based on a review of various organizations that have developed chemical specific toxicity criteria for use in risk assessments, including:
    - U.S. Environment Protection Agency (EPA) for Reference Dose (RfDs), Cancer Slope/ Potency Factors (CSFs);
    - Health Canada (e.g., Tolerable Daily Intakes, Tolerable Concentrations, etc.);
    - Ontario Ministry of the Environment (e.g., Ontario MOE's Intake of Concern (IOC) for lead);

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[12] The SLRA methodology is different than the CEPA requirements for 'Human Health Risk Assessment for Priority Substances'

In general, the toxicity criteria selected for each COC was obtained from one or more of the above sources, after a thorough evaluation of the basis for each criterion. In general, the non-cancer RfD or RfC and cancer potency factors developed by the EPA and presented on the Integrated Risk Information System (IRIS) database are recognized as the most authoritative. For CoCs not listed on the EPA IRIS or Health Canada databases, the toxicity criteria developed from the other agencies would be used, if considered appropriate.

- Risk Characterization: In this final step, the potential health risks and hazards to receptors are determined by comparing the estimated rates of exposure (from the Exposure Assessment) and the exposure limits (from the Toxicity Assessment) for the chemicals of concern.

Based on the results of the risk characterization, conclusions are drawn regarding the risks associated with the on-site contamination levels and the potential to have deleterious impacts on human receptors.

4.1 Problem Formulation

The Problem Formulation Step is an important information gathering and interpretation stage, which serves to plan and focus the approach of the risk assessment. The data gathered and evaluated in this stage provides information regarding the physical and geographic features of a potential generic site(s), identification of receptor(s), and possible exposure pathways, and any other specific areas or issues of concern to be addressed. For the current assessment, key tasks involved in the Problem Formulation Step included the following:

- Human receptor selection and characterization, and criteria and decision making processes used in identifying the CoCs for assessing risks to human receptors, and;
- Selection of exposure pathways and scenarios.

The outcome of these tasks formed the basis of the approach taken in the current assessment. A more detailed methodology for each of these tasks is described in the sections that follow.

4.1.1 Receptor Selection and Characterization

In examining the available literature and following the examination of the generic e-waste facility model, the following have been considered as potential receptors:

4.1.2 Facility workers

An adult female[13] was selected as this receptor as they represent an individual that is sensitive to exposure to certain chemicals of concern (e.g., lead, etc.), and will have chronic type exposure. In addition, as a result of direct work related activities including those associated with close contact to the recycling processes, this receptor was considered to have the highest expected exposure to the chemicals of concern (COCs).

4.1.3 Facility supervisors

The assessment also considered a facility supervisor as a receptor of concern. The facility supervisor represents a receptor assumed to have relatively less exposure than that expected of a facility worker as this receptor would have a lower frequency of exposure (e.g., 2-3 hours/day, 5 days/week). For example, a facility supervisor may be expected to spend more time in an office setting conducting administrative activities. Therefore, their time-weighted average exposure (chronic duration exposure) was considered to be less than an adult female workers exposure. The exposure to the CoCs for the facility supervisors, while expected to be less than that of the facility workers remains a chronic type exposure (i.e., greater than 1 year exposure duration). Typically, the US EPA guidance recommends assessing chronic duration using an exposure period (EP) of 27-30 years for an adult worker (US EPA, 1992).

4.1.4 Maintenance workers

The maintenance worker has unique exposure characteristics as the frequency of exposure to the CoCs is expected to be relatively lower when compared to facility workers or supervisors, however they have the potential for significant acute-type exposures. For example, a maintenance worker may be directly exposed to the CoCs while performing maintenance activities on parts of recycling equipment and machinery that are inaccessible to either the facility worker or supervisor (i.e., a maintenance work may need to remove a cover for an enclosed conveyor belt carrying e-waste laden with CoCs, or be exposed to small particles of metals from performing maintenance activities on a shredding machine, etc.).

4.1.5 Trespasser

In general, a trespasser represents a youth (Health Canada guidance defines a youth as ranging in age from 12 to 18 years old) who may be exposed to the CoCs if they undertake trespassing or other nuisance activities and contact the environmental media (i.e., soil, air, water) at the e-waste recycling facility. In general:

- the trespassers are expected to have either negligible exposure due to their low exposure frequency and duration (i.e., assumed to be sub-chronic exposure, estimated to be <2 weeks exposure period per year) to the CoCs and due to the low

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[13] A facility worker is, for the purposes of this assessment, a female adult aged 18-45 who is on the floor of the facility, spending the majority of the time at work (8 hours/day; 5 days/week, 48 weeks/year) involved in direct processes involving e-waste recycling.

concentrations of the CoCs expected to be detected and found surrounding the e-waste recycling facility;

- in conducting a quantitative assessment (where data are available), a youth trespasser will be 'conservatively' represented as a an individual (aged 7-12). The youth receptor aged 7-12 would have a lower body weight when compared to an older youth, thereby maximizing the exposure estimate for this receptor. Therefore, older and heavier youths would be protected by assessing this type of receptor.

In general, it is not expected that receptors described as infants, toddlers, or children would be expected to have access to these types of facilities due to fencing and other security measures typically employed at these facilities.

It should be stressed that no receptors were selected to represent individuals who may reside in residential areas in close proximity to e-waste recycling facilities. Examination of several facilities on numerous site-visits indicated that there was no apparent likelihood of contamination of groundwater or other environmental media within the area surrounding these types of facilities. The only issue of concern was emission of particulate (e.g., Total suspended particulate – TSP) that may impact nearby residential receptors. Although a detailed analytical sampling investigation was not carried out during this screening-level assessment, examples of readily available provincial Certificate of Approvals (CofA's) for air emissions for an urban facility obtained from the Ontario Ministry of the Environment's web-site showed that only particulate was emitted into the air as a result of activities at the facility. However, the levels of particulate resulting from the activities at the facilities were noted to be below Ontario MOE's ½-hr Point of Impingement (POI) limit for total suspended particulate (TSP) which is currently set at 120 $\mu g/m^3$). In general, the emission of particulate from a facility with a properly functioning bag house would not be considered to present a hazard for human receptors (e.g., children, elderly, other susceptible individuals) who may reside in the surrounding areas of a generic e-waste facility.

Overall, an adult female worker is considered to be the most sensitive receptor at a generic e-waste facility. In general, women of child-bearing age are considered to be particularly sensitive to various chemicals of concern (e.g., metals such as lead, etc.) because these chemicals may harm their developing fetus. This receptor is the focus for the chemical risk assessment in qualifying and quantifying the risk/hazard (i.e., quantitatively where data permits) or developing qualitative risk analysis associated with CoCs resulting from e-waste recycling facilities.

Table 4. Conceptual model based on site visit to a large-scale disassembly plant and follow-up literature survey.

Process	E-Waste Receiving	Classification of Shipment	Manual Disassembly	Classification of Individual Parts	Shredding	Packaging of Shreds for transport.
			Description			
Hazard	Ergonomic- spills from broken parts. Muscle strain from lifting, pulling, and pushing.	Equipment may be damaged from transport and be contaminated by solvent spills, ink spills, or sharp objects that are broken on inside	Operation of equipment to destroy housing of components will lead to exposure to various chemicals such as those provided in Table 1 of Section 1.1:	Parts containing various hazardous components. Improper sorting of parts could lead inadvertent exposure.	Noise, flying objects, creation of inhalable dusts that contain various chemical hazards. Explosion hazard due to exothermic processes that occur in batteries, sharp objects that can pierce the skin, threats to the eyes and ears etc.	Manual movement of shredded material to transport containers.
Exposure	Sharps, dermal, inhalation	Personnel may be exposed to solvents, spilled toners, radioactive compounds, electrical currents from batteries, etc.	Personnel may be exposed to sharps and dusts composed of	Personnel could be exposed to various chemicals in different forms- solid, liquid, fume, dusts, etc.	Sharp objects, dust containing many of the chemicals (metals) used in the manufacture of electronic products.	Formation of various dusts upon handling of the shredded waste leading to inhalation and dermal exposure. Ingestion is also possible.
Risks	Dermal cuts, muscle strain by handling big items	Dermal, inhalation, indirect ingestion, various organ systems affected	Ergonomic risk based on various repeated motions and positioning of equipment.	Improper classification of parts could lead to various risk scenarios.	Metals contained in the dust are minimally respiratory irritants and many are carcinogenic even at low exposure levels.	Cancer and non-cancer risk due to make-up of materials. Respiratory and dermal irritants.

4.1.6 Identification of Chemicals of Concern

Unlike a typical human health risk assessment where environmental or occupational sampling is conducted to determine the potential CoCs, apart from certified ambient air concentration data from an operational facility located in Ontario, information concerning contaminants associated with e-waste recycling has been identified from available literature, published reports, proceedings of conferences and articles. Contaminants identified as part of the examination of generic e-waste facilities were also included as potential contaminants of concern (CoCs). It is important to note that most of the information found in identifying potential contaminants of concern resulting from activities from e-waste facilities was focused on facilities involved in the recycling of personal computers, laptop computers and monitors. In general, there is a lack of available information and empirical data describing the chemicals present in other information technology (IT) and telecom equipment such as peripherals (i.e., scanners and printers), fax machines, telephones and mobile phones (Five Winds International, 2001).

The examination of medium to large-scale facilities provided little empirical data identifying the potential chemicals of concern that may potentially impact and result in occupational-type exposures. Therefore, the selection of chemicals of concern was focused toward data presented in peer-reviewed published literature reports as reasonable worst case estimates. A thorough search of the reference and literature sources indicates that quantitative and qualitative data pertaining and describing occupational exposure to chemicals associated with e-waste processing facilities was significantly lacking for North American operations. A previous report produced for Environment Canada (Five Winds International, 2001) has provided information concerning potential contaminants of concern likely to be present in IT and telecom products, as would be found in the typical electronic product stream sent to an e-waste recycling facility.

A large number of chemicals have been identified as components of electronic products (EIA/EICTA/GPSSI, 2003). A list of all chemicals used in the electronics industry are outlined in Table 1. However, in some cases the concentrations of the chemicals were found to be extremely low and were highly dependent on the type of product being processed (e.g., computer monitors versus a cell phone, etc.). It should also be noted that facility and maintenance workers may be periodically exposed to other compounds, such as solvents, however, these exposures are expected to be short in duration and non-continuous. In identifying the key CoCs that will be primary indicators of potential toxicity and should demand significant monitoring in the workplace, a number of criteria were used. The inherent toxicity of the compound to human receptors, the likelihood of presence in electronic products (i.e., how many e-products use this compound in their composition or constituent parts), percentage of the compound that is recycled, and in general, the compound's overall contribution by weight to a number of examined electronic products were all used to develop the list of CoCs (Appendix B).

4.2 Exposure Assessment

As indicated in the Occupational Health & Safety section (Section 3.0), practices involving the containment of dust and stockpiling in electronics recycling facilities which are contributing and major sources for contaminant exposure may be extremely variable (e.g., an operation with a fully functioning bag-house vs. an operation with a non-functional (or no) bag-house, etc.), and exposure would vary depending on these practices. For the purposes of this assessment, a reasonable worst-case scenario was examined as to not underestimate the potential for worker and trespasser exposure. Therefore, literature values were used (where available) to quantitatively model an assumed worst-case risk to workers and trespassers in association with more typical e-waste recycling processes in Canada.

4.2.1 Identification of Relevant Exposure Pathways

Identifying relevant exposure pathways to chemicals of concern (CoCs) for both the worker receptors (i.e., facility worker, supervisor, maintenance personnel) and a trespasser requires some knowledge concerning both the potential sources of the CoCs and activity patterns of the receptors (Table 7 -Conceptual Model). A number of processes during e-waste recycling may potentially result in exposure to worker receptors or a trespasser as identified in the conceptual model. While all worker receptors have the potential for exposure, it is the facility workers and in certain cases, maintenance workers who will have the greatest potential for exposure.

4.2.1.1 Exposure Pathways for Worker Receptors

There are three potential pathways by which facility workers could be exposed to CoCs from processing e-waste. The most likely and therefore, important pathway is via inhalation due to the dispersal of dust and particulate resulting from the continuous shredding processes. This was not identified as a potential source of worker exposure at the larger-scale facilities, as the shredding process was conducted under controlled conditions, with near complete containment of all the resulting particulate and dust (e.g., through the use of enclosures and bag-house apparatus). However, it is likely that the majority of less modern facilities do not have this type of equipment, thereby allowing for workers to be exposed to dusts and particulate as a result of shredding processes. The resulting dust and particulate exposure (i.e., a type of emission) could also lead to dermal and ingestion exposure of CoCs. Workers who do not wear personal protective clothing that covers the hands and arms (e.g., use of latex gloves, etc.) have the potential for dermal exposure. Chronic dermal exposure to dust and particulates in the workplace is considered to be an exposure pathway for workers. Although supervisors spend on average less time in the areas associated with waste processing, they are more likely to be wearing clothing that does not cover the arms completely. Incidental ingestion of dust and particulate is also of concern, as the CoCs may become airborne and as a result become ingested or deposited on the facility floor and subject to re-entrainment following worker movement and activity (e.g., forklift operators re-entraining dusts, etc.). Re-entrainment of dusts will result in the CoCs becoming airborne and potentially available for inhalation.

Dermal exposure to CoCs within an e-waste facility may be of greater concern than the inhalation of dust or particulate resulting from the shredding process, where occupational health practices are lax. Workers, both facility and maintenance, may be directly exposed to high concentrations of CoCs resulting from electronic equipment if personal protective equipment (PPE, e.g., gloves, goggles, cover-alls etc.) are not routinely worn.

4.2.1.2 Exposure Pathways for Trespassers

There are three potential pathways by which chemicals of concern could enter the natural environment surrounding the facility from processing electronic waste and result in exposure to a trespasser. The most important pathway, like that for the workers, is dispersal of dust and particulate resulting from the shredding process from the plant to the environment, resulting in CoC exposure to a trespasser via inhalation or ingestion. The dust and particulate emitted into the environment may become deposited in the soil surrounding the facility and again result in inhalation or incidental ingestion of impacted soil. The inhalation pathway is not likely to be significant, as dust in the air outside the plant would be dispersed by wind currents or deposited into the environmental media surrounding the site (e.g., soil, air, water, etc.). This assumption is plausible as a study investigating contaminant migration from indoor to outdoor air from a recycling facility reported no measurable levels of any CoCs (Sjodin et al. 1999).

A secondary pathway for exposure could potentially result if water were used in any part of the process, especially if dust and particulates were not controlled, and infrastructure such as collecting troughs and drains allowed the water to migrate from the site into nearby soils and sediments. However, the use of water has not been identified in the literature as a common practice for e-waste facilities; therefore, this exposure pathway is considered to be negligible. A third pathway would result if electronic components were stored outdoors before being disassembled. In this case, direct dermal contact with the CoCs may occur, however, in examining the normal practices within the literature and following the site visits at various facilities, storage of electronic waste in uncovered areas located outdoors may not typically occur.

Overall, the exposure of a trespasser to the CoCs resulting from activities at an e-waste facility is not expected to be significant; therefore, this receptor will not be examined further in the human health assessment.

4.3 Toxicity Assessment

The toxicity assessment component of the risk assessment considers the potential for a chemical contaminant to cause an adverse health effect in an individual receptor. It defines no effect exposure levels (NOEL) and/or provides a quantitative estimate of the relationship between the magnitude of exposure and the incidence of adverse health effects that may result from exposure. The toxicity assessment was completed for each of the CoC identified previously and outlined in Table 10, which may be represented by an individual compound (e.g., magnesium) or by a group of related compounds (e.g., asbestos materials).

In this assessment, exposure limits for exposure to each of the CoCs were examined from a number of recognized regulatory agencies. For the purposes of this assessment, the exposure limits derived by the US Environmental Protection Agency (US EPA) were selected as a default, for use in calculating the generic exposure limits. However, where exposure limits were not available from the US EPA, exposure limits from other agencies, including the Agency for Toxic Substances and Disease Registry (ATSDR), Health Canada and the World Health Organization, were examined and selected. An exposure limit for each of the CoCs is provided for the exposure route associated with the greatest concern due to toxicity (e.g., exposure route with the lowest exposure limit: inhalation versus oral) for use in determining the generic exposure limits.

4.3.1 Antimony/Antimony Compounds

Identified Exposure Limit for Antimony

	Exposure Route of Concern	**Toxicity Endpoint of Concern**	**Regulatory Exposure Limit**	**Reference**
Antimony	Oral	Biochemical changes in blood	0.4 μg/kg-day	US EPA, 1991a

The primary target organ for acute oral exposure to antimony appears to be the gastrointestinal tract (i.e., irritation, diarrhea, vomiting) and targets for long-term exposure are the blood (i.e., hematological disorders) and liver (mild hepatotoxicity). Inhalation exposure to antimony affects the respiratory tract (pneumoconiosis, restrictive airway disorders), with secondary targets being the cardiovascular system (altered blood pressure and electrocardiograms) and kidneys (histological changes). Only limited evidence exists for reproductive disorders due to antimony exposure.

Although some data indicate that long-term exposure of rats to antimony trioxide and trisulfide increased the incidence of lung tumors, the US EPA has not evaluated antimony or antimonials for carcinogenicity and a weight-of-evidence classification is currently unavailable (US EPA, 1991a).

4.3.2 Arsenic/Arsenic Compounds

Identified Exposure Limit for Arsenic

	Exposure Route of Concern	**Toxicity Endpoint of Concern**	**Regulatory Exposure Limit**	**Reference**
Arsenic	Oral	Cancer	1.5×10^{-3} $(\mu g/kg\text{-}day)^{-1}$	US EPA, 1998a

Epidemiological studies have revealed an association between arsenic concentrations in drinking water and increased incidences of skin cancers (including squamous cell carcinomas and multiple basal cell carcinomas), as well as cancers of the liver, bladder, respiratory and gastrointestinal tracts (US EPA, 1998). Occupational exposure studies have shown a clear correlation between exposure to arsenic and lung cancer mortality. US EPA (1998) has placed inorganic arsenic in weight-of-evidence group A, human carcinogen.

4.3.3 Asbestos\Asbestos Materials

Identified Exposure Limit for Asbestos

	Exposure Route of Concern	Toxicity Endpoint of Concern	Regulatory Exposure Limit	Reference
Asbestos	Inhalation	Cancer	0.23 $(f/ml)^{-1}$	US EPA, 1993a

Numerous studies in humans have established that long-term inhalation of asbestos fibers causes chronic, progressive pneumoconiosis (asbestosis). The disease is common among occupational groups directly exposed to asbestos fibers, such as insulation workers, but also extends to those working near the application or removal of asbestos and family contacts of exposed workers (US EPA, 1993). Asbestosis results from a prolonged inflammatory response stimulated by the presence of fibers in the lungs and is characterized by fibrosis of the lung parenchyma, which usually becomes radiographically discernible 10 years after the first exposure (US EPA, 1993). The main clinical symptom is shortness of breath, often accompanied by rales and cough. Because asbestos fibers are resistant to breakdown in the lungs, the inflammatory response triggered by the fibers is ongoing, even after exposure has ceased. It has been estimated that cumulative exposures of 17-75 fibers-year/mL would result in fibrotic lung lesions, and cumulative exposures of 3.5-300 fibers-year/mL would cause death in humans (US EPA, 1993). The US EPA inhalation unit risk is 0.23/(fibre/ml) which translates to $4.0E^{-6}$ fibres/ml at the 10^{-6} (1 in 1 million lifetime cancer) risk level.

Based on US EPA guidelines, asbestos was assigned to weight-of-evidence group A, human carcinogen (US EPA, 1993). The ACGIH have assigned a value of 0.1 f/cc for an Occupational Exposure Limit for asbestos (all forms; ACGIH, 2003).

4.3.4 Azo Colorants

Identified Exposure Limits for Azo Colorants

	Exposure Route of Concern	Toxicity Endpoint of Concern	Regulatory Exposure Limit	Reference
Azo Colorants –represented as benzidine	Inhalation	Cancer	0.23 (µg/kg-day)$^{-1}$	US EPA, 1993b

Several epidemiologic and case studies have shown that occupational exposure to benzidine results in bladder cancer (US EPA, 1993). Similarly, benzidine has been shown to produce various tumor types at multiple sites in animal species exposed by several routes. For example, dogs fed benzidine in capsules for 5 years developed bladder tumors, while lymphomas, hepatomas and adenocarcinomas were observed in mice treated by subcutaneous injection and benzidine given by gavage produced increased incidence of mammary tumors in Sprague-Dawley rats.

Based on US EPA guidelines, benzidine was assigned to weight-of-evidence group A, human carcinogen, based on the observation of increased incidence of bladder cancer and bladder cancer-related deaths in exposed workers (US EPA, 1993).

4.3.5 Beryllium/Beryllium Compounds

Identified Exposure Limit for Beryllium

	Exposure Route of Concern	Toxicity Endpoint of Concern	Regulatory Exposure Limit	Reference
Beryllium	Inhalation	Cancer	2.4×10^{-3} (µg/m^3)$^{-1}$	US EPA, 1998b

Epidemiological studies have suggested that beryllium and its compounds could be human carcinogens. Studies in workers exposed to beryllium, mostly via inhalation, have shown significant increases in observed over expected lung cancer incidences (US EPA, 1998b). The U.S. EPA (1998b), in evaluating the total database for the association of lung cancer with occupational exposure to beryllium, noted several limitations, but concluded that the results must be considered to be at least suggestive of a carcinogenic risk to humans. There was no toxicology data available to assess co-mixtures of beryllium/copper alloys.

Based on sufficient evidence for animals and inadequate evidence for humans, beryllium has been placed in the EPA weight-of-evidence classification B2, probable human carcinogen (U.S. EPA, 1998).

4.3.6 Bismuth/Bismuth Compounds

Identified Exposure Limit for Bismuth

	Exposure Route of Concern	Toxicity Endpoint of Concern	Regulatory Exposure Limit	Reference
Bismuth	No regulatory exposure limits were identified			

No data was available to determine potential adverse health effects with exposure to bismuth.

4.3.7 Brominated Flame Retardants (other than PBBs or PBBEs)

Identified Exposure Limit for Brominated Flame Retardants (BFR)

	Exposure Route of Concern	Toxicity Endpoint of Concern	Regulatory Exposure Limit	Reference
BFR's - represented by vinyl bromide	Inhalation	Liver toxicity	3.0 $\mu g/m^3$	US EPA, 1994a

In general, the literature indicates that aromatic brominated chemicals such as Tetrabromobisphenol A ('TBBPA') are the largest volume brominated flame retardants in production. TBBPA is known to be used as a reactive (primary use) or additive flame retardant in polymers and is used in electronic equipment as a reactive flame retardant in printed wiring boards.

Recently, the WHO, as part of its International Programme on Chemical Safety undertook a full scientific assessment of the human and environmental effects of TBBPA[14]. Its findings were as follows: TBBPA has little potential for bioaccumulation in humans, "the compound has not normally been found in environmental biological samples", environmental detection was limited to a few sediment/soil samples; and "the risk for the general population was considered to be insignificant".

The US EPA has currently not assessed TBBPA and very few other BFR's have undergone toxicity assessment.

However, aliphatic brominated chemicals such as hexabromocyclododecane (HBCD) and vinyl bromide (VBr) which may be used in various electrical components may cause significant human health effects following exposure. These compounds have been assessed by major

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[14] World Health Organization International Programme on Chemical Safety (IPCS): Environmental Health Criteria 172: Tetrabromobisphenol A and Derivatives.

regulatory jurisdictions such as US EPA and the Danish EPA. For example, vinyl bromide is classified by the US EPA as a Group B carcinogen and as a carcinogen by the Danish EPA. Acute (short-term) and chronic (long-term) studies indicate that the liver, the primary target organ following inhalation exposure to vinyl bromide in humans and animals may be significantly disrupted following exposure to VBr.

Because there was little toxicity data for TBBPA, VBr was used as a representative compound.

Acute and chronic studies indicate that the liver is the primary target organ following inhalation exposure to vinyl bromide (US EPA, 1994a). In high concentrations, vinyl bromide may produce dizziness, disorientation, and sleepiness in humans. Acute exposure of rats to very high concentrations via inhalation has showed liver and kidney damage and neurological effects (hypoactivity, drowsiness, and anesthesia). In rabbits, liquid vinyl bromide is slightly to moderately irritating to eyes, but nonirritating to skin.

Acute animal tests in rats have demonstrated vinyl bromide to have moderate to high acute toxicity by oral exposure.

No information is available on the chronic effects of vinyl bromide in humans. Chronic inhalation exposure primarily damages the liver, causing foci in the liver of rats. Hematological effects and elevated liver and kidney weights have also been observed in rats (US EPA, 1994a).

4.3.8 Cadmium/Cadmium Compounds

Identified Exposure Limit for Cadmium

	Exposure Route of Concern	Toxicity Endpoint of Concern	Regulatory Exposure Limit	Reference
Cadmium	Inhalation	Cancer	$1.8\text{x}10^{-3}$ $(\mu g/m^3)^{-1}$	US EPA, 1992a

The target organ for cadmium toxicity via oral exposure is the kidney. For inhalation exposure, both the lungs and kidneys are target organs for cadmium-induced toxicity.

There is limited evidence from epidemiological studies for cadmium-related respiratory tract cancer (US EPA, 1992a). The exposure limit of 1.810^{-3} $(\mu g/m^3)^{-1}$ is based on respiratory tract cancer associated with occupational exposure (US EPA, 1992a). Based on limited evidence from multiple occupational exposure studies and adequate animal data, cadmium is placed in weight-of-evidence group B1 - probable human carcinogen.

4.3.9 Chlorinated Polymers

Identified Exposure Limit for Chlorinated Polymers

	Exposure Route of Concern	**Toxicity Endpoint of Concern**	**Regulatory Exposure Limit**	**Reference**
Chlorinated Polymers	No regulatory exposure limits were identified			

No data was available to determine potential adverse health effects with exposure to chlorinated polymers, such as vinyl chloride polymer.

4.3.10 Chromium VI/Chromium VI Compounds

Identified Exposure Limit for Chromium VI

	Exposure Route of Concern	**Toxicity Endpoint of Concern**	**Regulatory Exposure Limit**	**Reference**
Chromium VI – represented as chromium VI oxide	Inhalation	Cancer	1.2×10^{-2} $(\mu g/m^3)^{-1}$	US EPA, 1998c

The inhalation of chromium VI compounds has been associated with the development of cancer in workers in the chromate industry. The relative risk for developing lung cancer has been calculated to be as much as 30 times that of controls (US EPA, 1998c). There is also evidence for an increased risk of developing nasal, pharyngeal, and gastrointestinal carcinomas (US EPA, 1998c). The results of inhalation studies in animals have been similar to those observed in occupational studies, with increased lung cancer risks reported (US EPA, 1998c).

Based on sufficient evidence for humans and animals, chromium VI has been placed in the EPA weight-of-evidence classification A, human carcinogen (U.S. EPA, 1998c).

4.3.11 Copper/Copper Compounds

Identified Exposure Limit for Copper

	Exposure Route of Concern	Toxicity Endpoint of Concern	Regulatory Exposure Limit	Reference
Copper – represented as copper cyanide	Oral	Decreased body weight, liver and kidney toxicity	5.0 μg/kg-day	US EPA, 1996a

Acute inhalation exposure to copper dust or fumes at concentrations of 0.075-0.12 mg Cu/m^3 may cause metal fume fever with symptoms such as cough, chills and muscle ache (US EPA, 1996a). Among the reported effects in workers exposed to copper dust are gastrointestinal disturbances, headache, vertigo, drowsiness, and hepatic toxicity (US EPA, 1996a). Dermal exposure to copper may cause contact dermatitis in some individuals (US EPA, 1996a).

No suitable bioassays or epidemiological studies are available to assess the carcinogenicity of copper. Therefore, the US EPA (1996a) has placed copper in weight-of-evidence group D, not classifiable as to human carcinogenicity.

4.3.12 Gold/Gold Compounds

Identified Exposure Limit for Gold

	Exposure Route of Concern	Toxicity Endpoint of Concern	Regulatory Exposure Limit	Reference
Gold	No regulatory exposure limits were identified			

No data was available to determine potential adverse health effects with exposure to gold.

4.3.13 Hydrochlorofluorocarbons/Isomers

Identified Exposure Limit for Hydrochlorofluorocarbons

	Exposure Route of Concern	Toxicity Endpoint of Concern	Regulatory Exposure Limit	Reference
Hydrochlorofluorocarbons – represented as Di-chlorofluoromethane (HCFC-21)	Oral	Reduced body weight in animal studies	200 μg/kg-day	US EPA, 1995a

Very little data is available to characterize the potential effects associated with exposure to hydrochlorofluorocarbons. The animal study that formed the basis the US EPA's exposure limit for oral exposure, reported a significant reduction in the body weight of exposed animals (US EPA, 1995a).

No hydrochlorofluorocarbon compounds have undergone a complete evaluation and determination for evidence of human carcinogenic potential (US EPA, 1995a).

4.3.14 Lead/Lead Compounds

Identified Exposure Limit for Lead

	Exposure Route of Concern	Toxicity Endpoint of Concern	Regulatory Exposure Limit	Reference
Lead	Oral	Neurotoxicity	3.57 µg/kg-day	Health Canada, 2003
Lead	All pathways	Neurotoxicity	1.85 µg/kg-day	MOE, 1996

Studies have shown that lead is a multi-target toxicant, causing effects in the gastrointestinal tract, hematopoietic system, cardiovascular system, central and peripheral nervous systems, kidneys, immune system, and reproductive system. Overt symptoms of sub-encephalopathic central nervous system (CNS) effects and peripheral nerve damage occur at blood lead levels of 40-60 ug/dL, and non-overt symptoms, such as peripheral nerve dysfunction, occur at levels of 30-50 ug/dL in adults; no clear threshold is evident (US EPA, 1990). Cognitive and neuropsychological deficits are not usually the focus of studies in adults, but there is some evidence of neuropsychological impairment and cognitive deficits in lead workers with blood levels of 41-80 ug/dL.

Inorganic lead and lead compounds have been evaluated for carcinogenicity by the US EPA (US EPA, 1989). The data from human studies are inadequate for evaluating the potential carcinogenicity of lead. Data from animal studies, however, are sufficient based on numerous studies showing that lead induces renal tumors in experimental animals. A few studies have shown evidence for induction of tumors at other sites (cerebral gliomas; testicular, adrenal, prostate, pituitary, and thyroid tumors). A slope factor was not derived for inorganic lead or lead compounds.

4.3.15 Magnesium

Identified Exposure Limit for Magnesium

	Exposure Route of Concern	Toxicity Endpoint of Concern	Regulatory Exposure Limit	Reference
Magnesium	No regulatory exposure limits were identified			

No data was available to determine potential adverse health effects with exposure to magnesium.

4.3.16 Mercury/Mercury Compounds

Identified Exposure Limit for Mercury

	Exposure Route of Concern	Toxicity Endpoint of Concern	Regulatory Exposure Limit	Reference
Mercury	Inhalation	Neurotoxicity	0.3 µg/m^3	US EPA, 1995b

The severity of mercury's toxic effects depends on the form and concentration of mercury and the route of exposure. Exposures to high levels of metallic, inorganic, or organic mercury can permanently damage the brain, kidneys, and a developing fetus. Effects on brain functioning may result in irritability, shyness, tremors, changes in vision or hearing, and memory problems. Short-term exposure to high levels of metallic mercury vapors may cause lung damage, nausea, vomiting, diarrhea, increases in blood pressure or heart rate, skin rashes, and eye irritation.

No data were available regarding the carcinogenicity of elemental mercury in humans or animals. The US EPA has placed mercury in weight-of-evidence Group D, not classifiable as to human carcinogenicity (US EPA, 1995b). Although it is not expected that significant amounts of methylated-mercury or mercuric chloride would be found within an e-waste processing facility, ecological receptors exposed to elemental mercury could potentially convert this form of mercury to the methylated form. EPA has classified both mercuric chloride and methyl mercury as possible human carcinogens (Group C).

4.3.17 Nickel/Nickel Compounds

Identified Exposure Limit for Nickel

	Exposure Route of Concern	Toxicity Endpoint of Concern	Regulatory Exposure Limit	Reference
Nickel – represented as nickel subsulphide	Inhalation	Cancer	4.8x10^{-4} (µg/m^{3})$^{-1}$	US EPA, 1991b

The most common adverse health effect of nickel in humans is an allergic reaction. Humans can become sensitive to nickel when jewelry or other nickel-containing items are in direct contact with the skin. Once a person is sensitized to nickel, further contact will produce a reaction; the most common reaction is a skin rash at the site of contact. Less frequently, some humans who are sensitive to nickel have asthma attacks or other reactions following exposure to nickel in food, water, or dust. Lung effects, including chronic bronchitis and reduced lung function, have been observed in workers who breathed large amounts of nickel. Current levels of nickel in workplace air are much lower than in the past, and today few workers show symptoms of nickel exposure. Humans who are not sensitive to it must eat very large amounts of nickel to show adverse health effects. In large doses (>0.5 g), some forms of nickel may be acutely toxic to humans when taken orally. Workers who accidentally drank water containing very high levels of nickel (100,000 times more than in normal drinking water) had stomachaches and effects on their blood and kidneys.

Epidemiological studies have shown that occupational inhalation exposure to nickel dust (primarily nickel subsulfide) at refineries has resulted in increased incidences of pulmonary and nasal cancer. Inhalation studies using rats have also shown nickel subsulfide or nickel carbonyl to be carcinogenic. Based on these data, the US EPA has classified nickel subsulfide and nickel refinery dust in weight-of-evidence group A, human carcinogen. Based on an increased incidence of pulmonary carcinomas and malignant tumors in animals exposed to nickel carbonyl by inhalation or by intravenous injection, this compound had been placed in weight-of-evidence group B2, probable human carcinogen. The US EPA has not evaluated soluble salts of nickel as a class of compounds for potential human carcinogenicity.

4.3.18 Ozone Depleting Substances/Isomers

Identified Exposure Limit for Ozone Depleting Substances

	Exposure Route of Concern	Toxicity Endpoint of Concern	Regulatory Exposure Limit	Reference
Ozone Depleting Substances	Inhalation	Accelerated mortality in	300 µg/m^{3}	US EPA, 1992b

Substances – represented as trichlorofluoromethane		mortality in exposed animals		

Very little data is available to characterize the potential effects associated with exposure to ozone depleting substances. The animal study that formed the basis the US EPA's exposure limit for oral exposure, reported accelerated mortality in the exposed animals when compared to control animals (US EPA, 1992b).

No ozone depleting substances have undergone a complete evaluation and determination for evidence of human carcinogenic potential (US EPA, 1992b).

4.3.19 Palladium/Palladium Compounds

Identified Exposure Limit for Palladium

	Exposure Route of Concern	Toxicity Endpoint of Concern	Regulatory Exposure Limit	Reference
Palladium	No regulatory exposure limits were identified			

No data was available to determine potential adverse health effects with exposure to palladium.

4.3.20 Phthalates

Identified Exposure Limit for Phthalates

	Exposure Route of Concern	Toxicity Endpoint of Concern	Regulatory Exposure Limit	Reference
Phthalates – represented as Bis(2-ethylhexyl)phthalate	Oral	Cancer	$1.4\text{x}10^{-5}$ $(\mu\text{g/kg-day})^{-1}$	US EPA, 1993c

There is no evidence that bis(2-ethylhexyl)phthalate (DEHP) causes serious health effects in humans. Most of what is known about the health effects of DEHP comes from high exposures to rats and mice. Brief exposure to very high levels of DEHP in food or water damaged sperm, but the effect reversed when DEHP was removed from the diet. Longer exposures to high doses affected the ability of both males and females to reproduce and caused birth defects. High levels of DEHP damaged the livers of rats and mice. Long exposures of rats to DEHP caused kidney damage similar to the damage seen in the kidneys of long-term dialysis patients. Whether or not DEHP contributes to human kidney damage, is unclear at present.

There is no direct evidence in any study on humans exposed to bis(2-ethylhexyl) phthalate that it causes cancer. Bis(2-ethylhexyl)phthalate is known to induce the proliferation of peroxisomes, which has been associated with carcinogenesis. Dose-dependent, statistically-significant increases in the incidences of hepatocellular carcinomas and combined carcinomas and adenomas were seen in mice and rats exposed to bis(2-ethylhexyl)phthalate in their diet. An increased incidence of neoplastic nodules and hepatocellular carcinomas was also reported in exposed rats.

Based on US EPA guidelines, bis(2-ethylhexyl)phthalate was assigned to weight-of-evidence Group B2, probable human carcinogen, on the basis of an increased incidence of liver tumors in rats and mice.

4.3.21 Polybrominated Biphenyls (PBBs)

Identified Exposure Limit for Polybrominated Biphenyls

	Exposure Route of Concern	**Toxicity Endpoint of Concern**	**Regulatory Exposure Limit**	**Reference**
Polybrominated Biphenyls – represented as decabromodiphenyl ether	Oral	Highest dose tested – no effects were observed	10 µg/kg-day	US EPA, 1995c

Very little data is available to characterize the potential effects associated with exposure to polybrominated biphenyls. The animal study that formed the basis the US EPA's exposure limit for oral exposure, reported no effects even at the highest dose level (US EPA, 1995c).

In several studies in animals, an increased incidence of tumour formation was observed. Based on this information the US EPA has classified polybrominated biphenyls (represented as decabromodiphenyl ether) as being possibly carcinogenic to humans.

4.3.22 Polychlorinated Biphenyls (PCBs)

Identified Exposure Limit for Polychlorinated Biphenyls

	Exposure Route of Concern	**Toxicity Endpoint of Concern**	**Regulatory Exposure Limit**	**Reference**

Polychlorinated Biphenyls – represented as Aroclor 1016	Oral	Reduced birth weights in exposed animals	$7.0x10^{-2}$ µg/kg-day	US EPA, 1996b

PCBs are absorbed after oral, inhalation, or dermal exposure and are stored in adipose tissue. The major route of PCB excretion is in the urine and feces; however, more important is the elimination in human milk. Accidental human poisonings and data from occupational exposure to PCBs suggest initial dermal and mucosal disturbances followed by systemic effects that may manifest themselves several years post-exposure. Initial effects are enlargement and hypersecretion of the Meibomian gland of the eye, swelling of the eyelids, pigmentation of the fingernails and mucous membranes, fatigue, and nausea. These effects were followed by hyperkeratosis, darkening of the skin, acneform eruptions, edema of the arms and legs, neurological symptoms, such as headache and limb numbness, and liver disturbance.

Data are suggestive but not conclusive concerning the carcinogenicity of PCBs in humans. However, hepatocellular carcinomas in three strains of rats and two strains of mice have led the US EPA to classify PCBs as group B2, probable human carcinogen.

4.3.23 Polychlorinated Naphthalenes

Identified Exposure Limit for Polychlorinated Naphthalenes

	Exposure Route of Concern	**Toxicity Endpoint of Concern**	**Regulatory Exposure Limit**	**Reference**
Polychlorinated Naphthalenes	No regulatory exposure limits were identified			

No data was available to determine potential adverse health effects with exposure to polychlorinated naphthalenes.

4.3.24 Selenium/Selenium Compounds

Identified Exposure Limit for Selenium

	Exposure Route of Concern	**Toxicity Endpoint of Concern**	**Regulatory Exposure Limit**	**Reference**

Selenium	Oral	Reduced birth weights in exposed animals	5.0 µg/kg-day	US EPA, 1991c

In humans, acute oral exposures can result in excessive salivation, garlic odor to the breath, shallow breathing, diarrhea, pulmonary edema, and death. Other reported signs and symptoms of acute selenosis include tachycardia, nausea, vomiting, abdominal pain, abnormal liver function, muscle aches and pains, irritability, chills, and tremors. The exact levels at which these effects occur are not known. Gastrointestinal absorption in animals and humans of various selenium compounds ranges from about 44% to 95% of the ingested dose. If too much selenium is ingested over long periods of time, brittle hair and deformed nails can develop. Upon contact with skin, selenium compounds have caused rashes, swelling, and pain. Respiratory tract absorption rates of 97% and 94% for aerosols of selenious acid have been reported for dogs and rats, respectively. In humans, inhalation of selenium or selenium compounds primarily affects the respiratory system. Dusts of elemental selenium and selenium dioxide can cause irritation of the skin and mucous membranes of the nose and throat, coughing, nosebleed, loss of sense of smell, dyspnea, bronchial spasms, bronchitis, and chemical pneumonia.

Studies of laboratory animals and humans show that most selenium compounds probably do not cause cancer. In fact, human studies suggest that lower-than-normal selenium levels in the diet might increase the risk of cancer. Selenium sulfide produced a significant increase in the incidence of lung and liver tumors in rats and mice. The US EPA has placed selenium and selenious acid in Group D, not classifiable as to carcinogenicity in humans, while selenium sulfide is placed in Group B2, probable human carcinogen.

4.3.25 Short-Chain Chlorinated Paraffins

Identified Exposure Limit for Short-Chain Chlorinated Paraffins

	Exposure Route of Concern	**Toxicity Endpoint of Concern**	**Regulatory Exposure Limit**	**Reference**
Short-Chain Chlorinated Paraffins	No regulatory exposure limits were identified			

No data was available to determine potential adverse health effects with exposure to short-chain chlorinated paraffins.

4.3.26 Silver/Silver Compounds

Identified Exposure Limit for Silver

	Exposure Route of Concern	**Toxicity Endpoint of Concern**	**Regulatory Exposure Limit**	**Reference**
Sliver	Oral	Argyria	5.0 μg/kg-day	US EPA, 1996c

Exposure to high levels of silver for a long period of time may result in a condition called arygria, a blue-gray discoloration of the skin and other body tissues. Lower-level exposures to silver may also cause silver to be deposited in the skin and other parts of the body; however, this is not known to be harmful. Argyria is a permanent effect, but it appears to be a cosmetic problem that may not be otherwise harmful to health.

Exposure to high levels of silver in the air has resulted in breathing problems, lung and throat irritation, and stomach pains. Skin contact with silver can cause mild allergic reactions such as rash, swelling, and inflammation in some people.

Data adequate for evaluating the carcinogenicity of silver to humans or animals by ingestion, inhalation, or other routes of exposure were not found. The only available animal studies showed both positive and negative results when silver was implanted under the skin. Based on US EPA guidelines, silver has been placed in weight-of-evidence group D, not classifiable as to human carcinogenicity.

4.3.27 Thallium/Thallium Compounds

Identified Exposure Limit for Thallium

	Exposure Route of Concern	Toxicity Endpoint of Concern	Regulatory Exposure Limit	Reference
Thallium	Oral	Biochemical changes	8.0×10^{-2} µg/kg-day	US EPA, 1990a,b,c

Exposure to high levels of thallium can result in harmful health effects. A study on workers exposed on the job over several years reported nervous system effects, such as numbness of fingers and toes, from breathing thallium. Humans who ingested large amounts of thallium over a short time have reported vomiting, diarrhea, temporary hair loss, and effects on the nervous system, lungs, heart, liver, and kidneys as well as death. It is not known what the effects are from ingesting low levels of thallium over a long time. Birth defects were not reported in the children of mothers exposed to low levels from eating vegetables and fruits contaminated with thallium. Studies in rats, however, exposed to high levels of thallium, showed adverse developmental effects.

Data suitable for evaluating the carcinogenicity of thallium to humans or animals by ingestion, inhalation, or other routes of exposure were not found. Thallium sulfate, selenite, nitrate, chloride, carbonate, acetate, and thallic oxide have been placed in EPA's weight-of evidence Group D, not classifiable as to human carcinogenicity based on inadequate human and animal data. The International Agency for Research on Cancer, has not classified pure thallium as to its human carcinogenicity. No studies are available in humans or animals on the carcinogenic effects of breathing, ingesting, or touching thallium.

4.3.28 Tributyl Tin, Triphenyl Tin and Oxides

Identified Exposure Limit for Tributyl Tin, Triphenyl Tin and Oxides

	Exposure Route of Concern	Toxicity Endpoint of Concern	Regulatory Exposure Limit	Reference
Tributyl Tin, Triphenyl Tin and Oxides	Oral	Immunosuppresion observed in exposed rats	0.3 µg/kg-day	US EPA, 1997

Because the inorganic tin compounds usually enter and leave the body rapidly when inhaled or ingested, they do not usually cause harmful effects. However, human and animal studies show that large amounts of these tin compounds can cause stomach aches, anemia, liver and kidney problems, and skin and eye irritation. Individual organic tin compounds have been associated with respiratory effects such as laboured breathing. Tin compounds have also been reported to cause effects on the central nervous system. Some of these compounds have been identified as causing immunosuppression following chronic exposure. Inorganic tin compounds, have however, not been found to affect reproductive functions, produce birth defects or cause genotoxic effects. Inorganic tin compounds have not been shown to result in cancer in animals or humans. However, there is some evidence that organic tin compounds found in pesticides, plastics, and paints may cause cancer. One organic tin compound used as a pesticide has been called a possible cancer causing substance by the EPA because of pituitary tumors found in female rats during one study.

4.3.29 Uranium/Uranium Compounds

Identified Exposure Limit for Uranium

	Exposure Route of Concern	Toxicity Endpoint of Concern	Regulatory Exposure Limit	Reference
Uranium	Oral	Kidney toxicity	3.0 µg/kg-day	US EPA, 1989

The health effects associated with oral or dermal exposure to natural and depleted uranium appears to be solely chemical in nature as opposed to radiological, while those from inhalation exposure may also include a slight radiological component, especially if the exposure is removed. A comprehensive review by the Committee on the Biological Effects of Ionizing Radiation (BEIR IV) concluded that ingesting food or water containing normal uranium concentrations would most likely not be carcinogenic or cause other health problems in most people. Inhaled uranium is associated with only a low cancer risk, with the main risk being associated with the co-inhalation of other toxic and/or carcinogenic agents, such as the radioactive transformation products of radon gas and cigarette smoke. Very high oral doses of uranium have caused renal damage in humans. Animal studies in a number of species and using a variety of compounds confirm that uranium is a nephrotoxin and that the most sensitive organ is the kidney. Hepatic and developmental effects have also been noted in some animal studies.

Uranium has not been evaluated by the US EPA as to its potential carcinogenicity, other than the potential of increased cancer risk associated with the radiological properties of uranium.

4.4 Quantitative Exposure Assessment

It is understood that a number of hazardous compounds may be potentially released during the recycling of e-waste products (e.g., lead, cadmium, beryllium, etc.). However, one of the most significant gaps and uncertainties identified is the lack of empirical data available to provide an estimate of the potential exposure to occupational receptors that work in facilities in North America, or even in countries where regulatory requirements are similar to those in North America.

Metals are assumed to be the most prevalent CoCs found in electronic waste. Their capacity for release into the work place environment has been documented to some extent in the literature. As mentioned previously, the generic site model identified a number of potential processes for which the release of CoCs could occur and result in exposure to the identified occupational receptors (i.e., facility and maintenance workers, supervisors).

The concentrations of CoCs potentially found in the workplaces associated with e-waste recycling were identified from several reports published in the literature and via sources on the internet associated with the worldwide electronics industry (e.g., EIA, EICTA, etc.). The exposure pathways of concern for occupational receptors included dermal, inhalation and ingestion (i.e., incidental ingestion of dust) and as such data concerning the concentrations of CoCs in the air and work surfaces available for dermal contact have been the focus (where available) for assessing the potential risk to workers.

Data were identified concerning the potential exposure of e-waste recycling workers to several metals and poly-brominated diphenyl-ethers (PBDEs), however, occupational monitoring for the majority the CoCs identified by the electronics industry were not found in the literature (Table 5). Therefore, no quantitative assessment of the risk to e-waste facility workers (workers, maintenance, supervisors) or trespassers can be provided for the majority of the CoCs. Due to the lack of available data concerning potential exposure to workers or site trespassers, generic exposure limits (based on conservative exposure scenario assumptions) for all the identified CoCs have been derived to provide criteria by which facilities may conduct more qualitative site-specific screening level assessments of their occupational monitoring data to provide an estimate of the potential health risks to workers The methodologies used to calculate the generic exposure limits are provided in Appendix B.

Table 5. Potential Workplace Exposures to Specific CoCs

Chemical of Concern	Source	Concentration	Reference	ACGIH TLV-TWA[a]
Beryllium	Levels in dust in a plant where beryllium-copper alloys were being cut with an automatic cutting machine and a hand cutter	12 µg/m^3, using particulates 0.4 mg/m^3 from Sjodin et al. (1999)	INCHEM, 1990	2 µg/m^3
Cadmium	Concentration in waste fraction including particles less than 2 mm in electronics recycling facility	15 mg/kg	Richter et al. 1997	10 µg/m^3 (total particulate); 2 µg/m^3 (respirable particulate fraction)
	Average air concentration in the area of a CRT operator	Non-detect	Peters-Michaud et al., 2003	
	Ambient air within an e-waste recycling facility	Non-detect	Peters-Michaud et al., 2003	

Chemical of Concern	Source	Concentration	Reference	ACGIH TLV-TWA[a]
Lead	Shredder waste	940 to 9400 mg/kg	Haloclean 2004	50 µg/m^3
	Average concentration in dust obtained from recycling of electronic equipment	200 mg/kg	Brandl et al. 2001	50 µg/m3
	Average air concentration in the area of a CRT operator	4.3 µg/m^3	Peters-Michaud et al., 2003	50 µg/m3
	Ambient air within an e-waste recycling facility	0.14-0.42 µg/m^3	Peters-Michaud et al., 2003	50 µg/m3
PBDEs	Air samples collected at an electronics recycling plant	0.175 µg/m^3	Sjodin et al. 2000	None available for the group of compounds

[a] Values obtained from ACGIH, 2003.

An examination of the data available from the literature sources concerning the concentration of CoCs measured in various e-waste facilities, indicates that workers may be exposed to levels of beryllium, cadmium and lead which may result in adverse human health effects. For example, the American Conference of Governmental Industrial Hygienists (ACGIH) occupational exposure limits have been exceeded based on exposure estimates provided in the literature (Table 5). By extrapolating the potential exposure of beryllium based on the level of particulate identified in Sjodin et al. (1999), it would appear that workers may be exposed to levels six-fold above the occupational exposure limit identified by the ACGIH (ACGIH, 2003). Similarly, by extrapolating from the oral concentration value of 15 mg/kg for waste fractions containing cadmium from an e-waste recycling facility, it is expected that the workers may be exposed to levels (52.5 µg/m^3) well above the ACGIH's occupational limits for cadmium (2 or 10 µg/m^3). Selecting the data to estimate the average concentration of lead in dust measured in an e-waste facility (200 mg/kg converts to an air exposure concentration of 700 µg/m^3), indicates that the exposure to workers to lead is potentially above the occupational limit.

4.4.1 Derivation of Generic Exposure Limits for Occupational Exposure in an E-Waste Facility

Generic exposure limits were derived for the most toxic compounds within each group identified (where a regulatory exposure limit was not available for the group); therefore, either a metal or group of organic compounds (e.g., within chromium (VI) compounds or within the polychlorinated biphenyls (PCBs)). Sample calculations of the generic exposure limits have been provided in Appendix B. The most toxic compounds within each group were identified by selecting the compound with the lowest regulatory exposure limit, as identified from the U.S. EPA's IRIS database or from other regulatory agencies. Default receptor parameters for a worker based on guidance provided by Health Canada (Health Canada, 2003) will be used to define the potential exposure of the facility worker (Table 6). Table 7 provides a summary of the derived generic exposure limits for potential CoCs within an e-waste recycling facility.

Table 6. Default Receptor Parameters for a Facility Worker

Receptor Parameter	Units	Worker Value	Reference
Exposure Frequency	d/yr	79.4	Health Canada, 2003
Exposure Duration	yr	27	Health Canada, 2003
Body Weight	kg	70.7	Health Canada, 2003
Averaging Time – non carcinogens	yr	27	Health Canada, 2003
Averaging Time – carcinogens, only time exposed via occupation considered	yr	27	Health Canada, 2003
Rate of Soil Ingestion	g/d	0.02	Health Canada, 2003
Rate of Inhalation	m^3/d	15.8	Health Canada, 2003
PM10 Concentration of CoC	mg/m^3	27.6	Health Canada, 2003
Skin Surface Area (hands + arms)	cm^2	3390	Health Canada, 2003
Rate of Dust/Soil Adherence	g·soil/cm^2/d	0.001	Health Canada, 2003

The generic exposure limits for the CoCs represent a cumulative exposure limit based on the sum of inhalation, ingestion and dermal contact for the non-cancer endpoint for a worker within an e-waste facility. However for those CoCs that may result in carcinogenic effects, the oral or inhalation cancer slope factor was used to determine the generic exposure limit for the workers. It should be noted that the "Regulatory Exposure Limit" values for those compounds which have been identified as being of greatest risk via inhalation have been converted from an air concentration [e.g., µg/m^3 or (µg/m^3)$^{-1}$] to an oral concentration [e.g., (µg/kg-day) or (µg/kg-day)$^{-1}$]. This has been done in order to compare the most relevant regulatory exposure limit to all applicable exposure pathways, which were calculated based on total oral concentrations of the compound (e.g., µg/kg-day). The conversion from an air concentration to an oral concentration is conducted via the following equation:

Equivalent oral concentration (µg/kg-day) = air concentration (µg/m^3) x (70 kg / 20 m^3)
Where:
70 kg represents the average adult body weight and,
20 m^3 represents the daily average adult inhalation rate

In the event that an identified CoC may result in carcinogenic effects via several routes of exposure (e.g., oral versus inhalation versus dermal contact), the most conservative regulatory exposure limit represented by the Cancer Slope Factor (CSF) was selected to calculate the generic screening limit. A generic exposure limit was calculated based on the exposure scenario expected for a facility worker (see Section 4.1.1 for receptor characteristics), as these individuals are expected to be exposed most frequently to the CoCs and therefore, represents the most sensitive receptor for determining risk.

Table 7 provides a summary of the derived generic exposure limits for potential CoCs assumed to be detected at a generic e-waste recycling facility.

Table 7. Derived Generic Exposure Limits for CoCs in an E-waste Facility

Group of Compounds	Representative Compound Modeled	Regulatory Exposure Limit/Toxicity Endpoint (µg/kg/day)	'Derived' Generic Exposure Limits (µg/kg/day)
Antimony/Antimony Compounds	Antimony	0.4 / Non-cancer via oral	38
Arsenic/Arsenic Compounds	Inorganic arsenic (tri- & pent-oxide)	1.5 / Cancer via oral and inhalation	$6.67\text{x}10^{-7}$
Asbestos/Asbestos Materials*	Asbestos	$4.0\text{x}10^{-6}$ / Cancer via inhalation	0.25 fibres/ml*
Azo Colorants	Benzidine	$2.3\text{x}10^{-2}$ / Cancer via inhalation	$4.35\text{x}10^{-5}$
Beryllium/Beryllium compounds	Beryllium sulfate tetrahydrate	8.4 / Cancer via inhalation	$1.19\text{x}10^{-7}$
Bismuth/Bismuth Compounds	No regulatory exposure limits were identified		
Brominated Flame Retardants (other than PBBs or PBBEs)	Vinyl bromide	$1.05\text{x}10^{-2}$ / Non-cancer via inhalation	1.0
Cadmium/Cadmium Compounds	Cadmium	6.3 / Cancer via inhalation	$1.59\text{x}10^{-7}$
Chlorinated Polymers (e.g., Vinyl chloride polymer (PVC))	No regulatory or occupational exposure limits were identified for the vinyl chloride polymer		
Chromium VI and its Compounds	Chromium VI oxide	420 / Cancer via inhalation	$2.38\text{x}10^{-9}$
Copper/Copper Compounds	Copper cyanide	5.0 / Non-cancer via oral	476
Gold/Gold Compounds	No regulatory exposure limits were identified		
Hydrochlorofluorocarbons/ Isomers	Dichlorofluoromethane (HCFC 21)	200 / Non-cancer via oral or inhalation	19060
Lead/Lead Compounds	Lead	3.57 / Neurotoxicity via oral	340
Magnesium	No regulatory exposure limits were identified		
Mercury/Mercury Compounds	Mercury, inorganic	0.09 / Neurotoxicity via inhalation	8
Nickel/Nickel Compounds	Nickel subsulphide	7.0 / Cancer via inhalation	$1.43\text{x}10^{-7}$
Ozone Depleting Substance/Isomers	Trichlorofluoromethane (CFC 11)	300 / Non-cancer via oral or inhalation	28589
Palladium/ Palladium Compounds	No regulatory or occupational exposure limits were identified		
Phthalates	Bis (2-ethylhexyl) phthalate	$1.40\text{x}10^{-2}$ / Cancer via oral	$7.14\text{x}10^{-5}$
Polybrominated Biphenyls (PBBs)	Decabromodiphenyl ether	10 / Non-cancer oral	953
Polychlorinated Biphenyls (PCBs)	Aroclor 1016	$2.00\text{x}10^{-3}$ / Cancer via oral	$5.00\text{x}10^{-4}$
Polychlorinated Naphthalenes	No regulatory or occupational exposure limits were identified		
Selenium/Selenium	Selenium	5.0 / Non-cancer oral	476

Group of Compounds	Representative Compound Modeled	Regulatory Exposure Limit/Toxicity Endpoint (µg/kg/day)	'Derived' Generic Exposure Limits (µg/kg/day)
Compounds			
Short-chain Chlorinated Paraffins	No regulatory exposure limits were identified		
Silver/Silver Compounds	Silver	5.0 / Non-cancer oral	476
Thallium	Thallium carbonate, thallium chloride, thallium (I) sulphate	0.08 / Non-cancer via oral	8
Tributyl Tin, Triphenyl Tin and Oxides	Tributyl tin oxide (TBTO)	0.3 / Non-cancer via oral	29
Uranium/Uranium Compounds	Uranium	3.0 / Non-cancer oral	286

*All values for asbestos and compounds are given as fibres/ml.

These generic exposure limits for many of the CoCs represent a cumulative exposure limit based on the sum of inhalation, ingestion and dermal contact for a non-cancer endpoint for a worker within an e-waste facility. However for those CoCs that may result in carcinogenic effects, the oral or inhalation cancer slope factor determined the generic exposure limit for the workers. In the event that an identified CoC may result in carcinogenic effects via several routes of exposure (e.g., oral versus inhalation versus dermal contact), the most conservative regulatory exposure limit represented by the Cancer Slope Factor (CSF) was selected to calculate the generic screening limit. A generic exposure limit was calculated based on the exposure scenario expected for a facility worker (see Section 4.1.1 for receptor characteristics), as these individuals are expected to be exposed most frequently to the CoCs and therefore, represents the most sensitive receptor for determining risk.

In general, it is expected that levels of exposure below the derived 'generic exposure limits' will not only afford protection of facility workers, but also ensure that other potentially exposed individuals such as maintenance workers and supervisors are protected. While the generic criteria are conservative exposure limits based on expected facility worker exposures, there is the potential that both facility and maintenance workers could be acutely exposed to levels of CoCs, which may result in adverse effects. The generic exposure limits provide a screening tool for assessing the potential risks to workers based on assumed average daily exposure within the workplace environment. However, acute exposure to high levels of a number of the identified CoC groups may result in adverse effects. Although not assessed in the current study, it is recommended that along with the generic exposure limits, the short-term exposure limits (STELs) derived by the ACGIH be used to assess potential acute effects associated with spills or direct dermal contact as would be the case during manual disassembly of e-waste.

4.5 Assessment of Lead Using the Adult Lead Model

For this screening-level risk assessment, the Adult Lead Methodology (ALM model) developed by the U.S. EPA was used to assess the potential hazards associated with concentrations of lead obtained from investigations of lead in dust samples collected from facilities involved in recycling of electronic equipment. The ALM model is specific for use in assessing lead, and is considered to be a rapid screening-level method.

4.5.1 Adult Lead Methodology-Background

To provide for a scientifically defensible approach for assessing human health risks as a result of exposure to lead from non-residential hazardous waste sites, the U.S. Environmental Protection Agency's (EPA's) Technical Review Workgroup for Lead (TRW) developed the Adult Lead Methodology (ALM). The methodology was originally developed to calculate cleanup goals for concentrations of lead found in soil and dust such that there would be no more than a 5% probability that a pregnant female (and their fetus) exposed to lead would exceed a blood lead (PbB) level of 10 µg/dL.

The 10 µg/dL blood lead level is a multi-Agency goal that has been designated by the US Centers for Disease Control (CDC) and the Agency for Toxic Substances and Disease Registry (ATSDR) as a level of concern to protect sensitive populations (i.e., neonates, infants, and children) from the harmful effects associated with exposure to lead. The protection of sensitive populations is assumed to also provide protection for less sensitive members of the population, including adults. The EPA's stated goal for lead is that children (up to 84 months of age) exposed at a risk-based cleanup level would have no more than a 5% probability of exceeding the level of concern (U.S. EPA, 1994; U.S. EPA, 1998). The adult lead methodology extends that same concept to develop cleanup goals preventive of fetal risk. Therefore, as a statistical goal, a probability of exceedance of up to 5% of the goal is considered to be acceptable (US EPA, 2004).

Although specifically designed to address lead in soil and dust at hazardous waste sites, the Adult Lead Methodology (ALM) may, in specific specialized circumstances be modified to evaluate other exposure pathways (e.g., dietary lead exposures, specifically fish ingestion exposures). Given that the concentration of lead obtained from the Brandl et. al. (2001) study was reported for indoor dust, for screening-purposes, the model was considered to be useful in assessing concentrations of lead in dust that may be found indoors at an e-waste recycling facility.

Concentrations of lead determined from dust samples have been reported in the literature for facilities involved in recycling of electronic equipment (Brandl et al., 2001). Brandl et al. (2001) reported an average concentration of 200 µg/g of lead in dust obtained from recycling of electronic equipment. Additional parameters regarding the concentrations of lead in dust were not reported in the study. In particular, the maximum concentration of lead measured in dust was not reported in the study, however, the maximum concentrations and the upper 95th confidence limits on the mean (95th UCL) will be greater than the arithmetic average concentration of samples collected and analyzed. As this is a screening level risk assessment, the use of the maximum concentration would be more appropriate for assessing the hazards associated with exposure to lead. This is done to ensure that the exposure point concentration of lead in dust is not under-predicted. In general, concentrations of lead are known to be elevated in areas where lead is smelted (MOE, 2002). Levels in soil and dust may exceed 1000 µg/g (MOE, 2002). Assuming a receptor (i.e., female adult) is exposed to a maximum represented by 5 x the average[15] concentration of lead in dust will ensure that the exposure point concentration (EPC) is not under-estimated in the screening-level assessment.

Therefore, for this assessment and simulation, an upper estimate of the concentration of lead in dust was represented as 5 x the average concentration (i.e., 5 x 200 µg/g) which is equivalent to 1000 µg/g. This value was used to represent the exposure point concentration (EPC) for an adult female receptor that works at the e-waste facility over a specific exposure duration (i.e., 27 years). This value was input into the ALM model and represents the default PbS term in the ALM model (i.e., the PbS term is the exposure point concentration that a receptor would be exposed to).

As indicated previously, in commercial/industrial type settings (i.e., non-residential settings), the most sensitive receptor is considered to be the female worker who develops a body burden of lead as a result of exposure to lead in a non-residential setting. This body burden may be readily available to transfer to the fetus for several years following exposure (Gulson et al., 1998; Gulson et al., 1999). Based on the available scientific data, a fetus is considered to be more sensitive to the adverse effects of lead than an adult (National Academy of Sciences, 1993), therefore, protecting a fetus will also confer protection of an adult male and female worker. The reader is referred to the US EPAs website for further details concerning the ALM methodology located at www.epa.gov/ Lead Methodology, Lead Workgroups, Superfund, US EPA site.

4.5.2 Adult Lead Methodology Simulation Run

The ALM model was run assuming a log-normal (default) distribution and that the concentration of lead in dust was 1000 µg/g. No other model parameters were modified and standard default values outlined in US EPA (2004) representative of all other parameters (e.g., exposure duration for a commercial worker, etc.) were used in the simulation.

The results of the Adult Lead Methodology (Appendix C) indicate that following exposure to lead in dust at 1000 µg/g there is a 6.5% probability that the target blood-lead level of 10 µg/dL for the fetal blood lead level will be exceeded (i.e., $PbB > PbB_t$).

Although this is marginally above the recommended cut-off value of 5%, nevertheless this would be considered to be an unacceptable hazard to the fetus and to pregnant female adult workers working in an electronics recycling facility were levels of lead in dust were determined to be at this level, and following similar exposure assumptions as outlined in US EPA (2004).

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[15] Important data, opinion, or assumption used assessing concentrations of lead in dust.

4.6 Screening Level HHRA Conclusions and Recommendations

Based on the foregoing, we offer the following:

- Concentrations of various inherently toxic metals including: chromium, beryllium, nickel, cadmium, arsenic, mercury, thallium, lead and other chemicals of concern (e.g., azo-colourants, brominated flame retardants, etc.) can be found in various components of e-waste;

- In general, the hazards following exposure to chemicals (i.e., metals, plastics, other compounds, etc.) resulting from e-waste recycling processes depend on the level of exposure and depend on the inherent toxicity of the compounds being assessed.

- Exposure to the metals and chemicals of concern can occur throughout the e-waste processing cycle, including for example, shredding, sorting, and packaging and as a result of exposure to various media which allow direct contact to these compounds (e.g., air, dust, soil, etc.).

- The assessment identified that maintenance workers may be exposed to acute levels of some compounds of concern, depending on the types of tasks that they perform and their duration of exposure to various industrial equipment located at a facility. Acute Occupational Exposure Limits (i.e., Short Term 15-minute exposure limits) identified by ACGIH and other reputable regulatory agencies and provided in this report are considered to be acceptable for use in protecting maintenance workers and plant workers who may be exposed to acute levels of chemicals of concern.

- The major human health hazards and effects associated with exposure to the compounds encountered in an e-waste processing facility (including cancer and non-cancer effects of the chemicals), in addition to guidance values (RfD's, RfC's, CSFs, etc.) were identified from peer-reviewed literature and summarized following review of recognized regulatory agencies hazard and toxicity information.

- A quantitative exposure model was developed using Health Canada exposure factors (i.e., uptake factors, exposure factors such as duration of exposure, etc.) and used to derive "generic, e-waste-specific exposure limits". The generic e-waste specific exposure limit estimates were developed and considered exposure through incidental ingestion, direct dermal contact and inhalation of fugitive dusts.

- The derived generic, e-waste specific exposure limits were ranked in terms of potential to cause human health toxicity from greatest to lowest, indicating that chromium > beryllium > nickel > cadmium > arsenic > azo-colourants > phthalate, following exposure of a female receptor of concern at a typical e-waste facility. This ranking is considered to be useful to identify chemicals or classes of chemicals for which practical mitigative measures could be developed to reduce and manage potential exposures. In addition, the exposure limits could be used in higher tiers of assessment, including site-specific risk assessments to ‘screen’ out potential chemicals and focus attention on those considered to be the most important.

- From the ranking, the metals and other compounds which can exist in particulate form and be subject to inhalation exposure are considered to pose significant risks to human health following exposure in a generic e-waste setting. Therefore, to reduce the exposure of workers and others to these metals, proper personal protective clothing, including use of proper dust masks, gloves, and other protective gear (coveralls, boots, etc.) is considered to be a practical risk mitigation technique.

- A further screening-level assessment and risk characterization was conducted specifically on lead using the U.S. Environmental Protection Agency’s Adult Lead Methodology (ALM) model. This model was used to assess the potential hazards associated with concentrations of lead in dust samples collected from facilities involved in recycling of electronic equipment.

- Assuming that an adult female was exposed to a maximum concentration of 1000 µg/g of lead in dust indicated that there would be a 6.5% probability that the target blood-lead screening level of 10 µg/dL for the fetal blood lead level would be exceeded.

- Although the ALM model simulation results were only marginally above the recommended cut-off value of 5% for a heterogeneous population, this scenario would be considered to present an unacceptable hazard to the fetus and to pregnant female adult workers exposed to lead while working at an e-waste recycling facility.

- With respect to residential receptors and trespassers, no measured or empirical data were identified concerning potential exposure to chemicals of concern for a trespasser or an adjacent resident who may live in close proximity to a generic, industrial/commercial zoned e-waste processing facility where chemicals may be released. A provincial Certificate of Approval (CoA) permit describing the modelled concentration of Total Suspended Particulate (TSP) in air was found to be below provincial limits and within acceptable limits considered to be protective of human health and the environment.

- In general, data from the ‘well resourced’ facilities suggest that low concentrations (i.e., below acceptable limits) of particulate (e.g., TSP; metals) are emitted into the atmosphere as a result of e-waste recycling.

- In general, the well resourced facilities for e-waste recycling have likely made major investments to protect both the facility workers and the environment. However, other facilities operating in Canada (i.e., both large and small facilities) may not employ as strict of occupational and environmental health practices as those demonstrated by the well resourced facilities.

- It is likely that the release of CoCs from e-waste facilities in Canada may, in general be underestimated based on data gathered and representative of the well resourced facilities.

- In general, the emission of particulate (e.g., TSP) from a facility with a properly functioning bag-house would not be considered to present a hazard for human receptors (e.g., children, elderly, other susceptible individuals) who may reside in the surrounding areas of a generic e-waste facility if those levels are found to be below acceptable limits established by federal and provincial environmental regulatory agencies. However, caution must be taken as not all Canadian provinces have implemented certificate of approval and air emission requirements.

- In summary, there is a paucity of available empirical and measured data concerning facility emissions for various e-waste recycling facilities operating in Canada. Therefore, no definitive conclusions can be made at this time concerning the likelihood or probability that e-waste processing facilities are completely risk free for residential and trespasser receptors.

- As a result of the significant data gaps identified in the assessment, further environmental monitoring, such as stack and effluent testing, groundwater/drinking water monitoring and soil sampling in close proximity to these facilities should be undertaken to reduce the uncertainties in the above findings.

- With respect to occupational workers conducting activities at an e-waste site (staff workers, supervisors, maintenance workers, etc.) in general, there is a paucity of data concerning the concentrations of the identified CoCs likely to be found in the work environment of an e-waste facility. Examining the data that was available concerning the concentrations of several metals within the work environment of e-waste facilities, it would appear that workers may be at risk, as the levels of several metals, including lead were found to be above the occupational exposure limits identified by the ACGIH.

In summary, further research addressing the potential for occupational exposure to CoCs within e-waste recycling facilities is recommended as an area of priority. To attempt to bridge this data gap and provide a means of quickly assessing the risks posed to e-waste workers, generic exposure limit criteria or screening level values were developed for a number of CoCs and associated compounds (e.g., chromium III and chromium VI are represented simply as chromium). To aid in determining the severity of the potential effects subsequent to the calculation of the generic screening limits, the values were ranked based on toxicity (potency) and therefore, likelihood of adverse health effects (Table 8).

Table 8. CoC Rankings Based on Generic Screening Limits

Chemical or Group of Compounds of Concern	Generic Exposure Limits – Screening Level Criteria (in µg/g or ppm)
Chromium	2.38×10^{-9}
Beryllium	1.19×10^{-7}
Nickel	1.43×10^{-7}
Cadmium	1.59×10^{-7}
Arsenic	6.67×10^{-7}
Azo Colorants	4.35×10^{-5}
Phthalates	7.14×10^{-5}
PCBs (as a result of older type e-waste)	5.00×10^{-4}
Brominated Flame Retardants (other than PBBs)	1.00
Thallium	7.62
Mercury	8.17
Tin	2.86×10^{1}
Antimony	3.81×10^{1}
Uranium	2.86×10^{2}
Lead	3.40×10^{2}
Copper	4.76×10^{2}
Selenium	4.76×10^{2}
Silver	4.76×10^{2}
PBBs	9.53×10^{2}
HCFC	1.91×10^{4}
Ozone Depleting Compounds	2.86×10^{4}
Asbestos	2.50×10^{-1} based on fibres/ml

- Based on the above data extra care should be taken within e-waste facilities to minimize the potential for exposure to a number of metals (e.g., chromium, beryllium, nickel, cadmium, lead etc.), azo compounds, phthalates and PCBs.

- To reduce the exposure of workers to these metals, proper personal protective clothing, including use of proper dust masks, protective gloves, and other protective gear (e.g., coveralls, boots, etc.) is considered to be a practical risk mitigation technique.

- Potential risks may be associated with occupational exposures resulting from activities in e-waste recycling. The paucity of available workplace monitoring data suggests that concentrations of a number of compounds may be resulting in unacceptable risks to workers. Due to a large data gap with respect to workplace environment concentrations and emissions of CoCs in Canadian e-waste facilities, it is currently not possible to provide a more accurate assessment of the potential risks to the identified human receptors (i.e., facility workers, maintenance personnel, facility supervisors, and trespassers).

- As a result of the lack of empirical data to support a risk assessment, it is recommended that sampling be conducted in the indoor environments at various e-waste facilities to obtain measured concentrations data for the various chemicals of concern in air, site soil, dust, and other relevant media.

- Given the differences in terms of a facilities operating capacity, and the potential for different e-waste processing methodologies to occur on site, it is recommended that individual e-waste facilities develop and complete, as a pro-active approach “potential problem analysis” or “failure and effect model analysis” assessments or other suitable approaches (e.g., Canadian Standards Association ‘*Standard CAN/CSA-Z731-03*’ methodology) for their facility operations (infrastructure, socioeconomic, processes, etc.). This would aid in identifying those components of an operation which, if a failure mode or catastrophic event were to occur (e.g., failure of a bag-house, shredding of an ink cartridge, etc.), could potentially result in a significant and unacceptable human health or ecological event. This proactive approach is employed and very common to other industries, such as the mining and chemical sector. An example PPA using CSA’s approaches is provided in Appendix C.

5.0 Identification of Canadian Environmental and OH&S Legislative and Regulatory Requirements

There is currently no specific legislation focusing solely on addressing e-waste processing facilities in Canada, however, certain sections of various provincial statutes, regulations, and guidance frameworks are considered to be applicable to e-waste processing facilities in Canada.

This chapter focuses on the identification, description and review of the Canadian environmental and occupational health and safety regulatory requirements which may be applicable to e-waste processing facilities, including federal, provincial, and if applicable, municipal. This section describing the environmental and occupational health and safety legislative and regulatory requirements should not be considered to be exhaustive, as new legislation and regulations continue to be developed to address these activities. Therefore, the reader is recommended to contact the appropriate authorities to determine the most up-to-date legislative and regulatory requirements associated with the management of e-waste in Canadian provinces.

5.1 Federal Environmental Legislation and Regulations

The *Canadian Environmental Protection Act, 1999 (CEPA)* is the primary legislation by which the federal government regulates activities which may have an impact on the environment. In general, CEPA encompasses the identification, assessment, and management of ‘toxic substances’ and authorizes regulations regarding their discharge into the environment. CEPA and its regulations are jointly administered by Environment Canada and Health Canada. CEPA deals with several environmental issues, including:

- toxic substances;
- pollution prevention;
- controlling pollution and waste management;
- information gathering, objectives, guidelines, and codes of practice;
- environmental emergencies, and;
- public participation.

Part 5 of CEPA addresses ‘Toxic Substances’. In general, Part 5 of CEPA permits the classification and regulation of toxic substances, which may be designed to include a ‘cradle to grave (i.e., life-cycle approach) system of controls for listed toxic substances. In general, toxic substances are substances that may have an immediate or long-term effect on the environment or that may potentially cause a danger to the environment or human or animal health (CEPA, 1999).

Part 5 of CEPA, 1999 is based on the provision and creation of various ‘lists of substances’, including:

- Domestic Substances List (DSL)
- Non-Domestic Substances List (NDSL)
- Priority Substances List (PSL)
- List of Toxic Substances
- Virtual Elimination List
- Export Control List

5.1.1.1 Priority Substances Lists

The following compounds which may be found in e-waste are considered to be toxic under CEPA, 1999[16], including:

- Asbestos fibres;
- Lead;
- Mercury;
- Inorganic cadmium compounds;
- Inorganic arsenic compounds;
- Hexavalent chromium compounds.

5.1.1.2 National Pollutant Release Inventory

Various manufacturing and 'processing' facilities must comply and participate in a federal government program intended to compile an annual inventory of pollutants being released into the environment in Canada. This program is known as the *National Pollutant Release Inventory* (NPRI). The NPRI reports the amount of the 'Listed Substances' discharged into the environment, as well as the amounts disposed of off-site and the locations of that disposal. E-waste facilities, if considered to be 'processing facilities' may be subject to NPRI reporting. A list of those chemicals of concern and NPRI designation is provided in Table 9.

Table 9. Chemicals of Concern Listed on the National Pollutant Release Inventory (NPRI) Substance List and Designation

Chemical or Group of Compounds of Concern	NPRI List and Designation
Antimony	Group 1 NPRI Substance[1]
Arsenic	Group 4 NPRI Substance[1]
Asbestos	Group 1 NPRI Substance[2]
Beryllium	Proposed NPRI Substance as of 2003
Cadmium	Group 3 NPRI Substance
Chromium	Group 4 NPRI Substance[3]
Copper	Group 1 NPRI Substance[1]
HCFC-22; 122; 123; 124; 141b; 142b	Group 1 NPRI Substances[4]

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[16] Considered to be "toxic" as interpreted under section 11 of the Canadian Environmental Protection Act (CEPA); updated as of August 13th, 2003 (CEPA Environmental Registry, Environment Canada, 2004).

Chemical or Group of Compounds of Concern	NPRI List and Designation
Lead	Group 4 NPRI Substance
Mercury	Group 2 NPRI Substance[1]
Nickel	Group 1 NPRI Substance[1]
Ozone Depleting Compounds	Proposed NPRI Substances as of 2003
Selenium	Group 1 NPRI Substance[1]
Silver	Group 1 NPRI Substance[1]

[1]"and its compounds"
[2]"friable form"
[3]Hexavalent Chromium Compounds
[4]including all isomers

5.2 Federal Worker Protection Legislation

The federal government has enacted several pieces of key legislation, including the *Hazardous Products Act (HPA), Controlled Products Regulations (CPR), Ingredient Disclosure List (IDL)* and the *Consumer Chemicals and Containers Regulations, 2001* which have application to the Workplace Hazardous Materials Information System (WHMIS). In addition, the federal government created the *Canada Labour Code* and regulations to outline the health and safety requirements for the federally regulated workplace. In general, 'hazardous waste' and 'manufactured articles' are considered exempt under the federal WHMIS system as there are additional requirements under other statutes (e.g., labeling, etc.) to address these items. Therefore, only provincial WHMIS requirements (e.g., workers rights to know, employee education, provision of MSDS sheets, etc.) are considered applicable with respect to WHMIS requirements.

5.2.1 Canada Labour Code

The *Canada Labour Code* (*CLC*) is the federal governments occupational health and safety legislation that applies to federally regulated employers such as the federal civil service, railways, banks and airports.

There are specific responsibilities listed under the *CLC* and the *Canada Occupational Health and Safety Regulations (Safety Regs)* for employers, including the requirement to ensure that concentrations of hazardous substances (controlled products) are controlled in accordance with prescribed standards. The CLC and associated regulations prescribed under the Act are not specifically designed to address e-waste processing facilities.

5.3 Provincial Acts and Regulations – Environmental Protection

In general, the mandates of the provincial environmental regulatory agencies allow them to enact legislation used to protect human health and the environment. For example, in Ontario, the mandate of the Ontario Ministry of the Environment (OMOE) is to protect the quality of the natural environment so as to safeguard the ecosystem and human health and to foster the efficient use and conservation of resources.

In many provinces, several pieces of legislation, together with numerous regulations, policies, objectives and guidelines, and instruments exist to assist the provincial governments and environmental Ministry's in fulfilling their goals of protecting human health and the environment. For example, in Ontario, legislation including the *Environmental Protection Act* (EPA), the *Environmental Assessment Act*, and the *Environmental Bill of Rights* (EBR) support each other and are designed to protect human health and the environment.

In general, the Acts and the regulations made under them, outline the authority and responsibility of the Ministry as well as establish and stipulate the legal requirements for clients and the rights of residents of the provinces. For example, in Ontario, the *Environmental Protection Act* requires that approvals or permits be obtained prior to the implementation of a variety of undertakings which may impact on the environment and also provide the residents of Ontario with the right to comment on these undertakings.

In addition to the approvals and permits required by the Ministry, other ministries, such as the Natural Resources or the Ministry of Northern Development and Mines, and other levels of government may have approval or permit requirements. It must be emphasized that approval under one Act does not generally abrogate the requirement to obtain approval under other Acts or other sections of the same Act.

Although not considered to be an exhaustive list of Acts and Regulations, the reader is referred to each of the provinces individual web sites for further information regarding legislation and regulations pertaining to occupational health and safety and environmental statutes.

5.4 Certificate of Approvals

In general, and unless specifically exempt, provincial Ministry of the Environment approval programs require that all undertakings requiring approval under Ministry legislation be carried out in accordance with all Acts, regulations, policies, objectives and guidelines administered by the Ministry, including the requirement to abide by provincial certificate of approval (CoA) permits.

The responsibility for obtaining a Certificate of Approval for equipment or a process which may discharge a contaminant into ambient air lies with the owner or operator of the equipment or process. For example, in Ontario, the statutory requirements for the approval of any equipment or process which may discharge to the air are contained in Section 9 of the Environmental Protection Act (EPA). Section 9(1) requires that approval be obtained from the Director before establishing new or modifying existing equipment or processes which may discharge a contaminant into the ambient air.

When approaching the Ministry to obtain a certificate of approval (CofA), the proponent of an 'e-waste facility' would be required to identify the following, including:

- the industrial processes that occur at the facility;
- the location of emission points, including stacks, bag-houses, emission points, etc;
- the types and rates of contaminants discharged, and;
- the proposed emission controls.

In general, the Ministry will assist the proponent in identifying all provincial environmental acts, regulations, policies, objectives and guidelines applicable to the project (i.e., facility), and provide information on the *Environmental Bill of Rights* (EBR) requirements for public notification (a requirement in Ontario). The Ministry will also identify any special concerns which must be addressed in the application for approval.

In general, following pre-application consultation, the proposed facility of representative will have a clear understanding of the Ministry's requirements and design the project or facility to meet these environmental objectives. The Ministry fosters pre-application consultation to save both time and money for the client and the Ministry and in addition, pre-consultation is required for all major projects, expansions or modifications proposed for a facility.

Approval of the application may be granted through the issuance of one of the following documents:

- a new Certificate of Approval;
- an Amended Certificate of Approval, or;
- a Notice of Amendment to a Certificate of Approval.

New Certificates of Approval are issued to approve new installations or modifications to existing unapproved equipment or processes.

Amended Certificates of Approval are usually issued to approve modifications to existing approved equipment or processes. An Amended Certificate of Approval revokes and replaces the existing Certificate of Approval.

Notices of Amendment to Certificates of Approval are usually issued to approve modifications to existing and previously approved equipment or processes, and/or modify the terms and conditions of existing Certificates of Approval. A Notice of Amendment becomes part of the Certificate of Approval.

In granting an approval, the Director usually imposes terms and conditions on the Certificate of Approval. These conditions cover the operation and performance of the equipment and may cover such items as maintenance of air pollution control devices (e.g., bag-houses, etc.), monitoring and reporting on emissions levels, and the minimum performance requirements necessary to achieve compliance with all applicable Acts, regulations, policies, objectives and guidelines.

In general, the emission levels must comply with provincial ambient air quality criteria, as outlined for various chemicals indicated in Table 10.

Table 10. Ontario Ambient Air Quality Criteria

Name of Contaminant	Unit of Measurement	Concentration or Total Amount of Contaminant	Period of Time Approximate Equivalent at 10℃ and 760 mm Hg pressure
Arsenic	µg/m³	25	24 hrs
Cadmium	µg/m³	2.0	24 hrs
Lead	µg/m³	2.0 0.7	24 hrs arithmetic average, 30 days
Mercury	µg/m³	2.0	24 hours
Nickel	µg/m³	2.0	24 hrs
Suspended Particulate Matter 120 24 hours 60 geometric mean 1 year	µg of suspended particulate matter/m³ of air	120 60	24 hours geometric mean (1 year)

Ontario Ministry of the Environment (2004).

In Alberta, particulate releases are regulated under the *Substance Release Regulation* (Substance Reg). For example, operations involving the processing, storing, or handling of chemicals may be subject to the limits prescribed under this regulation, including the Maximum Concentration of Particulate allowed (0.20 g/kg of effluent). The release of air emissions exceeding the limits set in the Substance Reg. are reportable in accordance with the substance release provisions of the *Alberta Environmental Protection and Enhancement Act (AEPEA)*. The reader is referred to www.gov.ab.ca for further information.

In the Province of British Columbia, the Environmental Protection Department (EPD) of the Ministry of Water, Land and Air Protection (MWLAP) regulates the discharge of potential air contaminants through the issuance, amendment, cancellation and administration of permits for the discharge of contaminants into air. A component of a permit evaluation may include the requirement to assess health and environmental impacts resulting from the emission of the contaminant in air. The MWLAP have adopted ambient air quality guidelines for total suspended particulate (TSP) which set out acceptable and tolerable concentrations. The reader is referred to www.gov.bc.ca for additional information regarding this provinces regulatory requirements.

5.5 Provincial Environmental Protection Acts and Regulations

In general, the provincial and territorial governments, under their environmental ministry's have established acts and regulations to provide protection of human health and the natural environment. Although this section is not considered to be an exhaustive list of Acts and Regulations, the reader is referred to each of the provinces individual web sites for further information regarding legislation and regulations pertaining to occupational health and safety and environmental statutes.

5.5.1 Province of Alberta

The *Alberta Environmental Protection and Enhancement Act (AEPEA)* is a broad, omnibus legislation which covers all aspects of the environmental protection in Alberta. Proponents operating e-waste recycling facilities in the province of Alberta may be subject to certain sections outlined in the Environmental Assessment Process (EAP) under the Environmental Assessment Regulations (*EA Reg*). This process is designed to ensure that 'projects' that could cause an adverse effect on the environment be reviewed. Under this regulatory regime, approvals and registrations are means by which projects are approved. The release of substances to the environment is regulated by Part 4 of *AEPEA*, and is designed to ensure that accidental releases, as well as those exceeding prescribed limits, are properly managed to protect both human health and the environment.

5.5.2 Province of British Columbia

The *Waste Management Act* (WMA) is the primary statute regulating the environment in British Columbia. This legislation is an omnibus act which regulates most aspects of the environment. In general, the WMA prohibits the discharge of all wastes to the environment and pollution, unless the discharge is specifically exempt from control under the WMA or is made following the issuance of permits or approvals set up under the WMA. In general, a person is prohibited from introducing or allowing waste to be introduced into the environment during the course of conducting an industry, trade or business, or from any prescribed activity or operation. In general, the WMA allows certain wastes under certain conditions to be discharged into the environment, for example, under compliance with a permit or specific approval. An e-waste facility may, under certain conditions, be required to obtain a permit to recycle certain wastes and recover certain re-useable resources under this regulatory framework.

5.5.3 Province of Ontario

The Ontario *Environmental Protection Act* (EPA) is a broad, omnibus enactment that deals with a broad range of environmental issues. The overall purpose of the act is to provide for the protection of human health and the natural environment. The EPA is divided into sections and sub-sections which deal with various matters, some of which include:

- regulations concerning the discharge of contaminants including the requirement to obtain Certificate of Approval's (CofAs) under a formal, transparent process;
- regulation of ozone depleting substances; and
- regulation of litter, packaging and similar products that pose waste management problems.

5.6 Provincial Occupational Health and Safety Acts and Regulations

In general, all of the provincial and territorial governments, under their labour sectors, have established acts and regulations to ensure occupational health and safety. These include the various occupational health and safety acts and regulations and the Workplace Hazardous Materials Information System (WHMIS) Regulations.

The following is a list of the provincial Acts or Regulations that regulate worker's safety (e.g., requirement for a Joint Health and Safety Committee, designated substances, etc.). In general, e-waste facilities would have to comply with the following provincial acts and regulations, depending on the location of e-waste facility operations.

The following acts and regulations apply to workers and employers covered by the various provincial jurisdictions:

5.6.1 Alberta's Occupational Health and Safety Act

The Alberta's Occupational Health and Safety Act is administered by the Alberta Minister of Labour. Although not as stringent as other provincial occupational health and safety legilsation, the act allows workers to refuse to work where they believe it will cause a danger to themselves or others. Briefly, the functions of the joint work site health and safety committees are listed in Section 25 of the Act. In addition, Alberta's Chemical Hazards Regulation (Alta. Reg. 393/88) Part 2, Controlled Products) deals with controlled products which may be components of e-waste. The CHR focuses on general workplace exposure to hazardous chemicals (e.g., asbestos).

5.6.2 British Columbia - Occupational Health and Safety Regulation

In general, WHMIS provisions in BC are provided in several key provincial statutes and regulations, including the *Workers Compensation* Act. In general, the requirements of the Occupational Health and Safety Committees are addressed in Section 3-5 - 3-6 of the Regulation. Section 30.17 specifically addresses personal protection requirements.

The WHMIS (Occupational Health and Safety Regulation), Part 5, Sections 5.3-Application, 5.4-Prohibition, 5.5-WHMIS program, 5.6-Worker education and 5.7 Worker training may be applicable at generic e-waste facilities.

The province of British Columbia's Occupational Health and Safety Regulation (B.C. Reg. 296/97) Part 5, Chemical and Biological Substances may be applicable at various e-waste processing facilities.

5.6.3 Manitoba - Workplace Safety and Health Act

Additional provisions for employees working with hazardous substances are addressed in the *Workplace Health Hazard Regulations* under the *Workplace Safety and Health Act*. Worker education and personal protective equipment requirements are included in these regulations. Requirements concerning workplace safety and health committees and representatives are discussed in Sections 40 and 41 of the Act, respectively. Provisions for medical examinations are included in Section 50 of the Act.

5.6.4 New Brunswick - Occupational Health and Safety Act

Requirements for joint health and safety committees are discussed in Sections 14-16 of the Act and requirements for health and safety representatives are discussed in Sections 17 & 18 of the Act. Medical examinations are discussed in Section 46 of the Act.

5.6.5 Newfoundland - Occupational Health and Safety Act

Requirements concerning occupational health and safety committees are discussed in Sections 38-40 of the Act and outlined in Section 21 of the Occupational Health and Safety Regulations under the Occupational Health and Safety Act. Provisions for medical examinations are addressed starting at Section 58 of the Act. The Newfoundland Department of Environment and Labour also provides a summary of this Act.

5.6.6 Northwest Territories - Safety Act

Requirements for a joint work site health and safety committee are addressed in Section 7 of the Act.

5.6.7 Nova Scotia - Occupational Health and Safety Act

Requirements for establishing a joint occupational health and safety committee and functions of the committees are addressed starting at Sections 29-32 of the Act. Requirements concerning medical examinations are provided in the Occupational Health Regulations.

5.6.8 Nunavut - Safety Act

Requirements for a joint work site health and safety committee are addressed in Section 7 of the Act.

5.6.9 Ontario – Occupational Health and Safety Act

Requirements for a health and safety representative and for joint health and safety committees are provided in Sections 8 and 9 of the Act, respectively. In addition, Ontario has identified ‘designated substances’ or ‘toxic substances’ under their provincial legislation (Ontario Regulation 833) to protect workers from these substances.

In Ontario, the *Occupational Health and Safety Act* (R.S.O. 1990,) places duties on employers to take reasonable precautions to ensure that the health and safety of workers is adequately protected. General guidelines and requirements are dictated for all hazardous materials. Since the early 1980's a list of nearly a dozen substances have been classified as "designated substances" largely in response to their inherently toxic or otherwise harmful characteristics.

All substances or combinations of substances, whether biological, chemical or physical in nature, deemed to fall under the criteria of a "designated substance" are subject to special treatment by workplaces in accordance to a set of substance specific rules and regulations.

At present specific regulations have been made to prohibit, regulate, restrict, limit or control workplace exposure to any of the following 'designated' substances, including:

- Arsenic;
- Asbestos;
- Lead, and
- Mercury.

The '*Occupational Health and Safety Act*' also clearly prescribes that any designated substance found to be present in a workplace requires the completion of a detailed use assessment of that substance by management. Part and parcel of this assessment is the determination of whether or not a health hazard exists for workers and finally whether or not a control program is needed. According to the Act the assessment must also include all of the following:

- information regarding the use, handling, storage and disposal of the designated substance,
- actual and potential exposure of workers to the substance, and
- methods and procedures required to control that exposure.

5.6.10 Prince Edward Island - Occupational Health and Safety Act

Criteria and functions of the joint health and safety committee are provided in Section 18 of the Act. Requirements for a health and safety representative are addressed in Section 19. Medical examinations are discussed under Part V, Section 25 of the Act.

5.6.11 Quebec - Loi sur la santé et la sécurité du travail

(An Act Respecting Occupational Health and Safety)

Requirements for health and safety committees are discussed in Chapter IV of the Act. Safety representative requirements are provided in Chapter V. Additional details of the health and safety committees are provided in the Regulation Respecting Health and Safety Committees* under the Act.

5.6.12 Saskatchewan - Occupational Health and Safety Act

Requirements for occupational health committees and representatives are discussed under Part III of the Act, starting at Section 15. Medical examinations and treatment are discussed in Part X, which starts at Section 64 of the Act.

5.6.13 Yukon Territory - Occupational Health and Safety Act

Requirements for health and safety committees and representatives are addressed starting at Section 12 of the Act WHMIS-NEW. Medical examinations are addressed in the Act starting at Section 45.

5.7 Occupational Exposure Limits

The Canadian provincial occupational exposure limits developed for the protection of workers based on 8-hr exposure durations, are summarized in the following section. A summary of the occupational exposure limits provided by various agencies (e.g., ACGIH, US NIOSH, etc.) and prescribed by various provincial legislation is provided in Table 11.

Table 11. Available Threshold Limit Values for Chemicals Associated with E-waste Processing.

Agency/ Jurisdiction	Units	TWA	STEL	Ceiling	Agency Notes
Antimony – Compounds (as Sb)					
ACGIH TLV	mg/m^3	0.5			TLV basis/Critical Effect(s): Irritation; lung, CVS
Alberta	mg/m^3	0.5	1.5		
British Columbia	mg/m^3	0.5			
Quebec	mg/m^3	0.5			
USA – NIOSH IDLH	mg/m^3			50	
USA – NIOSH REL	mg/m^3	0.5			
USA –OSHA PEL	mg/m^3	0.5			
Arsenic – Inorganic Compounds (as As)					
ACGIH TLV	mg/m^3	0.01			TLV basis/Critical Effect(s): Lung & Skin cancer; lung
Quebec	mg/m^3	0.1			
USA NIOSH – IDLH	mg/m^3			5	
USA – NIOSH REL	mg/m^3			0.002	
USA NTP					
USA – OSHA PEL	mg/m^3	0.01			
Asbestos – All forms					
ACGIH TLV	f/cc	0.1			TLV basis/Critical Effect(s): asbestosis; cancer, value is for fibres longer than 5 microns, with an aspect ratio =/> 3:1
BC	f/cc	0.1			As Low As Reasonable Approach
USA – NIOSH REL	f/cc	0.1			
USA – OSHA PEL	f/cc	0.1	1		

Agency/ Jurisdiction	Units	TWA	STEL	Ceiling	Agency Notes
Beryllium – Compounds (as Be)					
ACGIH TLV	mg/m^3	0.002	0.01		Basis/Critical Effect(s): lung cancer; berylliosis
ACGIH TLV-NIC	mg/m^3	0.0002			Basis/Critical Effect(s): lung cancer; berylliosis
Ontario	mg/m^3	0.002	0.01		
Quebec	mg/m^3	0.002			
USA – NIOSH IDLH	mg/m^3			4	
USA – NIOSH REL	mg/m^3			0.005	
USA – NTP					
USA – OSHA PEL	mg/m^3	0.002		0.005	
USA – OSHA PEL	mg/m^3			0.025	30 minute peak per 8-hour shift
Brominated Flame Retardants (e.g., Vinyl Bromide)					
ACGIH TLV	ppm	0.5			Critical Effect(s): liver, CNS; cancer
Alberta	ppm	5	10		
Ontario	ppm	0.5			
Quebec	ppm	5			
USA – NIOSH REL	na				
USA – NTP	na				
Cadmium – Metal & Compounds (as Cd)					
ACGIH TLV	mg/m^3	0.01			Critical Effect(s): kidney
Alberta	mg/m^3	0.05	0.2		
Ontario	mg/m^3	0.01			
Quebec	mg/m^3	0.025			
USA – OSHA PEL	mg/m^3	0.005			
Chromium (VI) inorganic compounds – water soluble (as Cr)					
ACGIH TLV	mg/m^3	0.05			TLV Criteria: liver, kidney; respiratory
USA – NIOSH IDLH	mg/m^3			15	
USA – NIOSH REL	mg/m^3	0.001			
USA – OSHA PEL	mg/m^3			0.1	measured as CrO$_3$
Copper – Dusts and/or mists (as Cu)					
ACGIH TLV	mg/m^3	1			Critical Effect(s): irritation; GI; metal fume fever
Alberta	mg/m^3	1	2		
Quebec	mg/m^3	1			
USA – NIOSH IDLH	mg/m^3			100	
USA – NIOSH REL	mg/m^3	1			
USA – OSHA PEL	mg/m^3	1			
Lead – elemental and inorganic compounds (as Pb)					
ACGIH TLV	mg/m^3	0.05			Critical effect(s): CNS, blood; kidney; reproductive
Alberta	mg/m^3	0.05			
British Columbia	mg/m^3	0.05			
Quebec	mg/m^3	0.15			
USA – NIOSH IDLH	mg/m^3			100	
USA – NIOSH REL	mg/m^3				TWA <0.1 Blood Pb < 0.06 mg/100 g whole blood
USA – OSHA PEL	mg/m^3	0.05			

Agency/ Jurisdiction	Units	TWA	STEL	Ceiling	Agency Notes
Mercury – Inorganic compounds (as Hg)					
ACGIH TLV	mg/m^3	0.025			Critical effect(s): CNS; kidney; reproductive
Alberta	mg/m^3	0.1	0.3	0	
Ontario	mg/m^3	0.025			
Quebec	mg/m^3	0.1			
USA NIOSH IDLH	mg/m^3			10	
USA NIOSH REL	mg/m^3			0.01	
US – OSHA PEL	mg/m^3			0.1	
NIckel (Elemental / Metal)					
ACGIH TLV	mg/m^3	1.5			Critical effect(s): dermatitis, pneumoconiosis
Alberta	mg/m^3	1	2		
B.C.	mg/m^3	0.05			
Ontario	mg/m^3	1			
Quebec	mg/m^3	1			
USA NIOSH IDLH	mg/m^3			10	
USA NIOSH REL	mg/m^3	0.015			
USA OSHA PEL	mg/m^3	1			
Selenium – Compounds (as Se)					
ACGIH TLV	mg/m^3	0.2			Critical Effect(s): irritation
Alberta	mg/m^3	0.2	0.6		
Quebec	mg/m^3	0.2			
USA NIOSH IDLH	mg/m^3			1	
USA NIOSH REL	mg/m^3	0.2			
USA OSHA PEL	mg/m^3	0.2			
Silver – Elemental / Metal					
ACGIH TLV	mg/m^3	0.1			Critical Effect(s): argyria (skin, eyes, mucosa)
Alberta	mg/m^3	o.1	0.3		
Quebec	mg/m^3	0.1			
USA NIOSH IDLH	mg/m^3			10	
USA NIOSH REL	mg/m^3	0.01			
Thallium – Soluble compounds (as Tl)					
ACGIH TLV	mg/m^3	0.1			Critical Effect(s): irritation, CNS, CVS
Alberta	mg/m^3	0.1			
Quebec	mg/m^3	0.1			
USA NIOSH IDLH	mg/m^3			15	
USA NIOSH REL	mg/m^3	0.1			
USA OSHA PEL	mg/m^3	0.1			

STEL: Short-term exposure limit, a value consisting of a TWA measurement during a reference period of 15 minutes. Exposures between the TWA and up to the STEL should not be longer than the specified time period, should not occur more than four times during the work shift, and there should be at least 1 hour between successive exposures at this range. If the STEL is identified as being other than a 15-minute period, the variance appears under the "Notes" column;

TWA: Time-weighted average concentration, usually for an 8-hour day and a 40-hour workweek. If the TWA is identified as being other than for 8 hours, the time is stated under the "Notes" column.

5.8 Regulatory Requirements - Conclusions and Recommendations

There is currently no specific legislation focusing solely on addressing e-waste processing facilities in Canada, however, certain sections of various provincial statutes, regulations, and guidance frameworks are considered to be applicable to e-waste processing facilities in Canada.

For example, the chemical constituents of e-waste may be subject to a number of federal and provincial legislative requirements, for example, designated substances lists, and other federal reporting lists (e.g., PSL, DSL, NPRI, etc.).

Depending on the location of operations in Canada, and based on the waste flow processes that occur at an e-waste processing facility, the facility may be required to abide by certain regulatory requirements, for example, obtaining Certificate of Approval permits (CofA's) for emissions of contaminants into the ambient environment.

From the assessment provided above, it is recommended that:

- Given the differences with respect to possible e-waste processing capacity, and divers e-waste processing methodologies currently available, it is recommended that individual e-waste facilities develop and complete, as a pro-active approach "potential problem analysis" or "failure model analysis" assessments or other suitable approach (e.g., CSA Standard CAN/CSA-Z731-03 methodology) for their facility operations (infrastructure, socioeconomic, processes, etc.). This would aid in identifying those components of an operation which, if a failure mode or catastrophic event were to occur (e.g., failure of a bag-house, shredding of an ink cartridge, etc.), could potentially result in a significant and unacceptable human health or ecological event. This proactive approach is a legislated requirement and is routinely employed and very common to other industries, such as the mining and chemical sector (e.g., under the *Metal Mining Effluent Regulations*, etc.).

- It is recommended that industries initiate and conduct further or additional pro-active approaches and methods to systematically deal with and manage their environmental and occupational health and safety risks. Management systems (such as ISO 14001, etc.) provide structured processed for the achievement of improved environmental and safety performance.

- Given the evolving nature of the e-waste recycling and processing business in Canada, legislative requirements are one of several possible approaches to addressing the risks associated with e-waste processing. Further risk characterization, and enhanced environmental monitoring is necessary to determine if mandatory (i.e., legislative) or voluntary (ISO-based etc.) approaches are appropriate.

6.0 References – Health Assessment

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Part B - Screening Level Ecological Risk Assessment

Generic Electronic Waste Processing Site

7.0 Part B - Screening Level Ecological Risk Assessment for a Generic E-Waste Processing Facility in Canada

7.1 Introduction

The primary resource that provides general guidance for ecological risk assessment in Canada is the Framework for Ecological Risk Assessment (ERA): General Guidance (CCME 1996). Other guidance documents are used in various provinces, for example, the Ministry of the Environment Guidance on Conducting Site Specific Risk Assessment in Ontario (MOE 1996). A Screening Level Environmental Risk Assessment (SLERA) is characterized by simple, qualitative and/or comparative methods, and relies heavily on literature information and previously collected data. Screening Assessment studies are likely to be focused mainly at the species level and to be descriptive, as opposed to predictive. Within the ERA framework, all sites undergo a screening assessment. Further tiers of risk assessment, which provide more complex analysis of the risk, are only undertaken if the initial tier (the screening level) cannot adequately characterize the risk with an acceptable degree of certainty.

Tasks to be undertaken for a SLERA are detailed in the CCME framework. These are detailed in later sections of this report. They include:
- Background review
- Receptor characterization
- Exposure Assessment
- Hazard Assessment
- Risk Characterization

The final product of these tasks should provide information on the result of the assessment and make recommendations for reducing data gaps and conducting further studies/risk assessments. The information in this report will be used as one of the components in deciding whether remediation or more assessment is necessary for the site.

7.2 Background Review

Discussions with individuals at Environment Canada and review of literature indicated that there were very little data available on the release of substances produced during e-waste processing into the environment, and no data on substances released in North America from current practices. However, these discussions included observations from visits to plants in Europe that indicated there was a potential for hazardous substances to enter the environment.

7.3 Methods

Selection of target chemicals for the assessment was a product of discussions with MJC and Associates and literature review. The list of Chemicals of Concern included compounds that have been shown to occur in the environment in the vicinity of e-waste, or that occur in high concentrations in e-waste. A selective literature and web search determined that there are few reports of levels of contaminants of concern in electronic waste.

As suggested in the CCME Framework for Ecological Risk Assessment, the assessment consisted of the following tasks:

- The environment chosen to represent the risk assessment of a generic facility was selected to be at the interface between an agricultural and urban area, in a non-marine environment. Background information was assumed for the ecological characteristics of the area from the author's experience on several projects conducting inventories at the interface between urban and rural areas.
- Reconnaissance site visits were conducted on January 23, 2004 to examine the environmental setting of several e-waste processing facilities located in southern Ontario. The visits provided context, during which the habitat capability of the site was assessed;
- Background information was reviewed to infer the typical inhabitants of the study area and ascertain whether their life history characteristics would make them vulnerable to any exposure pathways;
- Receptors were characterized, during which information obtained from the site visit and background review was used to identify potentially exposed habitats, communities, and ecosystems, identify receptors most likely to be exposed to stressors (depending on their ecological characteristics): with emphasis on individual species of indigenous populations as advised by CCME (1996);
- Valued Ecosystem Components (VEC's) were identified in context with a generic facility from inferences and consultation;
- Life history and background information was compiled for species of concern;
- Exposure was assessed, based on identification of possible exposure and transport pathways, and preliminary estimates provided, wherever possible, of exposure or tissue concentrations using qualitative methods and simple quantitative methods as advised for a screening level assessment by CCME (1996);
- A hazard assessment was conducted using toxicity information from the literature for the contaminants of concern. The sources were mainly secondary for these assessments, including data summarized by the U.S. Environmental Protection Agency (EPA) (including the ECOTOX database) and reviews of toxicological effects by Eisler, as well as primary literature for less well-understood chemicals;
- A risk characterization was conducted, using quotient analysis of expected environmental concentration (EEC) and toxicological benchmark concentration (BC) wherever possible; and
- Data gaps and uncertainties were identified that would indicate the need for a higher level of ERA.

7.4 Receptor Characterization

This section describes the organisms characteristic of the habitats that would likely occur in the vicinity of a generic facility.

7.4.1 Vegetation and Habitat

The environment surrounding the generic facility has been selected as one that is typical for newly-established industrial areas in southern or central Canada. The generic facility is likely to be at the interface between the urban and agricultural landscape. Abandoned agricultural fields, hedgerows and small patches of woods could be in close proximity to the facility. Small drainage ditches or small creeks, likely connecting with larger creeks or wetlands downstream, would likely be found nearby. Natural vegetation in fields is likely to consist mainly of grasses and coarse herbs (goldenrods and asters). A drainage ditch/creek tributary would be mostly vegetated with reed canary-grass (scientific names are provided in Table 1), with scattered willows and dogwoods. Forests and hedgerows are typically dominated by various proportions of deciduous and coniferous tree species such as sugar maple, white pine or trembling aspen.

For the purposes of the assessment, it was assumed that there could be significant natural features (e.g. significant species, Areas of Natural and Scientific Interest, provincially significant wetlands) in the vicinity (NHIC 2000).

7.4.2 Wildlife

Wildlife on the site would likely consist largely of species adapted to agricultural landscapes. It would likely include a few species that inhabit larger forests, that tend to disappear with urban expansion. It would include mainly species that are adapted to smaller woodland patches and narrow ravines through urban habitat. The native wildlife that uses these patches mainly includes those most familiar to urban residents, including mammals such as deer mice, short-tailed shrews, raccoons, skunks, and foxes, birds such as blue jays and northern cardinals, reptiles such as garter snakes and amphibians such as toads and leopard frogs.

7.4.3 Valued Ecosystem Components

Valued Ecosystem Components (VECs) can be any feature identified as valuable through scoping exercises. They are resources or environmental features that

- are important to human populations;
- have economic and/or social value;
- have intrinsic ecological significance; and
- serve as a baseline from which the impacts of development can be evaluated, including changes in management or regulatory policies.

The most appropriate definition of valued ecosystem components in this analysis is the native, resident species that typify the ecosystem. Therefore, all resident organisms could be considered VECs except non-native species such as house sparrow and rock dove and transient or migratory species such as ring-billed gull. The rationale for selection of each species as VECs is provided in Table 1. The most significant organism identified as a VEC in this study is the Red-shouldered Hawk. This species is considered vulnerable in Canada because of habitat destruction and contaminants (pesticides), and is at the southern edge of its range. This species is particularly dependent on larger tracts of forest with adjacent wetlands, as it breeds in large forests with a mature canopy and forages in wetlands, specializing in amphibian prey. It is one of the most likely significant species to be encountered in areas of urban expansion.

Table 12. Life cycle information for VECs inhabiting the environment in the vicinity of the Generic Facility

Common Name	Scientific Name	Habitat	Rationale for Inclusion
Grass family	*Poaceae*	Wetland species that can also invade uplands	Common throughout southern Ontario, consumed by herbivores
Mustard family	*Brassicaceae*	Pioneering in old fields, agricultural crops	Consumed by many herbivores; a large body of research exists on contaminants
Sediment-associated Invertebrates	*e.g. Daphnia spp.*	Stream bottom	Keystone species in aquatic ecosystems
Earthworm	*e.g.Lumbricus spp.*	Terrestrial soils	Maximum exposure to and ingestion of soils, keystone species in ecosystem; sensitive to deposition of substances of concern in soils
Fathead Minnow	*Pimephales promelas*	Stream habitat, feeds on organic detritus, bottom mud, zooplankton	Keystone aquatic species; abundant, a large body of research exists on toxicity
Northern Leopard Frog	*Rana pipiens*	Lays eggs in shallow edges of permanent or standing water in spring; overwinters in substrate under water, in summer feeds on terrestrial invertebrates, roams up to 1 km away from hibernation site in meadows	Common in wetlands in southern Ontario but declining in urbanized areas, common prey of higher trophic levels including Red-shouldered Hawk
Deer mouse	*Peromyscus maniculatus*	Gives birth in shallow burrows or concealing structures to 0.1 m depth, Omnivorous and opportunistic: feeds on seeds, arthropods, some green vegetation, roots, fruits and fungi	Keystone herbivore, common prey of higher trophic levels
Short-tailed Shrew	*Blarina brevicauda*	Mainly inhabits burrows in soft soils, feeds on earthworms and other invertebrates	Keystone insectivore, abundant, maximum ingestion of soil
Red-shouldered Hawk	*Buteo lineatus*	Feeds in wetlands, mainly on amphibians and small mammals, nests in large forest tracts	Species at Risk in Canada, at highest level of food chain

7.5 Assessment of Exposure Pathways

Practices regarding the containment of dust and stockpiling in electronics recycling facilities are extremely variable, and exposure would vary depending on these practices. At one end of the spectrum, in recycling plants with a high degree of environmental stewardship, components that contain high levels of chemicals of concern are removed prior to processing. Dust is removed from the air, strictly contained and itself shipped for recycling. No water is used anywhere in the process, and if water is required in an emergency (for example, for fire control) it is collected and analysed. Floor drains are not present. All components coming in to the plant are stockpiled indoors. Food is kept strictly outside the processing areas so animals are not attracted to areas where dust could be present. The risk that contaminants of concern could migrate to the environment or that VECs could be exposed outside this type of plant is negligible.

At the other end of the spectrum would be plants that store components out of doors prior to processing, that shred components without regard for their composition, and that do not collect dust. The dust is therefore released outdoors through the ventilation system and the doors and windows to become deposited outside, or is washed off the floor of the facility into floor drains that lead to the environment. At worst are the facilities where components are burned or acid treated in the open (and these have only been reported in China) without any regard for environmental safety. Risk of exposure from this type of facility is much greater.

There are three potential pathways by which chemicals of concern could enter the natural environment from processing electronic waste. The most important pathway is dispersal of dust resulting from the shredding process from the plant to the environment, where it could become deposited in the soils and wetland sediments outside the plant and then ingested or absorbed by VECs. A second pathway would result if water were used in any part of the process, especially if dust were not controlled, and drains allowed the water to migrate from the site into soils and sediments. A third pathway would result if electronic components were stored out of doors before being disassembled. In this case, water could leach through and drain to the local watershed, carrying with it dissolved chemicals of concern that would then be deposited in soils or water. Leachate could also percolate through the ground and contaminate groundwater.

Inhalation pathways are not likely to be significant, as dust in the air outside the plant would be dispersed by wind currents or deposited. In addition, the only measurement of any contaminant in air outside a recycling facility, i.e. Polybrominated Diethyl Ethers (PBDE) detected no measurable levels (Sjodin *et al*. 1999). This pathway would only be significant to animals that inhabited the facility, and these would likely be restricted to organisms such as insects, house mice and rats, mainly non-native species that are not in themselves considered Valued Ecosystem Components, and typically remain inside buildings (and would therefore represent no threat to predators outside the building). Exposure of native species to dust inhalation would be much less significant than exposure to ingestion of dust deposited in the soils and on plants.

The most significant exposure for plant and soil invertebrate species is directly through soils and sediments. Sediment associated organisms are also directly exposed through sediments. Wildlife species have different probabilities of exposure to contaminants, depending on life history characteristics. Ingestion of water is not considered in this assessment in the terrestrial system because all species are small and sedentary and would not be likely to obtain water from contaminated sources, and soil ingestion is likely to be much more significant as an exposure pathway.

In a screening assessment, it is generally assumed that small, sedentary wildlife species reside and therefore forage exclusively from the contaminated site (Sample *et al.* 1996). That is, 100% of the food they consume is contaminated. While this assumption simplifies the assessment, due to the mobility and diverse diets of most wildlife, it is likely to overestimate the actual exposure experienced. It should be remembered that the purpose of a screening assessment is to identify potential risks and the data gaps to be filled. Once these data gapes are filled, a definitive evaluation of risk may be made as part of the next tier of assessment.

The most significant pathway for exposure of aquatic organisms is through sediments and water. For this assessment, it will be assumed that groundwater discharge could be a significant exposure pathway in aquatic systems. Groundwater at 2-3 metres depth could be contaminated by outfalls from the plant, and if it discharges through sediments on the stream bank invertebrates could be exposed.

Figure 1 provides a conceptual model of exposure from a facility where contaminants are allowed to enter the environment. Table 2 summarizes the pathways through which species found on such a generic site could be exposed. Criteria for evaluation of amount of exposure are as follows:

- high (the animal is frequently exposed directly to contaminants),
- moderate (the animal is directly exposed to contaminants for a moderate proportion of its life cycle, or indirectly exposed during a significant portion of its life cycle) or
- low (the animal is exposed directly for a very small proportion of its life cycle, or indirectly for a small proportion of its life cycle).

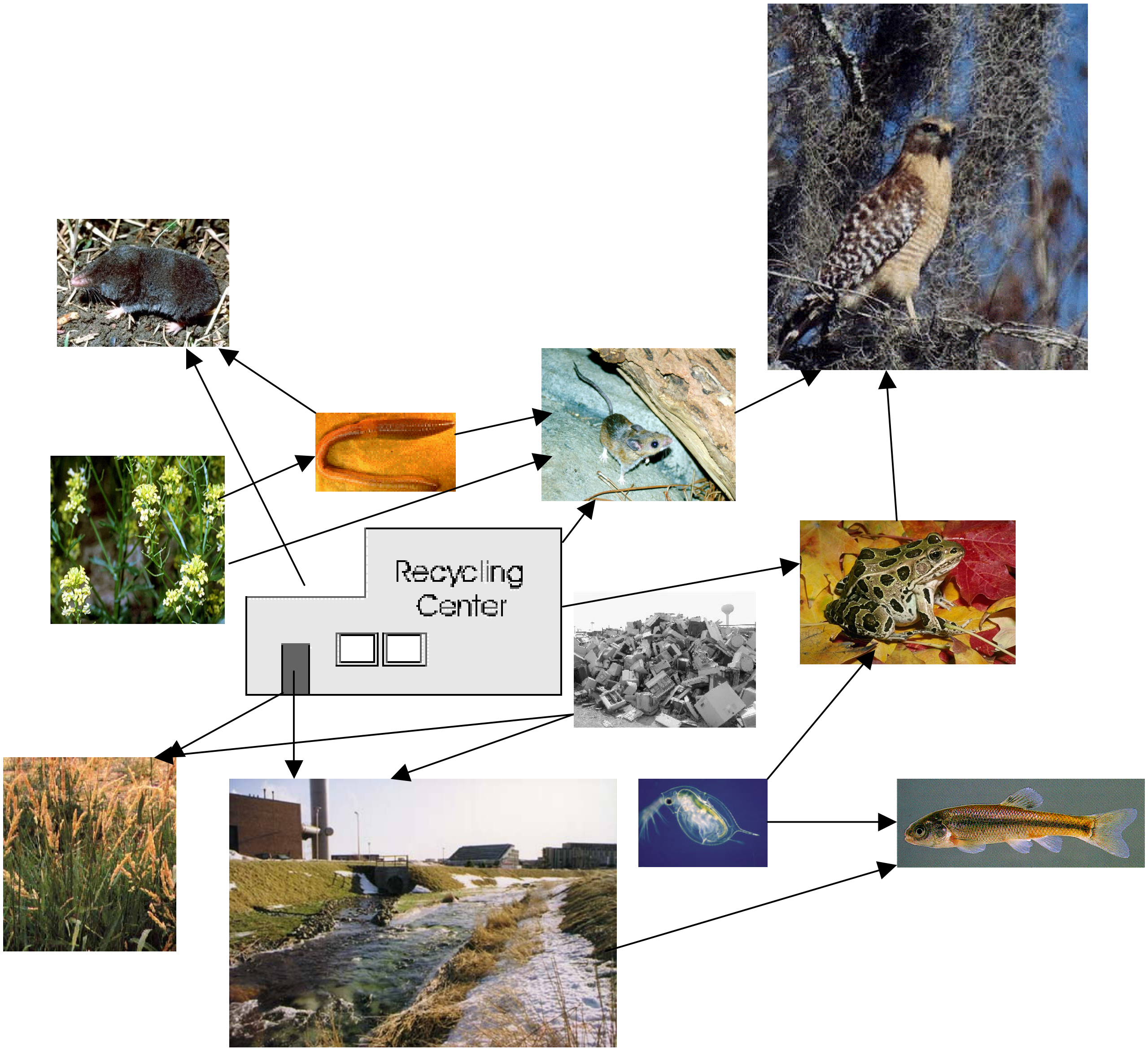

Figure 3. Exposure pathways in the environment of a generic electronic waste recycling facility

Table 13. Exposure Pathways for VECs on the Generic Site. > Indicates pathways between organisms and contaminant source.

Species	Exposure Pathways present	Worst-Case Frequency of Exposure	Amount of Exposure
Benthic-associated invertebrates	• sediment>aquatic invertebrate	Continuous, direct to sediment	high
Fathead minnow	• sediment>fish • sediment>aquatic invertebrate >fish	intermittent	low
Reed canary-grass	• Soil>roots>leaves	Continuous, direct to soil	High
Mustard family	• Soil>roots>leaves	Continuous, direct to soil	high
Earthworm	• Soil>earthworm	Continuous, directly to soil	High
Leopard Frog	• Soil>invertebrate>frog • Soil>plant>invertebrate >frog	Intermittent; indirect exposure: home range probably larger than site	Low
Short-tailed Shrew	• Soil>invertebrate (earthworm) > shrew • Soil>shrew	Frequent direct exposure due to burrowing lifestyle, ingestion of soil, earthworms (home range very small, may be within site boundary)	High
Deer Mouse	• Soil>mouse	Exposure to shallow soils in burrow, especially while digging and resting	High
	• Soil+plant>mouse	Indirect potentially frequent exposure while foraging: home range may be confined to site	Moderate
	• Soil+plant>invertebrate >mouse	Indirect but potentially frequent exposure: home range small, may be confined to site	Moderate

Species	Exposure Pathways present	Worst-Case Frequency of Exposure	Amount of Exposure
Red-shouldered Hawk	• Soil+plant>mouse >hawk • Soil+earthworm>shrew>hawk • Soil+earthworm>leopard frog>hawk • Sediment>invertebrate>frog> hawk	Indirect intermittent exposure to organisms exposed to soil; home range much larger than site	Low

7.6 Hazard Assessment

One of the most significant gaps in this analysis is that empirical measurement of contaminants in facilities in North America, or even in countries where regulatory requirements are similar to those in North America, have not been undertaken. As noted in the previous section, the most likely pathway for substances of concern to migrate out of recycling plants into the natural environment is through deposition of the dust generated from shredding components on the outside soils via water or air. The other pathway is likely to be leaching of contaminants from electronic waste stockpiled out of doors. There is also the possibility of hazardous material spills or fire in stockpiles, but assessment of hazard levels from these events would be extremely speculative.

The following is not an exhaustive analysis of all chemicals of concern in the environment of an e-waste recycling facility (as analysed for the human risk assessment), but an analysis of the more limited list of compounds that cause the most concern in terrestrial and aquatic environments. Data is too limited at this point to conduct a risk assessment of all chemicals of concern at an e-waste facility. A more detailed risk assessment should be conducted when hazard levels have been characterised.

Metals are the most prevalent chemicals of concern in electronic waste. Their capacity for entering the environment in the vicinity of electronic waste recycling facilities has been demonstrated. Lead is the substance of most concern, as it has a high potential for leaching from electronic waste.

The levels of hazard contained in this report are taken from the few literature reports and web resources where levels of contaminants of concern have been measured in water, sediments and dust (see Table 3 and 4), mainly using the following sources:

- Concentrations of metals have been measured in water and sediments in the vicinity of Guiyu, China. These measurements represent a “worst-case” analysis, as components are burned and acid-treated outdoors near a river, with runoff from these operations migrating untreated into the river (Basel Action Network 2002). It must be emphasized that this type of operation has never been reported in Canada.
- Concentrations of lead have been measured experimentally in leachate emanating from crushed electronic waste in a standard column during the Toxicity Characteristic

Leaching Procedure (TCLP), a standard Environmental Protection Agency (EPA) method for determining hazardous waste in landfills (Musson *et al*. 2000). The leaching compounds used (acetic acid and sodium hydroxide) are much more reactive than rain water, and are meant to simulate conditions inside a landfill, but nonetheless the procedure provides some estimate of concentrations of chemicals of concern that can result from electronic waste.

- Concentrations of some chemicals of concern have been measured in the dust of an electronics recycling plant in the course of experiments designed to evaluate the efficacy of microbes for extracting metals (Brandl *et al*. 2001).
- Concentrations of PBDE and beryllium have been measured in dust in air in only two facilities: an electronics recycling plant (PBDE) and a copper-beryllium alloy processing plant that was cutting metal with hand and mechanical cutters (beryllium). The particulates in the air were also measured in the electronics recycling plant (where PBDE was measured), so this figure was used to very roughly approximate the concentration of both PBDE and beryllium per weight of dust.
- Measurements of concentrations of beryllium are particularly lacking. Concentrations of beryllium in the vicinity of beryllium processing plants are included in Table 4 for reference, but they would be unlikely to represent the levels in the vicinity of electronics recycling plants and have not been used in this risk assessment.

Table 14. Water and Sediment Sampling results from the Liangjiang River outside Guiyu, China

Metal	**Water**		**Sediment**		
	Highest Level Recorded in water (mg/L)	**Canadian Water Quality Guidelines for the protection of aquatic life (mg/L)**	**Highest level recorded in sediment (mg/kg)**	**Probable Effect Levels (mg/kg)**	**Canadian Sediment Quality Guidelines (mg/kg)**
Antimony	0.079	-	25	-	
Arsenic	<0.01	0.005	8.1	17.0	5.9
Barium	<0.01	-	1620	-	
Beryllium	No data		No data		No guideline
Cadmium	0.033	0.000017	360	3.5	0.6
Chromium	0.02	0.001	70,000	90.0	37.3
Cobalt	<0.01	-	160	-	
Copper	2.6	0.002-0.004	136,000	197	35.7
Iron	2.8	0.3	49,900	-	
Lead	24	0.001-0.007	23,400	91.3	35.0
Manganese	0.2	-	560	-	
Mercury	<0.001	0.0001	0.4	0.486	0.17
Molybdenum	<0.1	0.073	13		
Nickel	0.02	0.025-0.150	580		
PBDE	No data		No data		
Selenium	<0.01	0.001	<0.1		
Silver	<0.1	0.0001	150		
Tin	0.4	-	8,080		
Vanadium	<0.1	-	<0.1		
Zinc	0.6	0.030	11,400	315	123

(note: where a range is given, guidelines depend on water hardness or pH)

Table 15. Concentrations of Substances of Concern recorded from studies on electronic waste processing or similar activities.

Chemical of Concern	Source	Concentration	Reference	Canadian soil quality guidelines (residential/parkland)
Lead	Shredder waste	940 to 9400 mg/kg	Haloclean 2004	140 mg/kg
Lead	Concentration in water during Toxicity Characteristic Leaching Procedure (TCLP) test of cathode ray tubes	<1 to 85.6 mg/L, average 18.5 mg/L	Musson *et al.* 2000	140 mg/kg
Lead	Average concentration in dust obtained from recycling of electronic equipment	200 mg/kg	Brandl *et al.* 2001	140 mg/kg
Cadmium	Concentration in waste fraction including particles less than 2 mm in electronics recycling facility	15 mg/kg	Richter *et al.* 1997	10 mg/kg
Mercury	No data	No data	-	6.6 mg/kg
Beryllium	Levels in dust in a plant where beryllium-copper alloys were being cut with an automatic cutting machine and a hand cutter	0.012 mg/m^3, using particulates 0.4 mg/m^3 from Sjodin *et al.* (1999) provides derived estimate of 30,000 mg/kg dust	INCHEM 1990	No guideline
Beryllium	Beryllium levels in soils around a beryllium processing facility (similar to U.S. background levels)	1.42-2.75 mg/kg	Thorat *et al.* 2001	No guideline
Beryllium	Beryllium concentration in water 1.6 km downstream of a beryllium processing plant	223 mg/L	USACE 2001	No guideline
Beryllium	Beryllium concentration in soils downstream from a beryllium processing plant	1.4-90 mg/kg	USACE 2001	No guideline

Beryllium	Average levels in soils around beryllium processing facility	396 mg/kg	USACE 2001	No guideline
PBDE	Air samples at an electronic recycling plant	.000175 mg/m^3; particulates estimated at 0.4 mg/m^3 in air; = 437.5 mg PBDE/kg particulates	Sjodin *et al.* 2000	No guideline
PBDEs	Air samples in outdoor air outside an electronics recycling plant	Not detectable	Sjodin *et al.* 1999	No guideline
PBDEs	Dust measured inside television sets	320,000 ng/g (32 mg/kg)	Watanabe *et al.* 2003	No guideline
PBDEs	Background levels in Lake Ontario surface water	4 to 13 pg/L	Watanabe *et al.* 2003	No guideline

7.6.1 Lead

Lead has been a focus of the highest concern as a contaminant in electronic waste because it is known that there are high levels of lead in many electronic components. There have been several estimates of lead concentration in dust from electronic waste. However, there are no measurements of lead in soils, water or sediments in the vicinity of electronic recycling plants, except in Guiyu, China which represents an extreme level of environmental contamination. Lead is one of the most abundant metals in dust from recycling of electronic waste.

Lead modifies the function and structure of kidney, bone, the central nervous system, and the hematopoietic system, and produces adverse biochemical, histopathological, neuropsychological, fetotoxic, teratogenic and reproductive effects in wildlife receptors (Eisler 1988). Its effects can be substantially modified by numerous physical, chemical and biological variables. Lead deposited in soils and vegetation can cause enhanced levels of lead in soil invertebrates. Earthworms have been studied extensively and have been found to accumulate several hundred mg/kg of lead (dry weight) in extreme cases. Small mammals living in areas of high lead deposition, such as roadways, also show elevated levels of lead in specific organs. However, studies on ruminants indicate that lead is inefficiently absorbed into the intestinal tract (Harrison and Laxen 1981).

Biological effects of various forms of lead include: reduced offspring weights, kidney damage in young mice (observed with chronic ingestion of 1000 mg/kg), and reduction in egg hatching success of quail (observed with chronic ingestion of 100 mg/kg lead acetate). The 30-day LC-50 value for leopard frog has been observed at 105 mg/L (in water), but some deaths and elevated liver residues have been noted at 25 mg/L (Eisler 1988). No effects were observed in kestrels during chronic ingestion of 50 mg/kg metallic lead in the diet. Toxicological benchmarks for a variety of terrestrial animals for lowest observed effects of lead ingestion are between 9 and 728 ppm. The lowest effect level for mice and shrews, derived from lowest observed effect levels of lead acetate on rats, is 159.77 mg/kg bw/day mg/kg for white-footed mouse and 175.83 mg/kg bw/day for shrews. Studies of metallic lead on American Kestrels were used to establish benchmarks of 11.3 mg/kg bw/day for Red-shouldered Hawk.

Lead has been found to reduce growth of plants at concentrations in soils of between 50 and 1000 mg/kg. Effects on soil microflora are variable (Efroymson *et al*. 1997b). Effects have been observed at between 375-12,000 mg/kg. A benchmark of 500 mg/kg has been established for effects of lead on earthworms, though the confidence in this benchmark is low (Efroymson *et al.* 1997b).

In aquatic systems, lead is toxic to freshwater and marine biota including fish and invertebrates. Lead tends to be deposited in sediments, and sediments are thus an important route whereby lead enters the food chain.

Lead is a significant bioaccumulator. Bioaccumulation of lead in soil invertebrates (earthworms) is widely documented, but is highly variable. For example, earthworms in soil with lead concentrations of 1000 mg/kg have tissue concentrations of between 1 to 1000 mg/kg dry weight (Sample *et al*. 1998). Plants are also highly variable in taking up lead, with uptake varying between less than 1% to, though rarely, bioaccumulation (Bechtel Jacobs 1998). Lead is also bioaccumulative in sediment biota. Though a single uptake factor was used to approximate uptake for the sake of simplicity, the percent uptake of lead is lower at higher concentrations than at lower concentrations (the relationship of uptake to soil concentration is non-linear).

7.6.2 Cadmium

Effects of cadmium on vertebrates include reduced growth, alterations in organ weights, and effects on the immune system (Government of Canada 1994). Increased rates of cancer and genotoxic effects have been observed in rodents. Earthworms and other essential soil organisms are extremely susceptible to cadmium poisoning. They can die at very low concentrations and this has consequences for the soil structure. When cadmium concentrations in soils are high they can influence soil processes of microorganisms and threaten the soil ecosystem. Cadmium tends to be more mobile than other metals in fresh water. Cadmium becomes recycled in marine environments, and is constantly removed from surface waters through settling (Government of Canada 1994). In soils, soil pH is the principal factor determining its mobility. Cadmium is more toxic to aquatic species at low pH (5 to 7), low salinity, and in soft water (<100 mg mg/L of calcium carbonate).

In aquatic systems, fish are affected in water concentrations as low as 0.5 µg per ml, invertebrates (Daphnia) have reduced reproductive output at 0.17 µg per L. Plants are affected by concentrations of 1 microgram per gram in water. Effects of cadmium in sediments have been observed in marine systems at 4 mg/kg. Lethal effects of cadmium on leopard frogs have been seen at concentrations of approximately 1200 µg/L of water. The sensitivity of flora and fauna to cadmium in soil is well established (Government of Canada 1994). In soil, effects of cadmium on both soil invertebrates and plants have been seen at 2 mg/kg dry weight. LD50 values for ingested cadmium are from 5 to 175 mg/kg bw/d in the mouse. Much lower concentrations (e.g. 0.04 mg/kg bw/day) administered to pregnant rats have been noted to cause effects on offspring, ranging from disruption of locomotor activity to biochemical changes. Altered kidney morphology or function are considered to be the most widely accepted endpoints of toxicity in both wild birds and mammals. Aquatic benchmarks are derived from LC50 and chronic effects tests on Daphnia and fish. Terrestrial benchmarks are derived from tests on rats and ducks.

In aquatic ecosystems cadmium can bioaccumulate in mussels, oysters, shrimps, lobsters and fish. The susceptibility to cadmium can vary greatly between aquatic organisms. Salt-water organisms are known to be more resistant to cadmium poisoning than freshwater organisms. Bioaccumulation also occurs in the terrestrial system. Bioaccumulation is non-linear, inversely related to concentration in soils.

7.6.3 Mercury

There is no data on the level of mercury around e-waste processing plants. Toxicological effects, including behavioural anomalies and loss of condition, have been noted in wildlife after chronic ingestion of food with between 0.084 and 9.3 mg/kg of mercury, depending on the form of the compound ingested. The toxicological benchmarks (based on testing of various forms of mercury on mice, rats, mink and mallard duck) for wildlife are: 0.75 mg/kg (mercuric chloride) and 0.053 mg/kg (methyl mercury dicyandiamide) for American robin, 2.1 mg/kg (methyl mercury chloride) for white-footed mouse.

Effects have been seen on invertebrates, including reduction in survival and cocoon production, at concentrations as low as 0.5 mg/kg (Efroymson *et al.* 1997b). The toxicological benchmark concentration for soil microorganisms is 30 mg/kg, and for soil invertebrates (earthworms) is 0.1 mg/kg. There have been very few studies of effects of mercury on plants. The toxicological benchmark for plants is 0.3 mg/kg, but there is low confidence in the benchmark (Efroymson *et al.* 1997a).

In aquatic systems, mercury can cause lethality, reduced fertilization, and impaired development of benthic organisms (CCME 1999). In aquatic systems, mercury is easily transported to sediments where it binds to organic compounds. Sediments are therefore are a significant route of exposure to mercury (CCME 1999).

Mercury is a notable bioaccumulator in some forms, particularly the methylated form (Eisler 1987). However, the extent of uptake can be difficult to predict (CCME 1999). Concentrations of mercury in dust from electronic recycling have not been published, but it is possible that there could be high levels in soils around recycling facilities accepting mercury-bearing lamps, and that ingestion of invertebrates or plants with toxic concentrations of mercury could represent a significant hazard in these facilities.

7.6.4 Beryllium

The hazards of inhaled beryllium have been well-documented in humans, but there are significant gaps in the understanding of the behaviour of beryllium in the environment and in individual organisms. Results of dust testing for beryllium in electronic waste have not been published, but it is known that beryllium is present in waste dust (see Section 4.3.30). Beryllium levels have not been measured in the outdoor environment near recycling plants.

It is known that beryllium is highly toxic in aquatic systems. It is chemically similar to aluminum, and like aluminum is more toxic in acidic water than in alkaline water. For example, beryllium concentrations of 10 µg/l caused increased mortality at pH 4.5 in perch, but only higher concentrations (>50 micrograms /L) were lethal at pH 5.5 (Jagoe *et al*. 1993). Reproduction in Daphnia is affected at concentrations as low as 5.3 µg Be/L (INCHEM 1990). LC50 values for beryllium in fathead minnows range from 0.15 to 0.2 mg/L. Beryllium has also been found to have effects on hatching of fish eggs. Concentrations of beryllium below 0.08 mg/L did not reduce hatching success of carp below the control level, but no eggs hatched at concentrations above 0.2 mg/L beryllium (Hildebrand and Cushman 1978). Daphnia may be adversely affected by very low concentrations of beryllium (5 ug/L) in long-term reproduction tests.

Benchmarks for plants have been derived from experiments on very few species (Efroymson 1997). Beryllium is phytotoxic, though toxicity varies according to soil type, species and pH

(Sajwan 1996). Soil-applied beryllium reduced soybean biomass by 90% at 150 mg/kg of soil. Plant species of a variety of families showed declines in growth when exposed to Be in nutrient solutions as low as 0.5 mg/L (Carlson *et al*. 1991).

The effect of beryllium on terrestrial organisms is very poorly understood. There are no benchmarks for earthworms. Benchmarks for shrews and mice are derived from experiments on rats (Sample *et al.* 1996). Guinea pigs have also been used as a model for human studies. The main responses in these organisms are respiratory disorders (including cancer) and dermatitis, though only guinea pigs have been reported to develop hypersensitivity to beryllium (INCHEM 1990). There are no benchmarks for birds because comparable experiments have not been conducted on birds (INCHEM 1990). There have also been studies showing chromosomal effects, carcinogenicity and enzyme inhibition (INCHEM 1990).

Beryllium does not usually appear to be bioaccumulative (INCHEM 1990). However, beryllium can be accumulated by certain plants growing within the range of dust emissions from sources of beryllium, attaining concentrations of 0.7 to 136.6 ug/g (Sarosiek and Kosiba 1993). Beryllium has been reported to be bioaccumulative in hickory trees (*Carya* spp.: INCHEM 1990).

7.6.4.1 Synergistic Effects of Metal Combinations

Many metals interact with others, producing more-than-additive toxicological effects. For example, lead and mercury interact with copper. However, interactions may be either beneficial or harmful to the organism (Eisler 1998). The patterns of copper accumulation, toxicity, and metabolism frequently differ from those produced by copper alone. Mixtures of copper and zinc salts in marine or freshwater fishes are more-than-additive in toxicity. However, other studies have shown that addition of zinc to mammalian diets protects against copper toxicosis. Zinc has also been shown to protect against lead toxicosis (Eisler 1993). There is little specific information about the additive effects of metals in concentrations such as those on a generic site. Additive effects will therefore not be considered extensively here, but they are likely a highly important factor when considering toxicity of individual metals.

7.6.5 Polybrominated Diphenyl Ethers

The most important halogenated organic chemicals reported from electronic waste are polybrominated diphenyl ethers (PBDEs), used in electronic components as flame retardants. The build-up of PBDEs in blood of humans exposed to PBDEs in a work environment has been recently explored (e.g. Sjodin et al 1999), but there has been very little analysis of the role of this group of contaminants as a contaminant in an ecological context. The estimate of PBDE in soils used in this report was derived very approximately from reported levels of PBDE in air samples, with the concentration calculated from comparison with reported particulate concentrations in air.

Comprehensive reviews of the occurrence of PBDEs in the environment have been conducted by de Wit (2002) and Watanabe *et al*. 2003. De Wit noted that environmental studies conducted primarily in Europe, Japan and North America indicated that these chemicals are ubiquitous in sediment and biota, even in remote northern regions, probably indicating their bioavailability, potential to bioaccumulate in a variety of organisms and their tendency to be transported long distances in air. Serious health effects such as thyroidogenic, estrogenic and dioxin-like activities (Watanabe *et al.* 2003) have been reported following exposure of various ecological receptors to a variety of flame retardants.

There are few studies of the effects of PBDEs on non-human organisms. Certain metabolites of PBDEs may be potent competitors of thyroxine and could disrupt normal thyroid function in wildlife if present (de Wit 2002). Some metabolites appear to be able to cause cancer in small mammals. Some compounds are immunotoxic. Exposure of young mice to flame retardants affected brain function (Viberg 2003). Reduction in spawning success, as well as various metabolic effects, have been noted in fish. There have been no studies of the effects of these contaminants on invertebrates and plants. Benchmarks reported in Table 4 are derived for shrews and deer mice from studies of laboratory mice.

PBDEs are bioaccumulative, but very little research has been done to characterize the amount of accumulation in terrestrial and freshwater organisms. Estimates of accumulation have been measured in marine organisms. Highest estimates were factors of 1,300,000 from water to mussels. Factors ranged between 3.5 and 19 from fish to seal, fish to bird and fish to fish in marine systems (de Wit 2002).

7.7 Risk Assessment

As outlined in the CCME framework for risk assessment, (CCME 1996) the extent and nature of the risk and the level of uncertainty associated with the estimate of risk has been derived by weighing the available information to determine whether the project should advance to a Preliminary Quantitative ERA. This qualitative assessment of risk and uncertainty is based on the information developed from the exposure assessment, receptor characterization and hazard assessment components in previous sections.

Qualitative and quotient methods were used for this risk characterization. The quotient is derived by taking the ratio of the environmental concentration and the benchmark concentration. Quotients less than 1 imply that the risk is slight and little or no action is required. Quotients near 1 represent uncertainty in the risk assessment and usually require additional data. Quotients greater than 1 imply that the risk is greater and that regulatory action may be implicated.

Tables 5 and 6 summarize the hazard, exposure and benchmarks for all VEC species in terrestrial and aquatic environments. The following assumptions were used to calculate risk quotients (as discussed in Section 4):

- Inhalation was not calculated as it is likely to be insignificant in relation to soil and food ingestion. The only tests for contaminants (PBDE) in air outside an electronic recycling plant were negative (Sjodin *et al*. 1999). An electronic waste recycling plant is likely to hold a negligible attraction for wildlife. Mice that might be present inside the plant are likely house mice (*Mus musculus*), a non-native species unlikely to leave the premises. In addition, there are very few benchmarks that could be applied to inhalation of metals or PBDE in wildlife.
- The assumption was made that dust would be deposited in the terrestrial environment as it is likely to be closest to the plant. Sediments and water in the aquatic environment would likely be contaminated by runoff from the plant.
- Ingestion of contaminated water was not considered, as most of the VECs would not likely obtain water from a contaminated source, and in any case there are very few data on levels in water.
- Ingestion of dust was treated as if it was the same as ingestion of soil, as there was no way of estimating how the ingestion rate would differ between dust and soil (and there are no data for soil contamination).
- The benchmarks are derived mainly from U.S. Environmental Protection Agency documents listing Lowest Observed Adverse Effect Levels (LOAEL) for individual species. These provide more specific information on the potential risks to VECs, and the use of LOAEL as benchmarks provides an indication that impacts would take place if risk quotients were greater than 1. CCME guidelines are provided in Tables 3 and 4 but these were not used as benchmarks because they are generic for all life forms. These guidelines are derived by applying uncertainty factors to known LOAEL and NOAEL benchmarks.

Table 16. Risk Assessment for Plants and Animals in the Terrestrial Environment of a Generic Site

LEAD	**Hazard and Exposure (lowest and highest indicate literature reports of levels measured in dust from recycling operations, Guiyu indicates levels measured in sediments at Guiyu, see text)**			**Benchmark (based on Lowest Observed Adverse Effect Level according to Sample et al. 1996, Efroymson et al 1997a,b, unless otherwise noted)**	**Risk Quotient (Potential Exposure /Benchmark Exposure)**
Species	**Soils** (lowest 200 mg/kg, highest 9400 mg/kg, Guiyu 23,400 mg/kg)	**Plants** (uptake factor 0.5)	**Invertebrates** (uptake factor lowest 5, Highest 10, Guiyu 4)		
Poaceae	Root exposure to lowest 200 mg/kg, highest 9400 mg/kg, Guiyu 23,400 mg/kg	None	None	250 mg/kg	Risk quotients from soil 0.8, 38, 94
Brassicaceae	Root exposure to lowest 200 mg/kg in soil, maximum 9400 mg/kg in soil, Guiyu 23,400 mg/kg in soil	None	None	1000 mg/kg	Risk quotients from soil <1, 9.4, 23.4
Earthworm	General exposure to lowest 200 mg/kg, highest 9400 mg/kg, Guiyu 23,400 mg/kg)	none	none	500 mg/kg	Risk quotients <1, 18.8, 46.8
Leopard Frog	Negligible	Negligible	Yes (no data)	No data	No data
Deer Mouse	Soil ingestion lowest 0.74 mg/kg/day highest 34.7 mg/kg bw/day Guiyu 86.3 mg/kg bw/day	Plant ingestion in plant lowest 18.081 mg/kg bw/day Highest 849.8 mg/kg bw/day Guiyu 2115.5 mg/kg bw/day	Negligible	159.77 mg/kg bw/day	Risk quotients from soils <1, <1, <1 Risk quotients from plants <1, 4.8, 13.2

LEAD	**Hazard and Exposure (lowest and highest indicate literature reports of levels measured in dust from recycling operations, Guiyu indicates levels measured in sediments at Guiyu, see text)**			**Benchmark (based on Lowest Observed Adverse Effect Level according to Sample et al. 1996, Efroymson et al 1997a,b, unless otherwise noted)**	**Risk Quotient (Potential Exposure /Benchmark Exposure)**
Short-tailed Shrew	Soil ingestion lowest 2.5 mg/kg bw/day Highest 117.4 mg/kg bw/day Guiyu 292.3 mg/kg bw/day	None	Invertebrate ingestion lowest 83.6 mg/kg bw/day Highest 7859.1 mg/kg bw/day Guiyu 7825.6 mg/kg bw/day	175.83 mg/kg bw/day	Risk quotients from soil <1, <1, 1.7, Risk quotients from invertebrates <1, 44.7, 44.5
Red-shouldered Hawk	Negligible	Negligible	Negligible	116.73 mg/kg bw (for similar Red-tailed Hawk)	Estimate of exposure to contaminants by ingestion of mouse that has consumed soil and plants for one day: lowest 0.76 mg/kg (RQ<1) Highest 35.7 mg/kg bw (RQ<1), Guiyu 88.9 mg/kg bw; RQ <1 Estimate of exposure to contaminants by ingestion of shrew that has consumed soil and invertebrates for 1 day: Lowest 1.27 mg/kg bw (RQ<1) highest 118.8 mg/kg bw (RQ=1), Guiyu 119.5 mg/kg bw (RQ=1)

CADMIUM	**Hazard and Exposure (lowest and highest indicate literature reports of levels measured in dust from recycling operations, Guiyu indicates levels measured in sediments at Guiyu, see text)**			**Benchmark (based on Lowest Observed Adverse Effect Level according to Sample et al. 1996, Efroymson et al 1997a,b, unless otherwise noted)**	**Risk Quotient (Potential Exposure /Benchmark Exposure)**
Species	**Dust/soil** (average 15 mg/kg, Guiyu 360 mg/kg)	**Plants** (uptake factor 3.2)	**Invertebrates** (uptake factor 41)		
Poaceae	Root exposure to average 15 mg/kg, Guiyu 360 mg/kg	No exposure	None	5 mg/kg	From soil: 3 (average) to 72 (Guiyu)
Brassicaceae	Root exposure to average 15 mg/kg, Guiyu 360 mg/kg	none	none	2.5 mg/kg	From soil: 6 (average); 144 (Guiyu)

CADMIUM	**Hazard and Exposure (lowest and highest indicate literature reports of levels measured in dust from recycling operations, Guiyu indicates levels measured in sediments at Guiyu, see text)**			**Benchmark (based on Lowest Observed Adverse Effect Level according to Sample et al. 1996, Efroymson et al 1997a,b, unless otherwise noted)**	**Risk Quotient (Potential Exposure /Benchmark Exposure)**
Earthworm	General exposure to average 15 mg/kg, Guiyu 360 mg/kg	None	none	20 mg/kg	From soil average RQ<1, Guiyu RQ 18
Leopard Frog	No data	No data	Yes (no data)	No data	No data
Deer Mouse	Soil ingestion average 0.06 mg/kg bw/day, Guiyu 1.33 mg/kg bw/day	Plant ingestion average 8.7 mg/kg bw/day; Guiyu 208.3 mg/ kg bw/day	negligible	19.26 mg/kg bw/day	Soil: average <1, Guiyu <1 Plants: average <1, Guiyu 10.8
Short-tailed Shrew	Soil ingestion average 0.06 mg/kg bw/day, Guiyu 4.5 mg/kg bw/day	none	Invertebrate ingestion average 83.6 mg/kg bw/day Guiyu 752.5 mg/kg bw/day	21.2 mg/kg bw/day	Soil: all RQ <1 Invertebrates: average RQ 3.9, Guiyu 35.5
Red-shouldered Hawk	negligible	negligible	negligible	20.0 mg/kg bw/day	Estimate of exposure to contaminants by ingestion of mouse that has consumed contaminated soil and plants for one day: lowest 0.33 mg/kg (RQ<1) Guiyu 8.45 mg/kg bw; (RQ <1 Estimate of exposure to contaminants by ingestion of shrew that has consumed soil and invertebrates for 1 day: Lowest 2.14 mg/kg bw (RQ<1) Guiyu 18.8 mg/kg bw (RQ~1)

MERCURY	**Hazard and Exposure (lowest and highest indicate literature reports of levels measured in dust from recycling operations, Guiyu indicates levels measured in sediments at Guiyu, see text)**			**Benchmark (based on Lowest Observed Adverse Effect Level according to Sample et al. 1996, Efroymson et al 1997a,b, unless otherwise noted)**	**Risk Quotient (Potential Exposure /Benchmark Exposure)**
Species	**Sediment** (Guiyu 0.4 mg/kg)	**Plants** (uptake factor = 5)	**Invertebrates** (uptake factor = 10)		
Poaceae	Root exposure to soil 0.4 mg/kg	None	None	0.3 mg/kg	RQ 1.3
Brassicaceae	Root exposure to soil 0.4 mg/kg	None	None	0.3 mg/kg	RQ 1.3
Earthworm	General exposure to soil 0.4 mg/kg	None	None	0.1	RQ 4
Leopard Frog	None	None	Yes (no data)	No data	No data
Deer Mouse	Soil ingestion 0.001 mg/kg bw/day mg/kg	Plant ingestion 0.36 mg/kg bw/day	none	0.32 mg/kg bw/day	Soil: RQ < 1 Plants: RQ 1
Short-tailed Shrew	Soil ingestion 0.005 mg/kg bw/day	None	Invertebrate ingestion 0.334 mg/kg bw/day	0.35 mg/kg bw/day	Soil: RQ <1 Invertebrates: RQ 1
Red-shouldered Hawk	Negligible	Negligible	Negligible	0.064 mg/kg bw/day (similar species red-tailed hawk)	Estimate of exposure to contaminants by ingestion of mouse that has consumed contaminated soil and plants for one day: Guiyu 0.01 mg/kg bw; (RQ <1) Estimate of exposure to contaminants by ingestion of shrew that has consumed soil and invertebrates for 1 day: Guiyu 0.005 mg/kg bw (RQ<1).

BERYLLIUM (note: calculation of concentration very approximate)	**Hazard and Exposure (lowest and highest indicate literature reports of levels measured in dust from recycling operations, Guiyu indicates levels measured in sediments at Guiyu, see text)**			**Benchmark (based on Lowest Observed Adverse Effect Level according to Sample et al. 1996, Efroymson et al 1997a,b, unless otherwise noted)**	**Risk Quotient (Potential Exposure /Benchmark Exposure)**
Species	**Soil** (30,000 mg/kg from aerial samples of dust from alloy processing plant)	**Plants** (no data on uptake factors)	**Invertebrates** (no data on uptake factors)		
Poaceae	Root exposure to 30,000 mg/kg	None	None	10 mg/kg	No data
Brassicaceae	Root exposure to 30,000 mg/kg	None	none	10 mg/kg	No data
Earthworm	30,000 mg/kg	No data	No data	No data	
Leopard Frog	negligible	negligible	Yes (no data)	No data	No data
Deer mouse	Soil ingestion 110.7 mg/kg bw/day	Yes (no data)	negligible	1.45 mg/kg bw/day (NOAEL)	Soil: RQ 76
Short-tailed Shrew	Soil ingestion of 374.8 mg/kg bw/day	negligible	Yes (no data)	1.45 mg/kg bw/day (NOAEL)	Soil: RQ 258
Red-shouldered Hawk	Negligible	negligible	negligible	0.65 mg/kg/day calculated from mouse NOAEL	Estimate of exposure to contaminants by ingestion of mouse that has consumed contaminated soil for one day 110.7 mg/kg RQ 173 Estimate of exposure to contaminants by ingestion of shrew that has consumed contaminated soil for one day 374.8 mg/kg RQ 576.6

PBDE (note calculation of concentration is very approximate)	**Hazard and Exposure (lowest and highest indicate literature reports of levels measured in dust from recycling operations, Guiyu indicates levels measured in sediments at Guiyu, see text)**			**Benchmark (based on Lowest Observed Adverse Effect Level according to Sample et al. 1996, Efroymson et al 1997a,b, unless otherwise noted)**	**Risk Quotient (Potential Exposure /Benchmark Exposure)**
Species	Dust (highest estimate PBDE/particulate weight estimated from air samples at a recycling plant 437.5 mg/kg; lowest estimate dust inside television sets 32 mg/kg)	Plants (no data on uptake factors)	Invertebrates (no data on uptake factors in terrestrial system)		
Poaceae	Root exposure to highest 437.5 mg/kg lowest 32 mg/kg	none	none	No data	No data
Brassicaceae	Root exposure to highest 437.5 mg/kg lowest 32 mg/kg	none	none	No data	No data
Leopard Frog	negligible	negligible	Yes (no data)	No data	No data
Deer mouse	Soil ingestion highest 1.6 mg/kg bw/day lowest 0.1 mg/kg bw/day	Yes (No data)	Negligible	0.8 mg/kg bw/day (calculated from laboratory mouse LOAEL 0.8 mg/kg bw/day according to de Wit 2002)	Soil RQ lowest <1, highest 2 No data for plant RQ
Short-tailed Shrew	Soil ingestion highest 5.5 mg/kg bw/day lowest 0.4 mg/kg bw/day	none	No data	0.9 mg/kg bw /day (calculated from laboratory mouse LOAEL 0.8 mg/kg bw/day according to de Wit 2002)	Soil RQ lowest <1, highest 6.1 No data for invertebrate RQ
Red-shouldered Hawk	Negligible	negligible	Negligible	0.4 mg/kg (calculated from laboratory mouse LOAEL 0.8 mg/kg bw/day according to de Wit 2002; estimate very approximate because of uncertainty of extrapolating from mammal to bird)	RQ lowest <1, highest shrew 14, mouse 4

Table 17. Risk assessment for plants and animals in the aquatic environment in the vicinity of the generic site.

LEAD	**Hazard and Exposure**			**Benchmark (based on sediment screening value or Lowest Chronic Values, sources Jones et al. 1997, Suter and Tsao 1996,Efroymson et al. 1997 unless otherwise noted)**	**Risk Quotient (Expected Environmental Concentration/Benchmark Concentration)**
Species	Sediment (Guiyu maximum 23,400 mg/kg)	Water (average leachate 18.5 mg/L; Guiyu 24 mg/L)	Invertebrates (uptake factor from sediments 0.96)		
Poaceae	Root exposure to 23,400 mg/kg	Root exposure to 18.5 mg/L 24 mg/L	none	Sediment: 250 mg/kg Water: 0.75 mg/L	From soil: RQ 93.6 Water: RQ leachate 25, Guiyu 32
Benthic invertebrates	General exposure to 23,400 mg/kg	General exposure to 18.5 mg/L 24 mg/L	negligible	Sediment: General benchmark for sediment-associated biota: 91.3 mg/kg Water: 12.26 µg/L	Sediment: RQ 256 Water: RQ leachate 1509; Guiyu 1958 Note: the levels in sediments also exceed severe effects level benchmark of 250 mg/kg (Jones et al. 1997)
Leopard Frog	General exposure to 23,400 mg/kg during hibernation	General exposure to 18.5 mg/L to 24 mg/L in water	Invertebrate ingestion 22,464 mg/kg	General benchmark for sediment-associated biota 30.2 mg/kg Water (specific for frog species): 0.47 mg/L (Devillers and Exbrayat 1992)	Sediment: RQ 775 Water: RQ leachate 39; Guiyu 51
Fathead Minnow	Sediment ingestion 23,400 mg/kg	General exposure to leachate 18.5 mg/L Guiyu 24 mg/L	Invertebrate ingestion 22,464 mg/kg	General benchmark for sediment-associated biota 30.2 mg/kg Water: 18.88 µg/L	Sediment: RQ 775 Water: RQ leachate 980; Guiyu 1271 Invertebrate 744 (using sediment benchmark)

CADMIUM	**Hazard and Exposure**			**Benchmark (based on sediment screening value or Lowest Chronic Values, sources Jones et al. 1997, Suter and Tsao 1996,Efroymson et al. 1997 unless otherwise noted)**	**Risk Quotient (Expected Environmental Concentration/Benchmark Concentration)**
Species	Sediment (Guiyu maximum 360 mg/kg)	Water (Guiyu maximum 0.033 mg/L)	Invertebrates (uptake factor from sediments 9.2)	Benchmark (based on sediment screening value or Lowest Chronic Values, sources Jones et al. 1997, Suter and Tsao 1996,Efroymson et al. 1997 unless otherwise noted)	

Poaceae	Root exposure 360 mg/kg	Root exposure to 0.33 mg/L	none	Sediment 5 mg/kg Water 0.1 mg/L	Sediment: RQ 72 Water: RQ 3.3
Invertebrates	General exposure to 360 mg/kg	0.33 mg/L	negligible	General Sediment benchmark for aquatic life: 0.6 mg/kg Water: 0.15 µg/L	Sediment: RQ 600 Water: RQ 2200 Note: levels in sediments exceed the severe effects level of 10 mg/kg (Jones et al. 1997)
Leopard Frog	Skin exposure to 360 mg/kg in sediments during hibernation	General exposure during aquatic stage 0.33 mg/L in water	Potential ingestion exposure to 3312 mg/kg in invertebrates	General sediment benchmark for aquatic life: 0.6 mg/kg Water: 15.81 mg/L for tadpole stage (Lefcort et al 1998) Ingestion: no data	Sediment: RQ 600 Water: RQ <1 Invertebrates: no benchmark Note: levels in sediments exceed the severe effects level of 10 mg/kg (Jones et al. 1997)
Fathead Minnow	Ingestion exposure to 360 mg/kg in sediments	General exposure to 0.33 mg/L in water	Potential ingestion exposure to 3312 mg/kg in invertebrates	General Sediment benchmark for aquatic life: 1 mg/kg Water: 1.7 µg/L Invertebrates: no data	Sediment: RQ 360 Water: 194 Invertebrates: no data Note: levels in sediments exceed the severe effects level of 10 mg/kg (Jones et al. 1997)

MERCURY	**Hazard and Exposure**			**Benchmark (based on sediment screening value or Lowest Chronic Values, sources Jones et al. 1997, Suter and Tsao 1996, Efroymson et al. 1997 unless otherwise noted)**	**Risk Quotient (Expected Environmental Concentration/Benchmark Concentration)**
Species	Sediment (0.4 mg/kg)	Water (<.001)	Invertebrates (Uptake factor 2.9)	Benchmark (based on sediment screening value or Lowest Chronic Values, sources Jones et al. 1997, Suter and Tsao 1996,Efroymson et al. 1997 unless otherwise noted)	
Poaceae	Root exposure to 0.4 mg/kg	No data	No exposure	Sediment: 0.3 mg/kg Water: 5 mg/L	Sediment: RQ 1.3 Water: RQ <1
Sediment-associated invertebrates	Ingestion/cutaneous exposure to 0.4 mg/kg	General exposure to <0.001 mg/kg	negligible	General sediment benchmark for aquatic life: 0.486 mg/kg Water: 0.96 µg/L	Sediment: RQ 2 Water: RQ <1

Leopard Frog	Cutaneous exposure to 0.4 mg/kg in sediments	General exposure to <0.001 mg/kg	Potential ingestion exposure to 1.16 mg/kg	General sediment benchmark for aquatic life: 0.486 mg/kg Water: 0.0073 mg/L (Devillers and Exbrayat 1992) Ingestion: no data	Sediment: RQ 2 Water: RQ <1
Fathead Minnow	Ingestion exposure to 0.4 mg/kg in sediments	General exposure to <0.001 mg/kg	Potential ingestion exposure to 1.16 mg/kg	General sediment benchmark for aquatic life: 0.486 mg/kg Water: <0.23μg/L	Sediment: RQ 0.8 Water: RQ <1

There was not enough data for Beryllium and PBDE to perform risk assessment in the aquatic environment.

Note: data insufficient for developing risk assessment of Beryllium and PBDE in water or sediments.

7.8 Conclusions, Level of Uncertainty, and Recommendations

This assessment shows there may be significant risks to all trophic levels from processing electronic waste if contaminated dust is able to migrate outside the plant in air or water and become deposited in soils, sediments, surface water and ground water. Water could possibly also become contaminated if recycled components were stored outdoors so rainwater could leach through them.

The risk of toxicological effects from heavy metals is very high for all organisms exposed directly to soil, including plants, amphibians, and burrowing mammals that ingest earthworms (since earthworms tend to contain soil in their gut). Risk quotients for organisms exposed to soils are greatest for lead, with cadmium and mercury following in descending order. Based on the findings of the Occupational Health and Safety section of this report, it appears that mercury may not be above guideline levels for human exposure. However, mercury is of concern in the aquatic environment because of its tendency to bioaccumulate. Data are very uncertain for beryllium and PBDE, but if these compounds are found in dust at the concentrations estimated, they could also pose significant risk to the environment at all trophic levels.

Risk of toxicological effects from heavy metals, particularly lead, is also likely to be high from exposure to plants or invertebrates that live in soils on the site, as uptake rates for heavy metals in plants and invertebrates can be very high. However, there is a degree of uncertainty associated with this statement, as uptake is extremely variable and predicted potential maximum concentrations may not represent real concentrations. There is also significant potential for exposure of higher trophic level organisms such as Red-shouldered Hawk to rodents and other prey species with accumulated metals, as most of the metals found on site are notable bioaccumulators. However, since levels of metals in lower trophic levels are not known, bioaccumulation of metals cannot be accurately modelled.

There are several factors contributing to a very high degree of uncertainty associated with assessment of risk at a generic site. The most important factors are

- there are almost no empirical measurements of concentrations of contaminants of concern in the vicinity of electronic waste sites in North America;
- the levels of contamination in dust are likely to be highly variable depending on the type of waste accepted by the recycling facility;
- levels of contaminants in soil, sediments and water are likely to be highly variable because of varying environmental practices;
- contaminants in dust may have variable bioavailability, depending on the other components in dust and leachate and the environment in which they are deposited;
- it is not known whether contaminants can move from dust to soil, sediments or water, or what form they may be found in those media;
- accurate benchmarks for beryllium and PBDE have not been derived.

Because of this uncertainty, it is recommended that a further tier of risk assessment be undertaken, which should include:

- measurement and characterization of metals (particularly lead, beryllium, cadmium and mercury) and PBDEs in soils and aquatic sediments in the vicinity of electronic waste recycling plants. The sampling should be large enough to encompass an array of plants with a variety of environmental practices, and should be especially focused in areas most likely to be contaminated by dust in air or drainage water: in front of loading doors, near ventilation systems, near drain outfalls, and at points of groundwater discharge;
- bioassays should be conducted on uptake of contaminants in dust by earthworms and benthic organisms, to characterize the bioavailability of contaminants of concern in waste dust;
- when concentrations of chemicals of concern have been better characterised, a further tier of ecological risk assessment is warranted to better understand the risk to the ecosystem;
- environment Canada should encourage the development of standards and guidelines for beryllium and PBDE;
- environmental and safety standards and Best Management Practices should be established for all facilities, limiting the deposition of water and dust in the environment.

7.9 References for Ecological Risk Assessment

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8.0 Glossary of Terms

Absorption	The process by which a chemical enters the circulatory system following ingestion, inhalation or dermal exposure.
COC	Chemical of (potential) Concern. This refers to any chemical (or asbestos fibres) for that may be found at a generic e-waste processing facility and are screened into the risk assessment.
Endpoint	Refers to an effect on a human or ecological receptor that can be measured and described in some quantitative fashion.
Ecological receptor	Means a non-human organism identified as potentially experiencing adverse impacts from exposure to a COC, either directly through contact or indirectly through food chain transfer.
Exposure	Means the contact between a contaminant (CoC) and an individual or population. The exposure may occur through pathways such as ingestion, dermal absorption or inhalation.
Exposure pathway	Means the route by which a receptor comes into contact with a CoC.
Hazard	Means the adverse (e.g., non-cancer) impact on health which results from the presence of or exposure to a substance.
LOAEL	The Lowest Observed Adverse Effect Level. This term identifies the lowest dose at which adverse effects are seen in the most sensitive individuals of a population.
NOAEL	The No Observed Adverse Effect Level. This term identifies the highest dose at which no adverse effects are seen in the most sensitive individuals of the population
Non-threshold	Means that if a chemical is present at any concentration, the potential for adverse effects is present (i.e., carcinogens)
Receptor	Means the person (adult female commercial worker, supervisor, maintenance worker, trespasser, etc.) or organism, including plants, terrestrial species subjected to chemical exposure).
Reference	

Dose (RfD)	An estimate of a daily exposure (in mg/kg bw/day) to the general population, including sensitive sub-groups, that is likely to be without an appreciable risk of deleterious effects during a lifetime of exposure.
Risk Assessment	Is the scientific examination of the nature and magnitude of risk to define the effects on both human and other receptors following exposure to contaminant(s)
Risk Management	Is the implementation of a strategy or measures to control or reduce the level of risk estimated by the risk assessment.
VEC	Valued Ecosystem Component. These are identified as the ecological receptors of concern, and are considered fundamental in the health of the ecosystem to which they belong.

APPENDIX A
Calculation of Generic Exposure Limits for CoCs in an E-waste Facility

Generic Exposure Limit Calculations

Receptor Parameters	Unit	Value
Exposure Frequency	d/yr	79.4
Exposure Duration	yr	27
Body Weight	kg	70.7
Averaging Time - non-cancer	yr	27
Averaging Time - cancer	yr	27
Rate of Soil Ingestion	g/d	0.02
Rate of Inhalation	m3/d	15.8
PM10 Concentration of CoC	ug/m3	27.6
Skin Surface Area	cm2	3390
Rate of Dust/Soil Adherence	g-soil/cm2/event	0.001

target HI = 1.0
target cancer risk = 1.0E-06

Non-Cancer

Generic Screening Level = Csoil / HI

where: Generic Screening Level is the screening level calculated for the CoC (ppm),
Csoil is the default exposure concentration for the CoC used in the exposure calculations (1 ug/mg), and
HI refers to the calculated HI for the CoC

Cancer

Generic Screening Level = (Csoil x Target cancer risk) / IILCR

where: Generic Screening Level is the screening level calculated for the CoC (ppm),
Csoil is the default exposure concentration for the CoC used in the exposure calculations (1 ug/mg),
Target cancer risk is the conservative regulatory guideline for acceptable cancer risk of 1x10^{-6}, and
IILCR is the Incremental Increase in Life-Time Cancer Risk (unitless), which has been calculated.

$$Exposure_{ingestion} = \frac{C_{soil} \times R_{ing} \times EF \times ED}{BW \times AT \times 365}$$

$$Exposure_{dermal} = RA_{der} \times \frac{C_{soil} \times A_{der} \times (SA \times R_{adher}) \times EF \times ED}{BW \times AT \times 365}$$

$$Exposure_{inhalation} = \frac{C_{soil} \times R_{inh} \times PM_{10} \times EF \times ED}{BW \times AT \times 365 \times 1E06}$$

Non-cancer

$$SSTL = \frac{\text{Target HI}}{C_{soil} \text{ x Calc HI}}$$

Cancer

$$SSTL = \frac{\text{Target cancer risk}}{\text{CSF}}$$

Calculation of Generic Exposure Limits for CoCs in an E-waste Facility

		Asbestos	Azo Colorants	Cadmium	Chromium	Lead	Mercury	Ozone Depleting	HCFC	PBBs	PCBs	Uranium
Incidental Ingestion												
Csoil	u g/g	1	1	1	1	1	1	1	1	1	1	1
Ring	g/d	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
EF	d/y	79	79	79	79	79	79	79	79	79	79	79
ED	y	27	27	27	27	27	27	27	27	27	27	27
BW	kg	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7
AT	y	27	27	27	27	27	27	27	27	27	27	27
days/year	d/y	365	365	365	365	365	365	365	365	365	365	365
EXP ing	**u g/kg.d**	**6.15E-05**	**6.15E-05**	**6.15E-05**	**6.15E-05**	**6.15E-05**	**6.15E-05**	**6.15E-05**	**6.15E-05**	**6.15E-05**	**6.15E-05**	**6.15E-05**
Inhalation - Outdoor Dust												
Csoil	u g/g	1	1	1	1	1	1	1	1	1	1	1
Rinh	m^3/d	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8
PM10	ug/m^3	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6
EF	d/y	79	79	79	79	79	79	79	79	79	79	79
ED	y	27	27	27	27	27	27	27	27	27	27	27
BW	kg	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7
AT	y	27	27	27	27	27	27	27	27	27	27	27
days/year	d/y	365	365	365	365	365	365	365	365	365	365	365
UC	unit conv.	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000
EXP inh dust	**u g/kg.d**	**1.34E-06**	**1.34E-06**	**1.34E-06**	**1.34E-06**	**1.34E-06**	**1.34E-06**	**1.34E-06**	**1.34E-06**	**1.34E-06**	**1.34E-06**	**1.34E-06**
Dermal Contact												
Csoil	u g/g	1	1	1	1	1	1	1	1	1	1	1
SA	cm^2/d	3390	3390	3390	3390	3390	3390	3390	3390	3390	3390	3390
Radher	g/cm^2	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
EF	d/y	79	79	79	79	79	79	79	79	79	79	79
ED	y	27	27	27	27	27	27	27	27	27	27	27
BW	kg	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7
AT	y	27	27	27	27	27	27	27	27	27	27	27
days/year	d/y	365	365	365	365	365	365	365	365	365	365	365
EXP der	**u g/kg.d**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**
Total Exposure	**u g/kg.d**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**
Endpoint		Cancer	Cancer	Cancer	Cancer	Non-cancer	Non-cancer	Non-cancer	Non-Cancer	Non-cancer	Cancer	Non-cancer
Exposure Route of Concern		Inhalation	Inhalation	Inhalation	Inhalation	oral	oral	oral	oral	oral	oral	oral
Tox Value (ug/kg-day)		4.00E-06	2.30E-02	6.30E+00	4.20E+02	3.57	0.1	300	200	10	2.00E-03	3
Generic Screening Level		**2.50E-01**	**4.35E-05**	**1.59E-07**	**2.38E-09**	**340**	**10**	**28589**	**19060**	**953**	**5.00E-04**	**286**

		Tin	Antimony	Arsenic	Beryllium	Brom Flame Retard	Copper	Nickel	Phthalates	Selenium	Silver	Thallium
Incidental Ingestion												
Csoil	u g/g	1	1	1	1	1	1	1	1	1	1	1
Ring	g/d	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
EF	d/y	79	79	79	79	79	79	79	79	79	79	79
ED	y	27	27	27	27	27	27	27	27	27	27	27
BW	kg	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7
AT	y	27	27	27	27	27	27	27	27	27	27	27
days/year	d/y	365	365	365	365	365	365	365	365	365	365	365
EXP ing	**u g/kg.d**	**6.15E-05**	**6.15E-05**	**6.15E-05**	**6.15E-05**	**6.15E-05**	**6.15E-05**	**6.15E-05**	**6.15E-05**	**6.15E-05**	**6.15E-05**	**6.15E-05**
Inhalation - Outdoor Dust												
Csoil	u g/g	1	1	1	1	1	1	1	1	1	1	1
Rinh	m^3/d	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8	15.8
PM10	ug/m^3	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.6
EF	d/y	79	79	79	79	79	79	79	79	79	79	79
ED	y	27	27	27	27	27	27	27	27	27	27	27
BW	kg	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7
AT	y	27	27	27	27	27	27	27	27	27	27	27
days/year	d/y	365	365	365	365	365	365	365	365	365	365	365
UC	unit conv.	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000	1000000
EXP inh dust	**u g/kg.d**	**1.34E-06**	**1.34E-06**	**1.34E-06**	**1.34E-06**	**1.34E-06**	**1.34E-06**	**1.34E-06**	**1.34E-06**	**1.34E-06**	**1.34E-06**	**1.34E-06**
Dermal Contact												
Csoil	u g/g	1	1	1	1	1	1	1	1	1	1	1
SA	cm^2/d	3390	3390	3390	3390	3390	3390	3390	3390	3390	3390	3390
Radher	g/cm^2	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
EF	d/y	79	79	79	79	79	79	79	79	79	79	79
ED	y	27	27	27	27	27	27	27	27	27	27	27
BW	kg	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7	70.7
AT	y	27	27	27	27	27	27	27	27	27	27	27
days/year	d/y	365	365	365	365	365	365	365	365	365	365	365
EXP der	**u g/kg.d**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**
Total Exposure	**u g/kg.d**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**
Endpoint		Non-cancer	Non-cancer	Cancer	Cancer	Non-cancer	Non-cancer	Cancer	Cancer	Non-cancer	Non-cancer	Non-cancer
Exposure Route of Concern		oral	oral	oral	inhalation	inhalation	oral	Inhalation	oral	oral	oral	oral
Tox Value (ug/kg-day)		0.3	0.4	1.5	8.4	1.05E-02	5	7	1.40E-02	5	5	0.08
Generic Screening Level		**29**	**38**	**6.67E-07**	**1.19E-07**	**1**	**476**	**1.43E-07**	**7.14E-05**	**476**	**476**	**8**

Note: All exposures were compared to one exposure limit for non-cancer, either RfD or RfC
For cancer endpoint the lower of the IUR and the oral CSF was selected to form the basis of the generic screening level

APPENDIX B
Adult Lead Model Simulations

Appendix 3. Simulation Run # 1. Adult Lead Methodology (ALM)

Exposure Variable	PbB Equation[1] 1*	PbB Equation[1] 2**	Description of Exposure Variable	Units	Values for Non-Residential Exposure Scenario Using Equation 1: GSDi = Hom	Using Equation 1: GSDi = Het	Using Equation 2: GSDi = Hom	Using Equation 2: GSDi = Het
PbS[2]	X	X	Lead concentration in dust	ug/g or ppm	1000	1000	1000	1000
$R_{fetal/maternal}$	X	X	Fetal/maternal PbB ratio	--	0.9	0.9	0.9	0.9
BKSF	X	X	Biokinetic Slope Factor	ug/dL per ug/day	0.4	0.4	0.4	0.4
GSD_i	X	X	Geometric standard deviation PbB	--	2.1	2.3	2.1	2.3
PbB_0	X	X	Baseline PbB	ug/dL	1.5	1.7	1.5	1.7
IR_S	X		Soil/dust ingestion rate (including soil-derived indoor dust)	g/day	0.050	0.050	--	--
IR_{S+D}		X	Total ingestion rate of outdoor soil and indoor dust	g/day	--	--	0.050	0.050
W_S		X	Weighting factor; fraction of IR_{S+D} ingested as outdoor soil	--	--	--	1.0	1.0
K_{SD}		X	Mass fraction of soil in dust	--	--	--	0.7	0.7
$AF_{S,\,D}$	X	X	Absorption fraction (same for soil and dust)	--	0.12	0.12	0.12	0.12
$EF_{S,\,D}$	X	X	Exposure frequency (same for soil and dust)	days/yr	219	219	219	219
$AT_{S,\,D}$	X	X	Averaging time (same for soil and dust)	days/yr	365	365	365	365
PbB_{adult}			**PbB of adult worker, geometric mean**	**ug/dL**	**2.9**	**3.1**	**2.9**	**3.1**
$PbB_{fetal,\,0.95}$			**95th percentile PbB among fetuses of adult workers**	**ug/dL**	**9.0**	**11.1**	**9.0**	**11.1**
PbB_t			**Target PbB level of concern (e.g., 10 ug/dL)**	**ug/dL**	**10.0**	**10.0**	**10.0**	**10.0**
$P(PbB_{fetal} > PbB_t)$			**Probability that fetal PbB > PbB_t, assuming lognormal distribution**	**%**	**3.7%**	**6.5%**	**3.7%**	**6.5%**

[1] Equation 1 does not apportion exposure between soil and dust ingestion (excludes W_S, K_{SD}).

When $IR_S = IR_{S+D}$ and $W_S = 1.0$, the equations yield the same $PbB_{fetal,0.95}$.

[2] Assumed to be represented by 5 x average concentration as outlined in Brandl (2001).

[3] All other exposure parameters maintained as US EPA default values (EPA, 1996).

***Equation 1, based on Eq. 1, 2 in USEPA (1996).**

PbB_{adult} =	$(PbS*BKSF*IR_{S+D}*AF_{S,D}*EF_S/AT_{S.D}) + PbB_0$
$PbB_{fetal,\ 0.95}$ =	$PbB_{adult} * (GSD_i^{1.645} * R)$

****Equation 2, alternate approach based on Eq. 1, 2, and A-19 in USEPA (1996).**

PbB_{adult} =	$PbS*BKSF*([(IR_{S+D})*AF_S*EF_S*W_S]+[K_{SD}*(IR_{S+D})*(1-W_S)*AF_D*EF_D])/365+PbB_0$
$PbB_{fetal,\ 0.95}$ =	$PbB_{adult} * (GSD_i^{1.645} * R)$

APPENDIX C
Qualitative Risk Analysis for an Electronic Waste Processing Facility

An assessment of the Quantitative Risk Analysis based on a modified version of the Canadian Standards Association *CAN/CSA-Z731-03* methodology (CSA, 2003) is provided in the following sections.

In general, the components of the qualitative risk analysis (QRA) for an e-waste processing facility are anticipated to include the following:

1. Hazard/ opportunity identification;
2. Consequence analysis;
3. Likelihood analysis;
4. Risk Estimation and assigning of a Planning Priority; and,
5. Risk Reduction (i.e., determining mitigative measures that can be taken to reduce the risk/ hazard).

The focus of the assessment is placed on assessing e-waste operations and processes, building infrastructure (e.g., improper design contributing to potential problems, etc.), as well as socioeconomic considerations (e.g., lack of employee morale due to low pay, etc.) which, in whole or in part may contribute to the release of potential deleterious compounds (e.g., lead and other metals, etc.) into the environment or result in a potential exposure or a hazardous situation posing a threat to the integrity of human or ecological health. For each hazard/ opportunity (potential problem), a risk estimation is conducted to assess the degree of risk (i.e., the impact that the hazard/ opportunity would have on human or ecological receptors, combined with the likelihood of the event occurring). The integration of the two components is conducted using risk estimation grid methodologies or other suitable procedures (see Figure 4). The output (i.e., a priority ranking) allows the organization (i.e., risk manager, regulatory agency) to assign a planning priority to each potential hazardous event or opportunity.

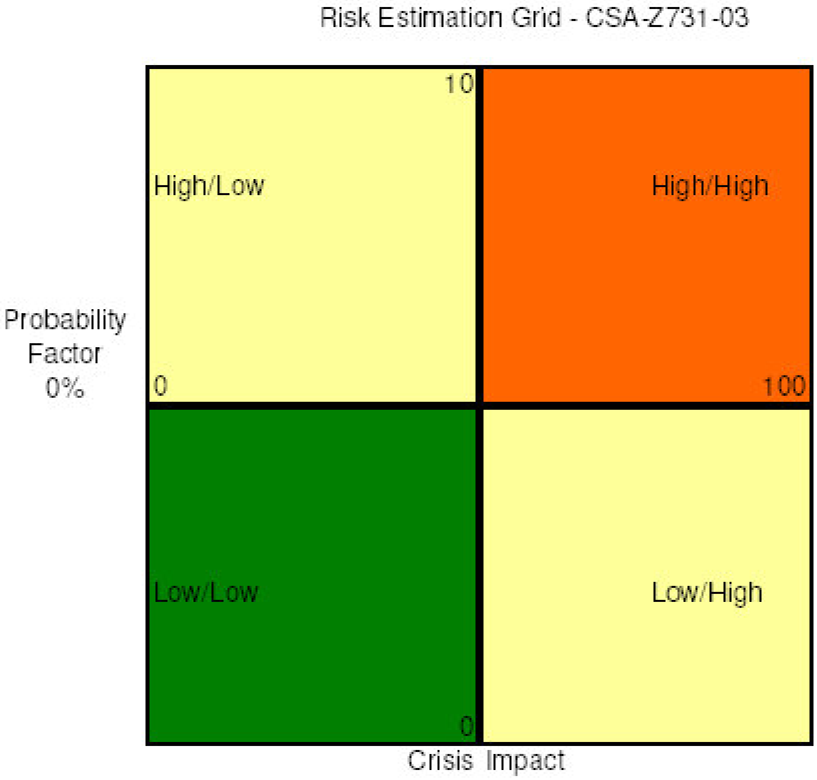

Figure 4. CSA Risk Estimation Grid

- Hazard Assessment

Consideration is given to identifying potential e-waste processes, e-waste infrastructure and socioeconomic considerations which could contribute to hazards associated with an e-waste processing facility. A list of potential e-waste processing tasks and operations whereby hazard points can occur during the process include the following:

  - E-waste receiving
  - Classification of Equipment
  - Manual Disassembly
  - Testing
  - Classification of Parts
  - Shredding of Components
  - Electrowinning Process
  - Storage
  - Disposal
  - Transport

- Consequence Analysis

The impact values to classify the human health consequence associated with each hazard/ opportunity are determined by assigning a category, after considering the intensity and severity of the event (Table 18).

Table 18. Classification of Environmental Consequences Following a Hazard Event

IMPACT VALUE (CONSEQUENCE)		
Category	**Numerical Estimate**	**Environmental Event**
Very Low	0-2	Minor incident, little or no human health impact; Short-term impact: minimal, Long-term impact: none.
Low	2-4	Minor event that may require engineering review and is easily and predictably mitigated.
Moderate	4-6	Moderate event that may need some immediate attention and engineering review. Minor human health impact, reversible.
High	6-8	Significant human health event that can be addressed, but with significant effort. Moderate injury or potential for significant injury.
Extreme	8-10	Major uncontrolled event or failure with uncertain and perhaps prohibitively costly remediation. Serious human health effects.

In addition to considering the intensity and severity of the environmental event, and its associated environmental impact, the (1) level of media or governmental scrutiny, (2) impacts on interference with normal business operations, (3) damage to public image, and (4) economic impacts, are considered under the CSA framework.

- Media or Governmental Scrutiny

This item includes the degree to which the media or government agencies would scrutinize the emergency or event. This issue considers the impact to health, safety and the environment. Values between 0 (no scrutiny) and 10 (significant scrutiny) can be used in the assessment.

- Interference with Normal Business Activities

This item consists of the degree to which the event could interfere with normal business operations, and includes consideration of the company's ability to process e-waste on time, etc. Values between 0 (no interference) and 10 (significant interference) can be used in the assessment.

- Damage to Public Image

This item includes the extent to which the company's public image and reputation could be damaged by the event or emergency. Values between 0 (no damage) and 10 (severe damage) can be used in the assessment.

- Damage to Economic Interests

This item includes the extent to which the company's economic interest could be damaged by the event or emergency. Values between 0 (no cost) and 10 (crippling cost) can be assigned to each event or emergency.

- Likelihood Analysis

The likelihood (i.e., probability) of an event leading to the particular outcome of concern (i.e., exposure to an inherently dangerous substance, etc) is estimated using a scale of 0% (an absolute impossibility) to 100% (a certainty that the event will occur within a certain duration) that the event would occur. The category and definition of the likelihood of an event is outlined in Table 19.

Table 19. Likelihood (Probability) Factor

LIKELIHOOD (PROBABILITY) FACTOR	
Category	**Definition**
N – Negligible (<1% probability)	Absolute impossibility - Not likely that it could happen
VL - Very Low	Unlikely to happen
L – Low	It could happen
M – Moderate	Has, or probably will happen
S - Significant >99% probability)	Happens regularly (certainty that it will happen)

- Uncertainty Analysis

The confidence of an event leading to a particular outcome of concern (i.e., release of a deleterious substance) is then qualitatively estimated for each event. The category and definition of the confidence (uncertainty) of an event are outlined in Table 20. In general, the estimates are typically based on the use of professional judgment.

Table 20. Confidence in the Risk Estimate

CONFIDENCE/ UNCERTAINTY	
Category	**Definition**
L – Low	Do not have confidence in the estimate, could vary significantly
M – Moderate	Have some confidence in estimate, moderate variability
H - High	Confident in estimate. Low variability

- Risk Estimation and Assignment of Priority

The point of intersection of the two descriptors (i.e., consequence and likelihood) on a risk estimation grid are plotted to fall into one of the risk estimation grid quadrants. The associated planning priority (1 - highest, 2 - second-highest, 3 - third-highest, 4 - lowest) for each event depends on the quadrant where the point of intersection occurs.

- Risk Analysis Results

The results of the risk analysis are presented for each component being assessed (i.e., e-waste processes/operations, e-waste infrastructure, socioeconomic).